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Net Zero Energy Buildings: Expense or Investment?

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Abstract

With the objective of reducing the heavy consumption of building sector, sustainable policies around the world promote, for the future, the construction of zero-energy or nearly zero-energy buildings.
Higher investment in efficient technologies for energy saving and exploitation of renewables, however, can cause doubts about the real convenience of these "new generation" buildings. Based on the analysis of a case study under development, this paper demonstrates that a zero-energy building represents an affordable investment cost, especially if integrated with photovoltaics.

keywords: Net Zero Energy Building; photovoltaics; techno-economic evaluation

1. Introduction

As a result of an obsolete way of building, which is nowadays outdated and inadequate to modern environmental requirements, the energy consumption of the building sector accounts in developed countries for a 20–40% of the total energy demand [1,2].

In recent years, the rapid growth of energy consumption and CO_2 emissions in building sector has made energy efficiency a priority objective in various countries by developing new building regulations and certification schemes targeting to minimum energy performance requirements [3]. It has been well demonstrated that it is possible to considerably improve the buildings performance by using energy-saving measures and renewables. Moreover, within the European Union, the recently adopted EPBD recast [4] states that by the end of 2020 all new buildings should be "nearly zero-energy buildings"(NZEB). The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including the one produced on-site or nearby. It is

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interesting to note that, in the preliminary drafts, the directive was referring to NZEB as "net zero-energy buildings". Anyway it seems that the global economic crisis of recent years has prompted lawmakers to scale back targets, evidently considering the fact that a NZEB (meaning net zero) is too expensive.

There are many definitions on the issue [5], but the more effective seems to be the official ASHRAE definition: "ZEB is a building which, on an annual basis, uses no more energy than is provided by on-site renewable energy sources". To avoid misunderstandings, in this study is referred to ZEB as " net zero-energy buildings " and NZEB as " nearly zero-energy buildings".

Appropriate building HVAC and system technologies are now already commercially available [6], however, as said before, there are still some doubts about the affordability of ZEB, especially in the short term. This study demonstrates, however, the convenience not only from the environmental but also from the economic point of view of this type of buildings.

2. The role of PV in the ZEB concept

Basically, the fundamental characteristic of a ZEB is the capacity to satisfy completely a low demand through renewable energy. There are many renewable sources suitable to be used in buildings, but almost all are strictly dependent from the integration context. For example, in the case of biomass, microwind, hydroelectric and others, their applicability is not always proven, because an area may be poorly windy or it can be difficult to find bio-fuel, etc. On the contrary, photovoltaics, although with some differences due to the specific climatic conditions and solar potential of the site, can be used almost anywhere. In fact in several of the ZEB prototypes, built around the world since the 80s of last century, it can be noted that PV has a major role, by satisfying most of the energy needs.

Then it becomes interesting to precisely determine what may be the contribution of photovoltaics in the ZEB concept. The Italian context can be considered illustrative of a wide range of geographic areas, as its climatic conditions vary from Mediterranean to Continental, and can be taken therefore as a reference for this evaluation. First of all it is necessary to define in detail the various buildings consumption items. It has to be noted that in Italy, as in many Countries, there is much difference between ordinary and new generation efficient buildings. Furthermore, with respect to ordinary buildings, we must distinguish between old buildings, built before the implementation of the EPBD, and new buildings that meet the minimum energy saving standards required by law, but are still far from an high energy efficiency level. Typical energy demands associated with various kind of buildings are presented in Table 1.

Table 1. Common and efficient building energy demand comparison

End- uses	Ordinary old building energy demand (kWh/m^2)	Ordinary new building energy demand (kWh/m^2)	Efficient building energy demand (kWh/m^2)
Space Heating	110	50	25
Domestic hot water production	30	30	25
Space cooling	40	40	30
Lighting and domestic appliances	40	40	20

Obviously the first requirement of a ZEB is a high degree of energy efficiency, mainly based on the synergistic operation of the building-plant system. Adopting the energy demand standards of efficient buildings and using energy efficient HVAC system, like GSHP system, final consumption can be very low and can be completely transformed into electricity. The energy performance of such a building is shown in Table 2.

Table 2. Energy performance of a typical energy efficient building

End- uses	Energy Demand (kWh/m^2)	HVAC Efficiency	Energy consumption (kWh_{el}/m^2)
Space Heating	25	3.5 (COP)	7.2
Domestic hot water production	25	3.2 (COP)	7.8
Space cooling	30	5.3 (EER)	5.7
Lighting and Domestic appliances	20		20
Total			40.7

Once estimated the electricity demand, it becomes relatively easy to assess how this can be covered by PV. The global solar irradiance and solar electricity potential within Italian territory are quite variable, depending on specific site and climate conditions. In general, it has been observed that the average annual available solar radiation across Italy on a optimal tilted south oriented surface varies between 1200-2000 kWh/m^2. Considering the technical characteristics of the market components, the productivity of PV systems can be estimated between 180-240 kWh per square meter of panels (1000-1500 kWh/kW_p).

Based on above exposed data, a simple calculations shows that the required PV area for achieving the ZEB goal varies from 15 to 20% of total heated floor area, according to the availability of global solar radiation across Italian territory and depending on the PV plant quality. This evaluation shows how, with a relatively small area of solar modules, the ZEB concept is feasible. Of course it must be taken into account the relationship between roof surfaces and total floor surfaces of the new buildings. This could significantly affect the architectural design of the future, thereby penalizing high-rise buildings.

3. NZEB/ZEB: a case study

As a reference for the next assessments, an example of NZEB is presented, where some apartments, being able to cover their own needs, can be considered as ZEB.

The analyzed case-study [7] is a residential settlement called "Terracielo", located in the eastern hinterland of Milan and divided into four different buildings with 60 apartments. The total net floor surface is about 7000 m^2, corresponding to 18000 m^3 of net volume.

Fig. 1. (a) render view of the complex; (b, c) views of the construction site.

During the design phase, different evaluations have been made about building envelope, in order to minimize thermal energy demand both in winter and summer. For example, thermal transmittances of vertical walls, as well as the basement floor, are on average comprised between 0.17 and 0.19 W/m^2 K, while the roof transmittance is around 0.2 $W/m^2/K$. In addition, the construction morphology of the entire complex has been planned to maximize the useful energy exchanges with the climatic context.

In order to supply required thermal energy, a centralized water to water GSHP system, based on horizontal heat exchangers and wells, with a total thermal power equal to 200 kW (heating mode) has been employed. In order to produce renewable energy to cover the complex needs, the roofs of buildings and of some shelters nearby were integrated with photovoltaics, for a total peak power of 87 kW_p committed to a centralized PV plant and 27 kW_p divided on 16 independent domestic systems.

The energy performance of the complex was simulated in detail with the software Energyplus[8]. The calculations reveals that the consumption for heating and cooling are lower than those reported in Table 1 for an efficient building. In this analysis, however, the table values are used as a precautionary measure.

Considering the PV plants configuration and the specific climatic conditions, an average production of roughly 1040 kWh/kW_p has been estimated through PVSyst simulations [9], allowing a total annual PV production equal to 118 MWh_{el}. The monthly electricity production of the PV systems has been shown in Fig. 2.

It has to be noted that the 16 apartments connected with additional PV power can be considered as ZEB, because their entire energy needs could be covered by solar electricity, assuming the use of high efficiency electrical appliances and luminaries. Otherwise, the rest of the settlement could be considered as NZEB.

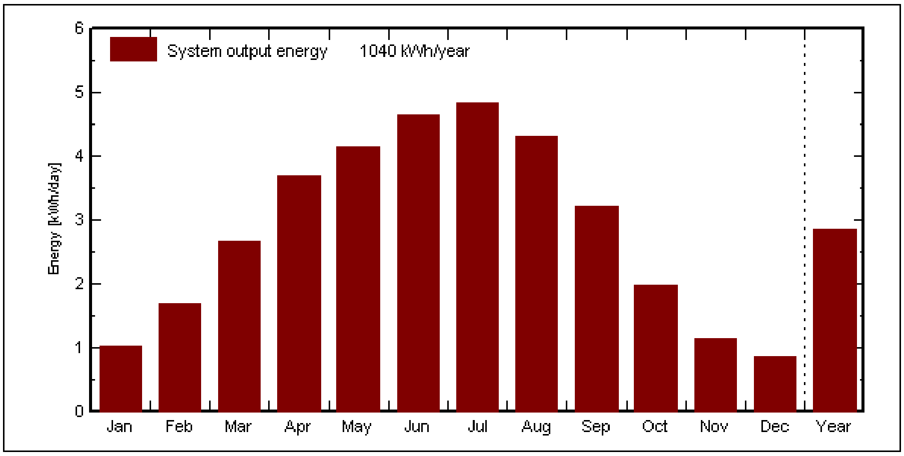

Fig. 2. PV plant monthly and yearly production expressed in kWh/kW_p.

4. Technical-economical evaluations

With the aim to demonstrate the economical sustainability of ZEB, the various building and operating costs have been analyzed, comparing the case-study building with ordinary residential buildings. In detail, for the case-study construction costs, that amount to 1780 €/m^2 for apartments with independent domestic PV plant and 1700 €/m^2 for other flats, have been considered. Similarly, for ordinary new buildings an average cost equal to 1400 €/m^2 has been estimated. This value actually represents the cost of construction of a high quality, but non particularly energy efficient, building on the outskirts of Milan. In this case HVAC are represented by common systems, like gas-boilers and multi-split air conditioners.

Regarding operational costs, energy performances data are considered according to following Table 3. On this basis, a long-term economic analysis has been carried out, using NPV (Net Present Value) index, referred to a discount rate equal to 4%. In this sense, all yearly costs and benefits have been considered; in particular, expenses for electricity and natural gas have been calculated considering an estimated value for electricity equal to 0.21 €/kWh and for natural gas 0.07 €/kWh [10]. From the literature [11] an estimate has been made regarding the increment in the future energy prices and this value is considered between 2–5% per year. In particular, 3% has been assumed for electricity and 4% for natural gas. Final results are shown in Figure 3a.

Table 3. HVAC system specifications

Case		System description	Energy demand	Overall efficiency/ COP/EER	Energy consumption [m^3 of gas/m^2]	Energy consumption/ production [kWh_e/m^2]
Ordinary building	Heating and DHW	Gas boiler + radiators	80.0	0.67	12.60	-
	Space cooling	Multi-split A/C	40.0	2.50	-	16.0
	Lighting and domestic appliances	Traditional appliances	40.0	-	-	40.0
	Renewable energy system	-	-	-	-	-
ZEB	Heating	GSHP and radiant floor	25.0	3.50	-	7.2
	DHW	GSHP	25.0	3.20	-	7.8
	Space cooling	GSHP and radiant floor	30.0	5.30	-	5.7
	Lighting and domestic appliances	High efficiency appliances	20.0	-	-	20.0
	Renewable energy system	PV plant	-	-	-	-36.4

Moreover, it is important to consider that, thanks to Italian feed-in tariff [12] on renewable energy production, the considered PV plant guarantees an annual income equal to approximately to 650 €/kW_p, for 20 years. If this cash-flow is considered, the NPV calculation is modified according to Figure 3b.

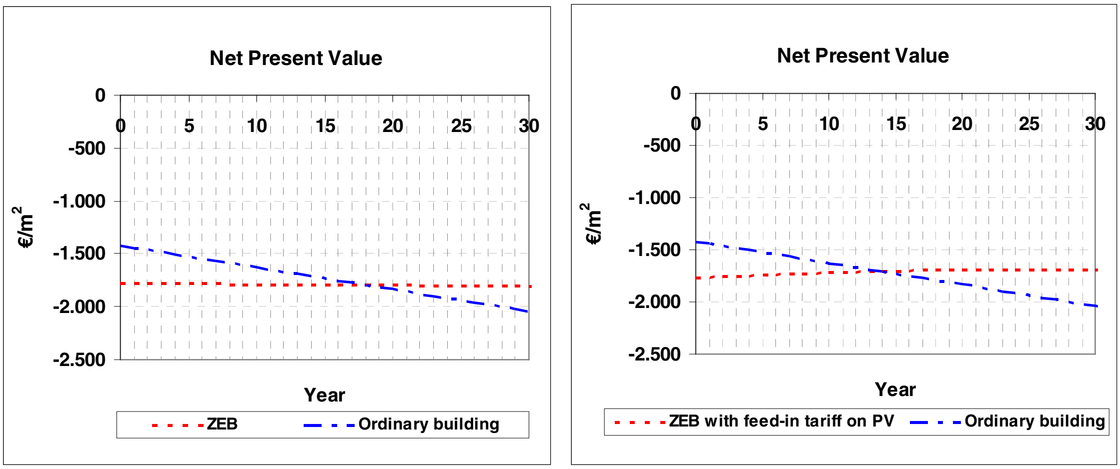

Fig. 3. (a) Economical comparison between ZEB and ordinary building; (b) Economical comparison between ZEB and ordinary building, considering PV feed-in tariff

As can be seen in the previous graphs, the economic payback time for ZEB is roughly 18 years while for ZEB with feed-in tariff on PV is slightly less than 14 years.

5. Conclusions

A technical-economic analysis of the ZEB case study was carried out in the present work. It must be noted that applied energy performances are lower than estimated ones, but corresponding to an average of efficient buildings. It can be assumed that the results of this study are conservative compared to those actually achievable, but precisely for this reason, more reliable.

The calculation of the NPV of building and operating costs shows that a ZEB becomes more economical convenient in comparison to a similar, but ordinary in terms of energy performance, building within a short period of time (15-20 years).

Presently, the building complex is under construction and within 2012 the first monitoring data on energy performance will be available for a further and more detailed analysis.

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