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Renovation of an UNESCO heritage settlement in southern Italy: ASHP and BIPV for a "Spread Hotel" project

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Abstract

Many small historical settlements in Mediterranean areas have a great value in terms of architectural and cultural heritage. Therefore it happens that the socio–economic situation of many of these settlements is backward and depressed. A succesful way to develop these important environments is to implement tourism, a profitable and available economical resource. "Spread Hotel" or "Diffuse Hotel" or "Albergo Diffuso" is an innovative concept which aims to renovate decayed buildings situated in historical locations. New economical inputs are needed to revitalize these settlements and their social tissue. "Diffuse Hotel" concept is very diffused in Italy due to its rich historical heritage. The present paper displays a renovation project of a rural historical settlement into a "Spread Hotel". The site under analysis is located in Palazzolo Acreide, Sicily, Italy. The settlement strongly needed to be refurbished in order to provide habitability and to guarantee a proper level of comfort according to italian standards. The area is also listed in the UNESCO Heritage. The "Diffuse Hotel" at a national level is considered as an affordable and comfortable concept that enables the travellers to experiance Italy through a tipical, historical and comfortable hotel. The historical built enviroment preservation is strategic in Italy and can strongly support economical revitalization. European Community supports the development of "Spread Hotels" projects in order to improve economical capacity of depressed areas by financing refurbishment programs. In this contest the authors present how "Palazzolo Acreide" renovation project was done. In particular, the design strategy was to respect the local characteristics, improve thermal performance and HVAC systems and exploting the on site renewable energy. In fact, in the Mediterranean areas solar radiation is a incredible resource to provide energy to the buildings.

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Keywords: Solar building renovation; photovoltaic building integration; Nearly ZEB

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1. Introduction

European Union (EU) is involved in developing local culture and national heritage in order to promote the social and economic improvement of local communities. In fact, EU financially supports the development of local and "sustainable" tourism. In the contest of EU economy tourism is a sector that involves stakeholders, both public and private, coming from many different fields and areas of competence [1]. The EU tourism industry generates more than 5% of the EU Gross Domestic Product (GDP), with about 1,8 million enterprises employing around 5,2% of the total labour force. In addition, it must be considered that tourism involves different industries and that indirectly generates more than 10% of the European Union's GDP and provides about 12% of the labour force [2]. The Lisbon Treaty [3] acknowledges the importance of tourism outlining a specific competence for the European Union in this field and allowing for decisions to be taken by qualified majority. The Lisbon Treaty specifies that "the Union shall complement the action of the Member States in the tourism sector, in particular by promoting the competitiveness of Union undertakings in that sector". Following its 2010 communication on tourism [4], the Commission has developed a rolling implementation plan [5], outlining major tourism-related initiatives to be implemented in close cooperation with national, regional and local public authorities, tourism associations and other public/private tourism stakeholders.

The specific concept of "Spread Hotel" or "Diffused Hotel" in Italy [6] involves historical and rural sites protected by the UNESCO. The challenge of this study is to approach the renovation in buildings from an energy efficiency point of view. This aspect is critical in the national building stock which is the major part of the national built environment [7]. The project' goal was to use the onsite renewables to supply energy to the buildings towards the concept of nearly Net Zero Energy Building (NZEB) as reported in the EPBD recast Directive [8]. The energy retrofit had to face many obstacles as the age of buildings, the habitability, decay issues and lack of a proper lever of comfort in particular by the hygrothermal point of view. The energy renovation was facilitated by the fact that in Mediterranean areas it is possible to take advantage of the favourable climate conditions to produce energy in an affordable way. The retrofit counted passive strategies as the refurbishment of the envelope (opaque and transparent) and the new high efficient thermal plant. In fact, in order to provide the conditioning of the buildings the local temperate climate, as air temperature and solar radiation, was used. The climate can be used as a tank of resources to feed systems as air source heat pump (ASHP) and photovoltaic systems.

In addition the "Spread Hotel" renovation concept aimed to preserve the character of the site, to promote the social environment and to guarantee economic feasibility.

Fig 1. (a) Palazzolo Acreide: Plan and (b) view of the settlement

2. Methodology

First of all the environmental conditions and built environment characteristics were analysed. The solar radiation on the buildings surfaces was evaluated taking into consideration high standard of quality for indoor spaces. The evaluation was useful to assess the possible use of daylighting, the exploitation of solar gains for winter period and the possibility to produce energy by integrated photovoltaic systems on the building surfaces. Furthermore the needs of ventilation and of efficient thermal plants were approached. The energy demand for winter and summer period was then calculated with the use of energy simulation tools. The tool used to perform the dynamic energy simulation was Open Studio BEST. Open Studio BEST is a dynamic energy simulation tool based on the free plugin Open Studio developed by the National Renewable Energy Laboratory (NREL) which uses SketchUp 8 as graphic interface and EnergyPlus 7.0 as energy calculation engine. The plug-in was customized by department of Building Environment Science and Technology (BEST) of Politecnico di Milano.

The retrofit project included the improvement of the glazing systems and of the envelope performance. It was done with the goal of reducing heat losses specifically by controlling the thermal transmittance of the opaque constructions. On parallel, the design of the heating and cooling plant fed by renewable energy sources was done. Considering the local characteristics an air source heat pumps (ASHP) coupled with building photovoltaic integrated plants (BIPV) was assumed. The design of the BIPV systems had to respect the regulation constrains of the historical centre of Palazzolo Acreide.

The final purpose of the authors was to show how to reach the status of "Nearly" Zero Energy Buildings (NZEB) using the electricity produced by the BIPV system focusing on a case study and to verify the affordability from an economic point of view as required by the European EPBD recast Directive.

3. The case study of Palazzolo Acreide

Palazzolo Acreide located in Sicily, Italy, is a small historical settlement characterized by small one to two stories buildings. The project wanted to realize a "Spread Hotel" diffused throughout a group of eleven small local buildings in down town Palazzolo Acreide. The core of the renovation project consisted in a socio – economical development with a special focus on the improvement of the energy efficiency of the buildings and also in reconcilement with the historical constrains.

First of all, an on-site energy audit of the buildings was conducted and new functions were identified. Many habitability, flexibility, thermal performance and hygrothermal related issues were listed in order to frame the weaknesses of the site. A detailed analysis of the tourist flows and management plan for investors was also conducted. According to this information a refurbishment of the small buildings was done preserving the historical value as well improving energy efficiency of the buildings.

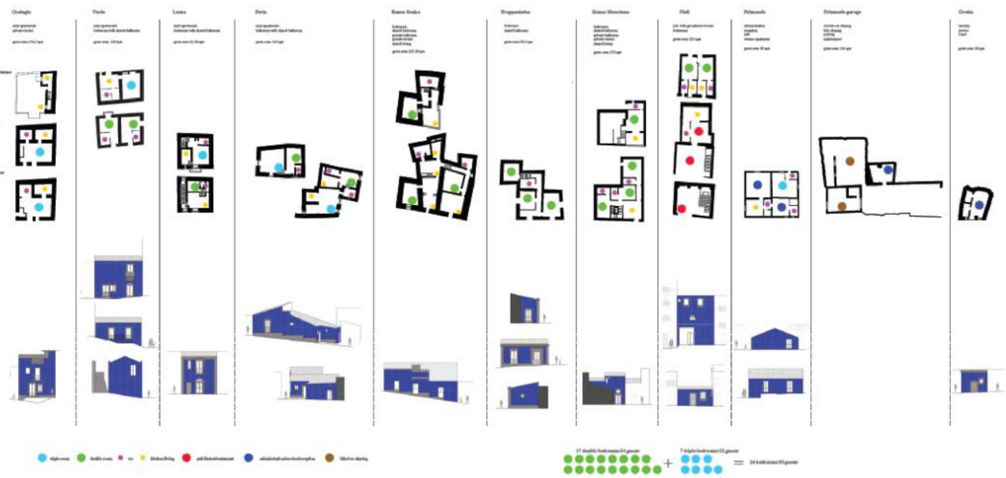

Fig. 2. Typical scheme for buildings' typology analysis, diagnosis of the characteristics to preserve, functional renovation strategy

4. Energy retrofit of the buildings

The energy consumption of each building was firstly evaluated. Consequently an air to water heat pump with a floor radiant heating was selected for both heating and cooling.

The heating schedule was set from November to April and from 8:00 pm to 8:00 am with a set point temperature of 20°C. A setback temperature of 18 °C was scheduled for the rest of the day hours. The cooling set point temperature of 26 ° C was scheduled from May to October. A value of 6 W/m^2 was considered for the internal gains according to the UNI/TS 11300-1. [9]

Table 1 shows the energy consumption and PV energy production for the four main types of the previously analysed buildings. The energy that can be produced by PV systems integrated in the building and the energy consumption calculated is basically equal.

Table 1. Energy consumption and PV energy production of the 4 main types of the analysed buildings

	Primosole	Ferla	Lenza	Casa Verde
Floor area (m^2)	100,5	148,5	30,86	118,32
Heating consumption (kWh/m^{2}y)	3,19	8,3	23,1	19,18
Cooling consumption (kWh/m^{2}y)	9,29	29,99	36,4	9,48
Pick power installed (kW$_p$)	4,4	4,05	-	11,1
PV energy production (kWh)	4027	5437	-	16760

4.1. The Study case of building "Primosole"

The building named "Primosole" is now analyzed in detail.

Particular attention was given to the insulation of the envelope and to allow maximum solar gain during winter. The entire existing building envelope is made of tuff stones and has a transmittance (Uvalue) equal to 1.7 W/m^2 K. The intervention included an additional polystyrene insulation layer. The new solution achieved excellent thermal characteristics (U value of 0.34 W/m^{2}K) with just very little additional thickness (10 cm). The previous single-glazed windows have been replaced by a high performance double-glazed solution with a low-E glass in order to give the equivalent performance of triple glazing (U value of 1 W/m^{2}K). Windows were equipped with timber frames in order to minimize the heat losses through the frame. Large glazing areas on the south facades were designed to admit the winter radiation which is consequently stored in the thermal mass of the ground floor slab. In addition, the thermal mass also modulates the internal temperature during summer acting as a heat sink.

As mentioned above the new installed thermal plant consists of an air-water heat pump combined with a radiant system with a water temperature of 35 °C during winter and of 18 °C during summer.

The following table reports the Coefficient of Performance of the heat pump as a function of the outside air temperature and the flow temperature of the water.

Table 2. Coefficient of Performance of the heat pump in relation to the outside air temperature

	Jan	Feb	Mar	Apr	Mar	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ambient temperature [°C]	9,3	8,9	10,6	12,7	17,1	21,2	23,9	24,4	20,7	18,2	13,9	10,8
Coefficient of Performance	4,0	4,0	4,0	4,5	4,2	3,8	3,6	3,5	3,9	4,1	3,2	4,0

4.1.1. Renewable energy sources

Renewable energy sources are used to provide electrical power generation. Monocrystalline silicon modules with 100 W_p characterized by a temperature coefficient of 0,46%/°C, were used to cover an area of 40 square meters in order to define a system of 4 kW_p peak. They are placed on the south side of the roof with the same tilt angle of the roof (20 degree).

This configuration allows getting maximum use of the sun's energy throughout the seasons. All the electrical appliances, and also the heat pump use just the electricity provided by these solar modules.

In order to estimate the net energy from the PV system the influence related to the conversion losses DC/AC was quantified. **Fehler! Verweisquelle konnte nicht gefunden werden.** shows the simulation model of the building and the efficiency of the inverter assumed as a function of power produced by the photovoltaic module DC.

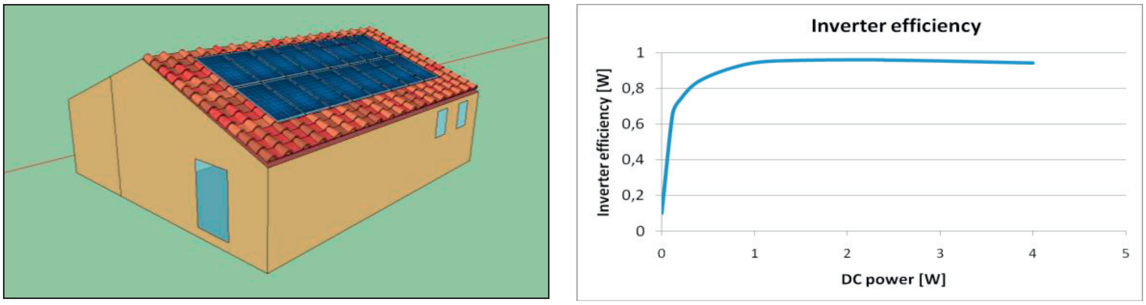

Fig. 3. (a) Model of the Primosole Building and (b) inverter efficiency related to the DC power

To evaluate the performance of the PV systems the software TRNSYS has been used [10-16]. TRNSYS is a so-called procedural language which allows predicting the behavior of complex system under dynamic condition. TRNSYS has the capability of interconnecting system components in any desired configuration.

Therefore the user can define several configurations and solve easily differential equations. TRNSYS allows processing the system and additional file, such as weather data file to perform simulation using one built-in solver using each component model in an iterative manner until convergence is reached for each time step.

It has been shown by analyzing the results of several validation studies that TRNSYS provides results with a mean error between the simulation results and the measured results on actual operating systems under 10% [11].

The weather and meteorological data considered were the taken from the Typical Meteorological Year (TMY) a data bank of Meteonorm [17- 20] for the reference city.

Fig. 4 shows the configuration of the system adopted for the present study.

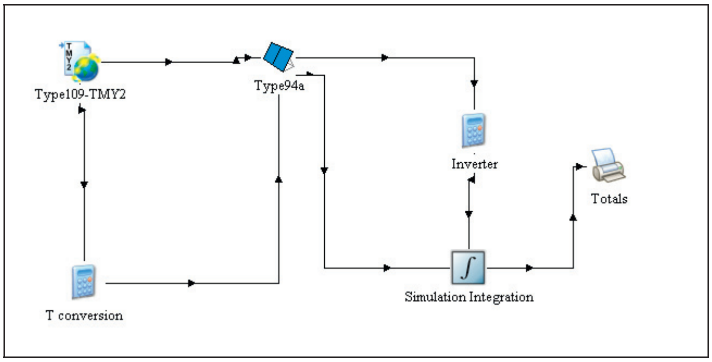

Fig. 4. TRNSYS screenshot showing the adopted system configuration

5. Results

With the aid of the simulations in dynamic conditions it was possible to calculate the energy demand and consumption of the building in more detail. Fig. 5 shows the energy demand of the case study with no intervention (Base case) compared to design project.

Energy demand in winter strongly decreased in the project design. This is due to the reduction of the heat losses through the envelope caused by the replacement of the windows and by the implementation of additional layers of insulation in existing masonry

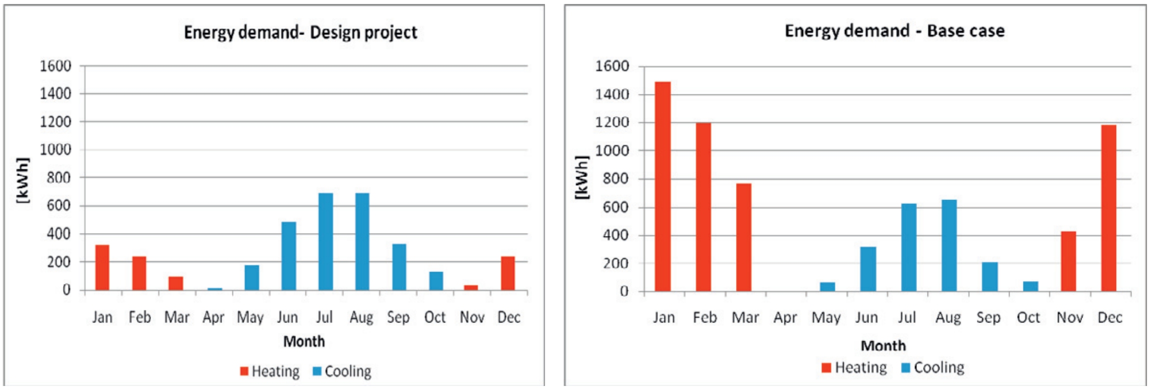

Fig. 5. (a) Cooling and heating demand of the Base case and (b) Design project

The specific energy consumption of the building was calculated and then converted to primary energy. The primary energy factor used for the conversion was 2,16 kWh_{th}/kWh_{el} [21]. The base case building consumed 112 kWh/m^2 year and the design project consumed 27 kWh/m^2 year after retrofitting with a reduction of almost 76%. The greatest consumption decrease occurred during the winter period but also in summer there is a decrease in energy demand of 25%. The replacement of a conventional heating system such as a boiler with the heat pump strongly affected the energy consumption.

The energy produced by the PV system (Fig.) can entirely cover the winter and summer energy use. In fact, the PV system, as previously described will produce 4027,5 kWh/year which is significantly greater than the 1249 kWh/year needed by the building for heating and cooling shows the energy produced by the

PV system. Furthermore, the rest of the energy produced by the PV system will cover the energy consumed by the equipment commonly used in a hotel, which may be assumed equal to 2500 kWh/year.

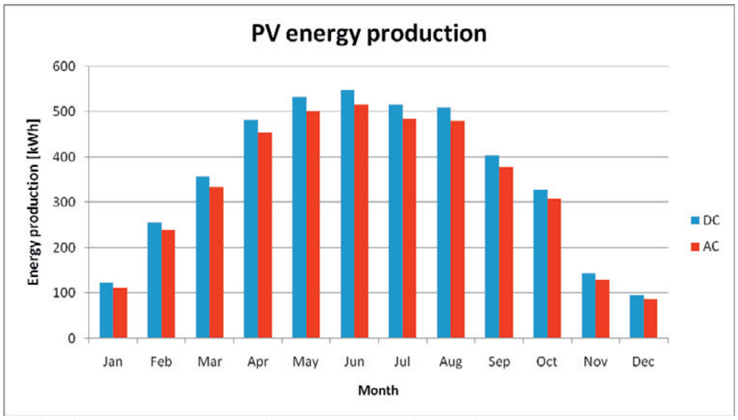

Fig. 6. Energy production by the PV system in DC (direct current) and AC (alternate current)

6. Economical Evaluation

The new "Spread Hotel" of Palazzolo Acreide will attract a new flow of tourism which can balance the upstream financial investment. In order to evaluate the payback time, some possible values of rent of the house were hypothesized according to the numbers of beds occupied and the season. The following table displays the number of beds in each apartment and the relative daily cost.

Table 3. Number of beds in each apartment and the relative daily cost according with the season

N° of Bed	High season [€] From July 14th to August 31th from December 21th to January 6th	Medium season [€] From the June 1st to July 13th from September 1st to September 30th;	Low season [€] All other periods
1	70	50	35
2	160	140	110
3	240	210	165
4	320	280	220

According to the above data, the estimated payback time showed in Fig. 7 considers an initial investment of € 110.000 calculated on the specific intervention for Primosole Building. This value is derived from detailed estimation of the costs of each individual component.

Each curve of Fig. corresponds to a different percentage of occupancy of the Primosole rooms by a different number of users, and consequently a different payback time.

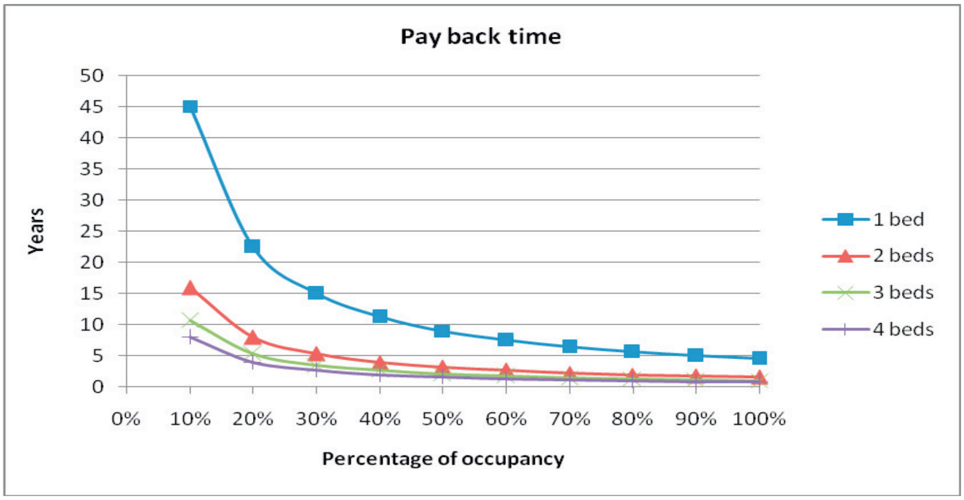

Fig. 7. Payback time of the initial investment

It is possible to appreciate that with a medium occupancy of 3 beds already with a 20% ratio of occupancy during the tourist seasons the payback time is 5 years. Better results can be achieved with a high percentage of bed occupied on the percentage of the seasons.

7. Conclusions

The project of a "Albergo Diffuso" is more than just a new hotel or a renovation project. It is a synthesis of different updated concepts. It was a chance to protect and revitalize a whole local system from economical, social, cultural and energetic points of view, in an affordable manner.

As confirmed by previous experiences of "Spread Hotel", this kind of projects [22] have benefits on the entire local community, local municipality and also on the image of the country [23]. It actually renews the existing buildings patrimony and, on parallel, preserves and promotes the "genius loci" [24]. In addition, "Spread Hotel" concept avoids the construction of new buildings and the consequent environmental impact. It also offers the opportunity to exploit a rural settlement with an historical center, as an open air museum and it helps to maintain the local population in order to perpetuate the local traditions.

The design experience in Palazzolo Acreide can show how to reach also high energy targets in buildings which have low energy performance in their existing status. Using climate resources and strategies to decrease energy demands it is possible to produce the residual energy needed by renewable sources. In sensitive built environment, such as UNESCO Heritage buildings or cities, it quite difficult to develop strong strategies and it is unacceptable to change the historical features of the buildings with components to produce energy. The challenge is to operate in the urban tissue identifying the buildings which can be interested by solar installation and design synergic technological solutions to supply energy. ASHP and PV plants as systems to provide energy to a renovated built environment by the thermal point of view are a winning strategy in Mediterranean country.

NZEB which are the highest energy goal identified by the regulations for new constructions can be realized also in sensitive buildings since there is the possibility to carry out a strategy which engages the overall concept of the construction. Advanced energy concepts and traditional features can cohabit in buildings giving the comfort level required and improving the conditions of the buildings and the community.

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