The Evaluation of Energy Performances of a Net Zero Energy Building: an Italian Case Study

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Abstract

Over the past decades the impact of construction on the primary energy consumption and greenhouse gas emissions has highlighted [1]. The interest of the international scientific community has therefore focused on the concept of a Net Zero Energy Solar Building (NZESB), which is generally defined as a building that produces all primary energy it needs during a year [2]. Among the many research activities focused on these buildings, it should be mentioned the case study developed within the IEA SHC Task 40/ECBS Annex 52 "Towards Net Zero Energy Solar Buildings". The paper shows a case study of a Net Zero Energy Building (NZEB) located in Ancona (Italy):"Life Energy And Future (Leaf) House" (LH). This building produces energy from renewable sources with the aim to cover the energy annual needs. After a detailed description of the case study, authors show the methodological approach adopted in the design phase, including the analysis of the environmental condition of the house given by a sensors system which monitors temperature, humidity, CO_2 level, energy consumption and energy production. The paper presents the results of the analysis of the first year of monitoring phase concerning the energy consumption and production of the house.

1. Introduction

Energy consumption in worldwide buildings accounts for over 40% of primary energy use and 24% of greenhouse gas emissions [3]. Energy waste and emissions include both direct, on-site use of fossil fuels as well as indirect use from electricity, district heating/cooling systems and embodied energy in construction materials. To reduce the building energy consumption a prominent vision proposes the so called "Net Zero Energy", "Zero Energy Costs", or "Net Zero Carbon" buildings. Several countries have adopted this vision as a long-term goal of their building energy policies. One of the main significant research experiences is developed inside the IEA Solar Heating and Cooling Task 40/ECBCS Annex 52 and the issues of the design, optimization and modelling of such buildings are being addressed by Sub Task B (STB). The aim of the STB research group is to identify and refine design approaches and tools to support industry adoption of innovative demand/supply technologies for NZEBs. The paper shows the Italian case study of a NZEB: the LH.

2. The building case study: the Leaf House

2.1. General description

The LH is a technologically innovative house located in Angeli di Rosora (Ancona, Italy); the latitude and longitude of the site are respectively 43°47 'N and 13°07 'E while the altitude is 130 m above sea level. The climate is moderate and characterized by a mean annual temperature of 15.8 °C, a mean humidity of 67% and a mean horizontal solar radiation of 302 W/m^2.

The house is composed of six flats and its net conditioned floor area is 477 m^2. The area of a single flat is 85.65 m^2.The two apartments of the second floor are smaller than the first two apartments, and their area is 58.39 m^2each; besides there is an intermediate floor of 9.35m^2. Fig. 1 shows the inner division of the first floor flat.

Inner division of a single flat:

Entrance: 7.47 m^2;

Staircase room: 3.83 m^2;

WC: 5.30 m^2;

Living room: 36.90 m^2;

Bedroom 1: 13.52 m^2;

Bathroom: 5.52 m^2;

Bedroom 2: 15.02 m^2

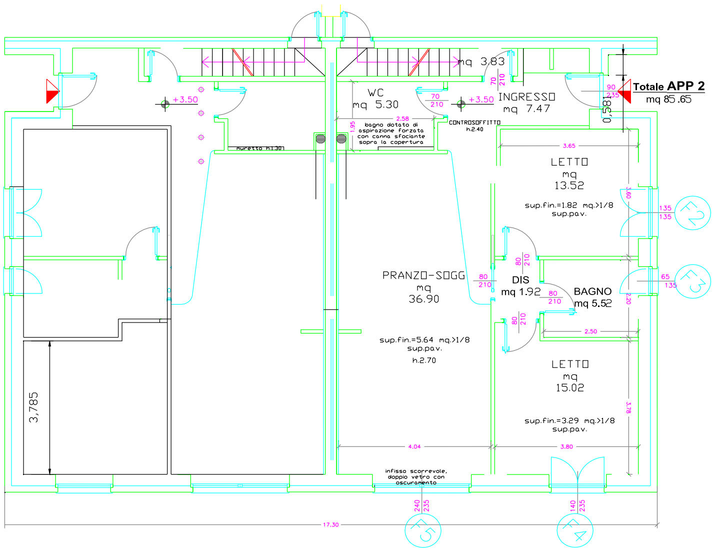

Fig. 1 Plant of the ground floor and the first floor

The structure of walls is composed of five layers and Tab.1 shows the detailed description of the layers composition. The roof structure is composed by 10 layers (from inner to outer surface) as the Tab.2 shows, while the basement was properly insulated by 4 cm of Polyurethane (the thermal resistance is 2.45 K m^2/W).

The LH was built according to the Italian Legislative Decree 311/2006 that defines the limits for the thermal transmittance of the walls and of the glazing components. These limits are respected by all the components of the building envelope. The Tab. 3 shows the global transmittance limit U values for the opaque vertical structures. It is clear how the U values of the building structures are smaller than the limits imposed by the Italian Ministerial Decree March 11th 2008.

In the Leaf House, windows guarantee the maximum insulation according to the Italian Legislative Decree 311/2006 and the Ministerial Decree of March 11th 2008 and subsequent amendments and additions. The windows are double panel insulated glazing U=1.1 W/(m^2K) with a 6 mm of external glass, 14 mm gap filled with argon and 4 mm of internal glass, the average global U value is 0.75 W/(m^2K). The Solar Heat Gain Coefficient (SHGC) is 0.6. The window frame is made by a triple panel of wood, thermal foam and aluminium.

Tab. 1 Description of the wall structure

Layer Description	s	λ	R
(From inner to outer surface)	[cm]	[W/(mK)]	[m²K/W]
Plaster	2.00	0.290	0.07
Poroton Brick 30	30.00	0.21	1.43
Polystyrene Rofix EPS100	18.00	0.036	5.00
Plaster	2.00	0.300	0.07
R_{Tot} [m²K/W]		6.57	

Tab. 2 Description of the roof structure

Layer description	s	λ	R
(from inner to outer surface)	[cm]	[W/(mK)]	[m²K/W]
Plasterboard Pregyplac	0.95	0.210	0.05
Plasterboard Pregyplac	0.95	0.210	0.05
Plasterboard Pregyplac	0.95	0.210	0.05
Klober Wallint T3	0.10	0.130	0.01
Wood fibre (170kg/m^3)	10.00	0.120	0.83
Rock wool	10.00	0.040	2.50
PermoEasy H	0.10	0.350	0.00
Air space	4.00	0.280	0.14
Pinewood	2.00	0.120	0.17
R_{tot} [m²K/W]			3.80

Tab.3 Comparison between the U value limits imposed by the Ministerial Decree March 11th 2008 and the real U value of the structures.

External structures	Nomenclature	Limits for the global transmittance value (MD March 11th 2008) [W/(m^{2}K)]	Real U value of the structures [W/(m^{2}K)]	**Percentage reduction [%]**
Opaque vertical structures	Stru32-MuroEst.tamponL	0.364	0.15	**-58%**
Opaque horizontal floor	Stru40-SoffittoTerrazzaL	0.312	0.30	**-3.8%**
Opaque sloping roof	Stru28-TettoPannelliL	0.351	0.25	**-32%**

About occupancy, four apartments are occupied by two people each and two apartments are occasionally occupied.

In the Leaf House there is mechanical ventilation with heat recovery and pre conditioning in an underground duct. The mechanical ventilation is 0.2 volumes/h at 20°C and the efficiency of the heat recovery system is 80%. There is a control strategy based on a CO_2 level measured by a system of environmental sensors; besides the ventilation is stopped if windows are open.

2.2. Energy supply systems

The heat and cold generation is carried out by a geothermal heat pump (GHP). The GHP gives the energy needed to activate the cooling and heating system and the Coefficient Of Performance (COP) is 4.6. The Air Treatment Unit (ATU) is provided with batteries for the heat exchange: before being introduced into flats the outer air is heated in winter and cooled in summer thus exchanging thermal energy with the water coming from the heat pump. The outer air is also naturally pre-conditioned through an underground path of about 10 m before getting to the ATU. Different sensors system has been installed, to measure the presence of carbon dioxide. If the CO_2 is more than a user defined value the ATU is activated; anyway, if windows are open, the air system will automatically stops to avoid energy wastes. In this way the air quality in the apartment remains always extremely high.

The subfloor is a radiant floor made by several layers: an acoustic barrier (6 mm), an insulating layer (10 mm), a tubing base module which allows an easier installation of the tubing system; the underlayment has a high global transmittance value and is 50 mm thick. The water circulating in the tubing is heated in winter at a temperature of 25-28°C, besides the temperature in each room is controlled by regulating the flow of hot water through each tubing loop. This is done by a system of zoning valves and thermostats; this reduces the energy consumption which, in the first period of collecting data, was of 27 kWh/m^2 per year.

The space cooling system is provided by the Geothermal Heat Pump, and it is combined to the natural cooling (heat exchanged with the ground). During the first period of collecting data the monitored energy need for cooling was 20 kWh/m^2 per year.

In the Leaf house there are seven flat solar thermal collectors (2.6 m^2 each). They integrate or completely replace (according to the season) the heat pump in the production of domestic hot water and produce about 4,230 kWh_t per year.

The electric energy needs for the heat pump are covered by the energy produced by the photovoltaic (PV) panels which cover all the surface of the roof house (150 m^2) facing the South. During the first year of monitoring data the PV production was 25,650 kWh_e/year.

2.3. Sustainable solutions

In the Leaf House particular attention is paid to the energy savings, so the following efficiency measures have been installed. In the rear part of the house facing the North, the sunlight arrives carried by solar tubes: a similar solution to the mirrors system. The home automation system modulates the lighting according to the natural light available. The rain water is collected in a tank buried under the garden and reused for WC and irrigation. During the first year of collecting data the water consumption covered by the reuse of the rain water was 492,200 l which is the 69% of the total hydro consumption. It is also calculated the CO_2 reduction by the energy efficiency measures that was of 20,860 kg, while the CO_2 reduction from the energy produced by the PV system was 13,220 kg.

2.4. Control strategy

In the Leaf House there are more than 1,200 sensors. Some of them are used to measure data needed by the building automation software while the rest is used to make the Leaf House a laboratory. All the data collected are stored in a database and they can be used for simple analysis and data mining operations. The monitored data are: air and water flow, electricity, heat flow, temperature, humidity, CO_2 and weather parameters.

2.5 Data storage and data analysis system

The data measured by the sensors described by now have to be stored to use them in several activities:

- Building thermal performance analysis;
- Machineries performance analysis;
- Fault prevention and detection;
- Sensors fault detection.

3. The methodological approach

3.1. Objectives of the building

The initial goal of the design was to develop a carbon neutral house. This house is the concretization of new concepts of the architectural design: comfort, sustainability, energy and economy. It was also built as a Laboratory where new sustainable technologies are studied and further developed as the monitoring of the quality of the air, the humidity, the CO_2 level by a system of sensors that are installed in the different rooms of the six apartments; the overall energy annual consumption of the sensors system was 6,715 kWh_e.

Another goal of the building was the Net Zero Energy; in general a conventional building might be called NZEB as long as the annual energy needs or the associated carbon emission are balanced by credits from excess energy fed into the grid. In the main typologies of NZEB they are classified as site-ZEB and source-ZEB depending on where the energy balance is calculated [3].With respect to the NZEB aim an energy balance has to be established on the level of primary energy. In the LH the Net Zero Energy goal should be reached by reducing the energy demand and by the PV production (the first year of collecting data was of 25,650 kWh_e).

3.2. Cost analysis

The Leaf House was designed not only to be a Net Zero Energy Building but also to have a reasonable price. The technologies chosen should satisfy both energy saving and money saving objectives. The results are really interesting: the Leaf House costs only 30% more than a traditionally built house of the same heated surface (480 m^2) and the payback time is of about 14 years.

Tab. 6 Comparison between the global cost of a traditional house and the Leaf house

	Leaf House	**Traditionally built house**
Global cost	1,340,000.00 €	1,000,000.00 €

That is partly due to the Italian government incentives: in fact the electricity produced by PV is paid 0,598 €/kWh - thanks to the fact that the PV system is installed on a high efficient building - while the electricity absorbed from the net costs 0.168 €/kWh. The incentives are guaranteed for 20 years. This means that the global cost of the house (initial investment + maintenance bills) starts increasing after the end of the incentives, however, the tendency is better if compared to the tendency of a traditional house. The predicted Payback Period (PBP) is of almost 14.5 years, a period of time significantly shorter if compared to the life of the house. The following data on the contrary are the real data that are measured after the first year of life of the Leaf House. In the Tab. 7 are described the bill costs of the Leaf House for electricity, water consumption and the annual revenue for electricity production of PV.

Tab. 7 Bill cost and revenues of the Leaf House

Leaf House		
Utilities	Consumption	€
Electricity	25,000 kWh_e	4,200
Water	209,300 l	363
Total bills		4,563
PV Production	25,650 kWh_e	15,338
		Annual revenue

In the Tab. 8 typical bill costs of a traditionally built house are presented. They include heating and Domestic Hot Water (DHW) provided by a gas boiler, cooling provided by a traditional air cooled split chiller, water and electricity consumption.

Tab. 8 Total bill costs of a traditionally built air-conditioned house

Traditionally built house		
Utilities	Consumption	€
Heating	48,000 kWh_{th}	4,480
Domestic Hot Water	22,080 kWh_e	2,060
Electricity	25,650 kWh_e	3,360
Water	234,000 l	1,143
Cooling	7,200 kWhe	1,210
Total bills of a traditionally built house		12,250

In the Fig. 4 the costs and revenues of the Leaf House and of a traditional air-conditioned house are compared.

Fig. 4 Comparison between LH and traditional air-conditioned house

It could be useful to divide costs in four different classes:
Building Envelope: Includes materials and manpower used to build the structure, the walls, the roof, the floor, etc. and it also includes the architectural design and the building supervision.
Electrical plant: Includes cables, electrical boards, temperature sensors, pressure sensors, humidity sensors, CO_2 sensors, manpower.
Thermal plant: Includes pipes, air duct, pumps, air handling unit, heat pump, water storages, geothermal probes, heat exchangers, radiant floors, valves, manpower.
Building automation: Includes software, Programmable Logic Controller (PLC), actuators, manpower.
Tab. 9 Different cost classes

	Building Envelope [€]	**Electrical Plant [€]**	**Thermal Plant [€]**	**Building Automation [€]**	**Total [€]**
Apartment 1	124,000	33,000	24,000	3,900	184,900
Apartment 2	124,000	33,000	24,000	3,900	184,900
Apartment 3	124,000	33,000	24,000	3,900	184,900
Apartment 4	124,000	33,000	24,000	3,900	184,900
Apartment 5	104,000	29,000	20,000	3,200	156,200
Apartment 6	104,000	29,000	20,000	3,200	156,200
Power plant	112,000	48,000	83,000	33,000	276,000
Total	**816,000**	**238,000**	**184,000**	**55,000**	**1,328,000**

4. The monitoring results: first year of collecting data

4.1 Electric production and consumptions

The Electricity is provided by a photovoltaic system, completely integrated on the roof, with a nominal power of 19.8 kW_p covering a surface of 150 m^2. The photovoltaic production during the first year was of 25,650 kWh_e with a production of 1,288 kWh/kW_p guarantying an income (provided by the public incentive) of 305,000 €, thanks to the maximum rate given (0.598 €/kWh).
The electricity consumptions have been reduced with the installation of different solutions such as solar tubes that contribute to illuminate one of the two bathrooms of the first and second floor apartments, by highly efficient lighting sources and high efficient home appliances. Moreover an hydrogen store system allows to store energy during the day that is used during night to supply the external lighting. The hydrogen is produced through electrolysis (efficiency 42%), stored in a metal hydride storage system, and converted in DC current using a PEFC (polymeric electrolyte fuel cell) with an efficiency of 40%. The power supplied by the fuel cell is just 1 kW and unfortunately the global efficiency of the system is very low. An integration of these solutions through a building automation system developed by the Loccioni Group contributes to reduce electric consumptions by more than 50%, from 20,000 kWh - which is the electric of a traditional house with the same characteristics of the LH – to 9,658 kWh which is the effective consumptions of Loccioni's building.

4.2 Domestic hot water

The seven thermal panels, that cover a surface of 15 m^2, provide to satisfy the DHW need. In the first year of monitoring these thermal collectors covered total domestic hot water need by 63%, providing 4,227 kWh_t out of 6,638 kWh_t.

4.3 Heating and Cooling

Heating and cooling within the Leaf House are provided by a geothermal heat pump which is an electrical machine with three vertical probes reaching 100 m under the ground where the average temperature is 12 - 14°C. In order to reduce the energy consumption, the external wall of the Leaf House are composed of 18 cm of insulation reducing the heating need from 100 kWh/ m^2 per year of a traditional house to 27 kWh/ m^2 per year of the LH.
Concerning the cooling need, it has been reduced from 30 kWh/(m^2year) of a traditional house to 20 kWh/(m^2year) of the LH.

5. Conclusion

The paper shows the detailed description of the Italian Case Study, selected as case study by the STB research group. The building produces energy from renewable sources (photovoltaic system, solar thermal panels, geothermal heat pump, etc.) with the aim to cover the energy annual needs. After a detailed description of the geometrical and thermo-physical characteristics of the building, authors show the methodological approach adopted in the design phase, including the analysis of the environmental condition of the house given by the system of sensors which monitor temperature, humidity, CO_2 level, energy consumption and energy production. This system gives to the house the characteristic of a Laboratory where the environmental and energetic conditions are studied.
The first year of collecting data shows that the energy production of the photovoltaic system was of 25,650 kWh_e. In the paper the costs of the house are also analysed; from the analysis appears that the payback time of the house is roughly 14 years; moreover the LH costs more than a traditionally built house of about 712.79 €/m^2, and this extra cost is covered by the income received in 20 years thanks to the public incentives given by the Italian Energy Laws.

References

[1] IEA Promoting Energy Efficiency Investments – case studies in the residential sector ISBN 978-92-64-04214-8 (2008). Paris.
[2] Torcellini, P., et al., Zero Energy Buildings: A Critical Look at the Definition (2006). ACEEE Summer Study, Pacific Grove, California.
[3] Torcellini, P., Pless, S., Deru, M. and Crawley, D. (2006), Zero Energy Buildings: A Critical Look at the Definition, National Renewable Energy Laboratory and Department of Energy, (US).
[4] Athienitis, A., Torricellini, P., Hirish, A. et al., Design, Optimization and Modelling Issues of Net Zero Energy Solar Buildings. Proceedings of EuroSun 2010. Graz, Austria.