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Research article

Energy efficient measure to upgrade a multistory residential in a nZEB

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Abstract: Developing nearly Zero Energy Buildings (nZEB) represents a path toward sustainable communities as required by the Energy Performance of Building Directive (EPBD). As consequence, nZEB target for new or existing buildings has become a mandatory priority for the multidisciplinary researchers involved in architectural engineering and building physics. Therefore, it is grown the interest in design energy efficient measures for reaching the nZEB status of both new and existing buildings. In this paper, the energy efficient measures adopted for reaching the nearly Zero Energy Building standards, for a multi-floor residential building located in the Mediterranean area, are presented. The extra cost necessary to reach the nZEB target have been calculated in the case of the energy retrofit of an existing building (scenario 1) and in the case to directly realize a building with achieve the nZEB status (scenario 2). Further, the two scenarios have been compared under financial point of view. The results of this paper provide to builders and stakeholder useful information for quantify the convenience to build a nZEB building in advance in order to prevent the additional expenses necessary by future energy retrofit programs.

Keywords: NZEB; efficient building envelope; solar thermal; photovoltaic; economic analysis

Nomenclature

c	specific heat and thermal capacity	(kJ/kg·K)
C	cost	(€)
D	Debt	(€)
DPP	Discount Pay Back	(year)
E	Equity	(€)
ERR	External Rate of Return	(€)

ES	Energy saving	(kWh)
E_{RES}	annual renewable energy	(kWh)
g	Solar factor	(-)
h	Height	(m)
h_0	Coefficient of adduction	($W/m^2 \cdot K$)
i_d	Opportunity cost of Equity	(-)
i_e	Interest rate for Debt	(-)
IRR	Internal Rate of Return	(€)
MS	Superficial Mass	(kg/m^2)
NPV	Net Present Value	(€)
PE	Primary energy	($kWh/m^2 \cdot y$)
PI	Cost of the investment	(€)
PI_T	Point input	(€)
PP	Payback period	(year)
Q	Energy needs	(kWh)
Q_{usable}	Total usable heat delivered by HPs	(kWh)
r	Discounted rate	(-)
r_f	Reflectance of vegetation layer	(-)
r_s	Minimum stomatal resistance	(s/m)
R	Revenues	(ε)
R_i	Thermal resistance of a masonry	($m^2 \cdot K/W$)
s	Thickness	(m)
S	Surface	(m^2)
SPF	Seasonal Performance factor	(-)
t	Time	(year)
t_f	Transmissivity of vegetation layer	(-)
T	Life Cycle	(year)
T_o	Outdoor air temperature	(°C)
T_{si}	Indoor surface temperature	(°C)
T_{so}	Outdoor surface temperature	(°C)
U	Thermal transmittance	($W/m^2 \cdot K$)
V	Heated gross volume	(m^3)
Y	Periodical thermal transmittance	($W/m^2 \cdot K$)
w	Cost of Capital	(€)
W	Weighted Average Cost of Capital	(€)

Greek letters

α	Absorbance	(-)
β	Tilt	(°)
η	Efficiency	(-)
λ	Thermal conductivity	($W/m \cdot K$)
ε	Emissivity	(-)
ρ	density	(kg/m^3)
θ	Moisture content	(m^3/m^3)

Ψ	Linear thermal transmittance	(W/m·K)

Subscripts

C	Cooling
e	External
f	Foliage
g	Ground
g,H	Globally for heating
gl	Heating + Production of hot water
H	Heating
i	Internal
ie	Internal-external
ij	Intervention "j" at the "i" month
p	Constant pressure
RE	Renewable Energy
Sat	Saturation
u	Net floor area
V	Ventilation
w	Window
W	Production of hot water

Acronyms and Abbreviations

ACs	Air Conditioning system
BIPV	Building Integrated Photovoltaic
CB	Condensing Boiler
DCF	Discounted Cash Flow
DHW	Domestic Hot Water
EPBD	Energy Performance of Building Directive
ETICS	External Thermal Insulation Composite Systems
EU	European Union
GR	Green roof
HP	Heat Pump
HPs	Heat Pump system
mESE	Multiplicative Energy Saving Effects
nZEB	Nearly Zero Energy Building
PV	Photovoltaic
RES	Renewable Energy Sources
$S1_{HS1}$	New building with Condensing Boiler
$S1_{HS2}$	New building with Heat Pump
$S2_{HS1}$	Retrofit with Condensing Boiler
$S2_{HS2}$	Retrofit with Heat Pump
ST	Solar Thermal
TB	Thermal Bridge
TI	Thermal Insulation

TR	Traditional roof
VF	Ventilated Facades
WI	Low-E Reflective windows

1. Introduction

The Energy Performance of Buildings Directive (EPBD) requires all new buildings to be nearly zero-energy by the end of 2020, while new public buildings must be nearly zero-energy by 2018 [1].

Further, policies and measures to stimulate the refurbishment of the existing building stock into nZEB are also required.

The energy performance of existing buildings is expressed in terms of their annual specific primary energy consumed, which falls in the range of 150–400 kWh/m^2 per year for residential buildings and 250–550 kWh/m^2 per year for office buildings [2]. Such energy needs are enormous compared with the standards of 40–60 kWh/m^2 per year set for low energy buildings.

As result, plenty of papers were devoted for identifying cost-effective energy efficient measure promoting low energy consumption. Hamdy [3] applied a method to find the cost-optimal and nZEB energy performance levels for a study case of a single-family house in Finland. He considered different options of building-envelope parameters, heat-recovery units, and heating/cooling systems as well as various sizes of thermal and photovoltaic solar systems as design options. The economic and environmental trade-offs show that primary energy consumption ≥ 93 and ≤ 103 kWh/m^2 is a cost-optimal energy performance level in Finland. Georges et al. [4] investigated a single-family dwelling in Belgium, addressing combinations of sixteen heating systems and five building designs. Marszal and Heiselberg [5] found the minimum life-cycle cost for a multi-storey residential net-zero-energy building in Denmark, addressing three levels of energy demand and three alternatives of energy supply systems.

The concept of nZEB refers to a building with a net energy consumption of nearly zero over a typical year. The target of a nZEB is not limited to minimize the energy consumption with energy efficient envelope and the rational use of energy (RUE), but requires balancing their energy requirements exploiting of on-site renewable sources, locally available, non-polluting, low-cost [6,7,8].

Therefore, nZEB are buildings connected to any energy infrastructure with which they realize a bilateral energy flux. The connection to an energy infrastructure introduces the issues of the building/grid interaction [9], as well as the balance between delivered and exported energy. Figure 1 depicts the connections between building and energy grids [10].

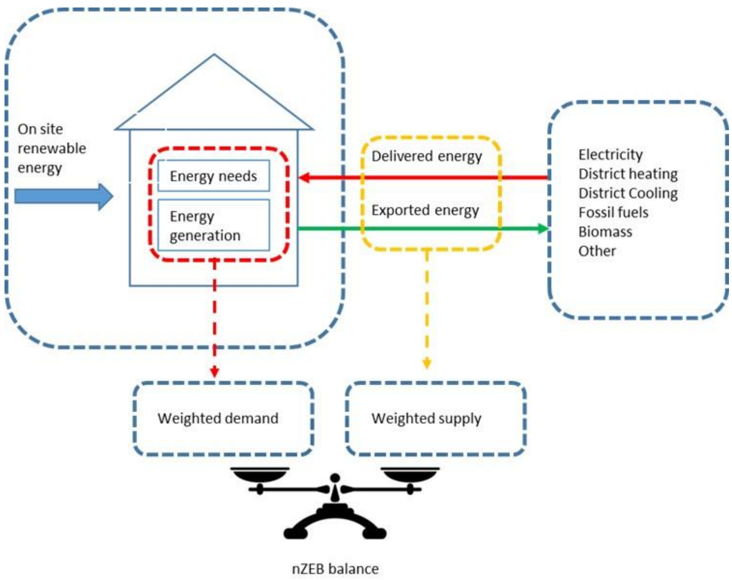


Figure 1. Connection between building and energy grid rearranged by [11].

The Primary Energy (PE) is the metric adopted for making the balance between energy needs and renewable energy production (PE_{RE}). The energy needs are those related to space heating (PE_H) and cooling (PE_C), production of hot water (PE_W), ventilation (PE_V) and lighting (PE_L). Consequently, the following expression holds:

$$PE = \sum_{year}(PE_H + PE_W + PE_C + PE_V + PE_L - PE_{RE}) \tag{1}$$

The result of equation (1) shall be almost zero in order to center the target of nZEB buildings. In literature, energy calculation methodologies [12,13], system design [14,15] integration with renewable energies [16], as well as system control/management optimization for reach the nZEB target are presented [17,18,19]. Moreover, an important issue is the economic feasibility of the energy efficiency measure to reach the nearly zero energy buildings status.

The economic features of sustainability in architecture involve practical and symbolic values that monetary valuation captures only partially and multidimensional analyses are welcome [20]. Nonetheless, many applications in the ground of architectural design and urban planning confirm that economic and financial indices play a significant role of morphogenetic variables [21], whereas at the basic level, the monetary quantitative approach aims at minimizing the investment cost given the energy saving goal.

As the energy retrofit programs are typically characterized by large starting expenses, the correct and systematic economic assessment of these investments is an important basis for choosing the energy efficient measures most suitable to the needs and financial possibilities of homeowners who—not being professional investors—needs of clear guidance about the environmental and economic balance.

In the outlined perspective, the economic issue works as a sort of double interface: downward, with the natural and technological sphere; upward, with the political sphere. In fact: on the one hand, natural environment provides some boundaries and constraints to the human behavior that economy transforms in rational commitments; on the other hand, economics provides useful tools to the policy, making possible what is convenient just for some, thus balancing individual rationality and collective intelligence.

Furthermore, in geographical areas with different climate according to the costs of the technological equipment, gas and electricity market price, the decrease of the energy needs in heating and cooling are differently welcomed, so that some technologies and processing times are preferred, some others excluded, despite the general environmental effectiveness that makes them highly recommended by the EU regulations.

This paper analyses a set of energy efficient measures broadly adopted nowadays, which allow reaching the nZEB target for a residential multistore building.

Two different scenarios have been analyzed that are the energy retrofit of an existing building (scenario 1) and to build in advance a new one (scenario 2), considering in both cases, the extra cost necessary to reach the nZEB target. Further, the two scenarios have been compared under financial point of view. The novelty of this paper is to provide to builders and stakeholder useful information for quantify the convenience to build a nZEB building in advance in order to prevent the additional expenses necessary by future energy retrofit programs.

2. Materials and Method

As well known, the achievement of the energy and environmental target established for nZEB can be reached through possible combinations of energy efficient measure.

In this paper, a set of widespread and suitable solutions have been selected for the refurbishment of multi-story residential building located in mild climate area. Thus, in the following paragraph, the authors describe:

(1) the systems and technologies proposed to reduce the energy needs of buildings;

(2) the software used for calculating the energy performance to achievement the target of nZEB;

(3) the economic analysis for evaluating of the financial feasibility and economic convenience of the investments.

2.1. Systems and technologies

The external wall insulation systems (ETICS), “Low-E and reflective” windows, load bearing thermal insulation element, ventilated façades and green roofs are widespread constructive techniques frequently implemented for realizing the building envelope of an nZEB, as well condensing boilers (CB) and a Heat Pumps (HP) are the energy generation system used for space heating and domestic hot water.

As regard the renewable energy plant photovoltaic and a solar thermal plants are two technologies often implemented.

2.2. Simulation software

The energy needs (Q) and Primary energy (PE) for Heating, Cooling and DHW have been calculated through MasterClima Software [22], which operates in accordance with EN 15316, UNITS 11300 parts 1–4. DesignBuilder Software was used for simulating the performance of green roofs [23].

2.3. Economic analysis

The economic analysis aims at optimizing the bundle of technical solutions to hit the target of nZEB standard considering the set of constraints externalities (costs, taxes etc.) and opportunities (energy market prices, incentives etc.).

According to the two main issues of the economic-financial approach—financial feasibility and economic convenience—a two-stages methodology has been developed. The first stage (A) take into account of cost and revenues; the second stage (B) concerns the economic and financial analysis of the different technologies implemented.

2.3.1. Cost of the nZEB program (first stage)

The costs of the nZEB program is constituted by manpower, materials, equipment, design and work supervisor, while the revenues come from government incentives and the energy savings. The costs of manpower, materials, and equipment have been obtained from price list or market surveys.

The budgets for the refurbishment have to include the needs for temporary structures, such as scaffoldings, and the costs for removing the existing equipment (i.e. external plasters, window frames, HVAC plant and so on).

The maintenance costs are: Thermal Insulation (TI) 1.00%; Windows (WI) 0.50%; Ventilated Facades (VF) 0.00%; Green Roof (GR) 1.00%; Condensing Boiler (CB) 2.00%; Heat Pump (HP) 1.00%; Thermal Solar plant (ST) 1.00%; Photovoltaic (PV) 0.01%; Thermal Bridge (TB) 1.00%.

Design and work supervisor accounts for a percentage of about 10% of the total costs of the interventions.

The revenues come from energy savings, have been accounted at the current prices of gas (0.80 €/Nm^3) and electricity (0.17 €/kWh).

The refurbishment scenario can count on the government incentive, which accounts by 65% of the cost of the energy efficient measure (including design and supervisor costs). This incentive is fragmented in ten annual quotas starting from the first year.

2.3.2. Discounted cash flow analysis (second stage)

A discounted cash flow analysis [24,25] allows measuring and comparing the financial attractiveness of the two proposed scenarios. In particular, the following financial indices have been evaluated.

(1) Net Present Value (NPV), it is the sum of the discounted values of incoming and outgoing cash flows, that are revenues (R) and costs (C), discounted by the rate (r) during the time period (T):

$$NPV = \sum_{t=0}^{T} \frac{R_t - C_t}{(1+r)^t} \tag{2}$$

In order to compare different options with almost equal (NPV), (r) has to be assumed equal to the cost of capital, which can be calculated according to the Weighted Average Cost of Capital (WACC):

$$r \equiv w \equiv WACC = \frac{i_d D + i_e E}{D + E} \tag{3}$$

Where: (w) is the cost of the invested capital, (i_d) is the interest rate for Debt (D) and (i_e) is the opportunity cost of Equity (E).

The interest rate for Debt and the opportunity cost of Equity are referred respectively to the active and passive interest rates charged to households and consumers, according to the statistics of Bank Italia (2015), set at 4.66% (over 5 years loan life) and 0.12%; assuming a leverage ratio of 50%. Consequently, the value of WACC is 2.39%.

(2) The External Rate of Return (ERR), is the discount rate by which the future value of the point input (PI_T) at the end of the life cycle (T) is equal to the future value of the positive cash flows invested at the Minimum Attractive Rate of Return (MARR) [25] that in this case is assumed equal to (w):

$$ERR = \sqrt[t]{\frac{1}{PI}(1+w)^t \sum_{t=0}^{T} \frac{\left(R_t - C_t\right)}{\left(1+w\right)^t}} - 1 \tag{4}$$

ERR has to be greater than (w) so that, assuming as relevant this criterion, the decrease of the Debt interest rate could help the financial feasibility of the nZEB program.

(3) The Internal Rate of Return (IRR) is the discount rate that makes (NPV) of all cash flows from the investment equal to zero:

$$\sum_{t=0}^{T} \frac{\left(R - C\right)_t}{(1+IRR)^t} = 0 \tag{5}$$

It corresponds to the maximum rate of return of an investment assuming the discount rate equal to zero. The IRR depends on the distribution of the costs and revenues along the lifecycle of the investment; (IRR) needs to be greater than discount rate, given that the discount rate is assumed as the global cost (interest rate and opportunity cost) of the invested capital (w).

(4) The Discounted Payback Period (DPP) or simply Payback Period (PP) is the length of time (T^*) required to recover the cost of the investment (PI), calculated with ($r > 0$) [26] or without ($r = 0$) [27]; the higher the discount rate, the longer the (DPP).

DPP can be calculated as the ratio between the discounted outgoing cash flow and the annual average incoming:

$$DPP = \frac{\sum_{t=0}^{T} \frac{C_t}{\left(1+w\right)^t}}{\sum_{t=0}^{T} \frac{R_t w q^T}{\left(1+w\right)^t q^t - 1}} \tag{6}$$

In equation (6) the denominator is the average annual income, calculated by transforming the discounted variable revenue stream in a constant rate, and $q = 1 + w$.

The above mentioned indices have been calculated both for each component of the nZEB program and for the program as a whole, in order to allow procurers to make informed decisions about the best allocation of the available budget.

3. Test Case

The case study used as reference is a multi-storey residential building with 39 apartments located in Sicily (Acireale; latitude 15°9', longitude 37°36'). The building consists of three floors above ground and it is subdivided in five blocks. The blocks 1, 3 e 4 have three apartments for each floor, (total 27 units), instead the blocks 2 and 5 have two apartments for floor (total 12 units).

Figure 2 and Table 1 show the existing building and its main geometric data.

Figure 2. a) East façade; b) South-East prospective; c) South façade.

Table 1. Geometric data and characteristic parameters.

Heated gross- volume	V	12580,88 m^3
Surface/volume coefficient	S/V	0,417 l/m
Net floor area	S_u	3189 m^2
Ventilation rate	-	0.30 vol/h

As regard, the ventilation the air change rate of 0.30 vol/h has been adopted, since it is typical of a building under natural ventilation condition. The current rules on building energy efficiency impose specific thresholds of thermal insulation of the building envelope components as well as limits to the primary energy needs, and do not impose the achievement of the target of NZEB. Thereby, the U-values (thermal transmittance) and Ψ-values (thermal transmittance per unit length) of the components of a standard building envelope must satisfy the threshold reported in Table 2 (Italian climatic zone C).

Table 2. Geometric data and features.

	External wall	Roof slab	Ground floor	Glazing surfaces
Uvalue ($W\ m^{-2}\ K^{-1}$)	0.43	0.41	0.43	3.16
		Thermal bridge		
Ψ ($W\ m^{-1}\ K^{-1}$)		0.80		

3.1. Energy needs of the test case building

The energy needs of the test building has been calculated through the software Masterclima, which allow to calculate the terms PE_H, PE_W and PE_C in equation (1).

The energy needs are calculated assuming an internal design temperature of 20 ℃ during the heating period (15st November–31th March) and 26 ℃ during the cooling period (1st April–15th November). The daily hot water needs have been evaluated in 150.00 l/day per apartments.

The thermal energy for heating space and DHW (Domestic Hot Water) production are both provided through combined centralized gas-fired system with a seasonal average yield, called global efficiency ($\eta_{g,H}$) of 77.80%. The standard building configuration has the following energy needs: Q_H = 155.55 MWh; Q_W = 55.19 MWh; Q_C = 89.86 MWh.

The primary energy for heating, $Q_{P,H}$ = 199.832 MWh, and DH, $Q_{P,W}$ is 70.873 MWh, area obtained introducing the global efficiency of the heating system. Thus, the primary specific energy for space heating (PE_H) and DHW production (PE_W) are:

$$PE_H = \frac{Q_H}{\eta_{g,H} S_u} = 62.66 \text{ kWh/m}^2\text{y} \quad (7)$$

$$PE_W = \frac{Q_W}{\eta_{g,H} S_u} = 22.22 \text{ kWh/m}^2\text{y} \quad (8)$$

PE_c is a specific useful energy for cooling space of building and it is given by:

$$PE_C = \frac{Q_C}{S_u} = 28.17 \text{ kWh/m}^2\text{y} \quad (9)$$

Where (S_u) is net floor area of whole building equal to 3,189 m^2. Therefore, global primary specific energy needs (PE_{gl}) is calculated as follows:

$$PE_{gl} = PE_H + PE_W = 84.882 \text{ kWh/m}^2\text{y} \quad (10)$$

Thus, if the buyer would like upgrade this test building in an nZEB configuration the adoption of energy efficient measures is necessary. Now, two possible alternative emerge, the first one is the refurbishment of this standard configuration (scenario 1) and the second is the implementation of the energy efficient measure directly in advance when the building is build (scenario 2).

4. Performance of the Upgraded Building

4.1. Building envelope

The energy performance of the test building has been improved applying the constructive technologies previously mentioned.

New windows are realized in aluminum with thermal break and double glazing composed by two panes of 6 mm and 16 mm of air gap between panes. The U-value of the windows is calculated in according to UNI EN ISO norms [28,29].

As regard the ETICS a thickness of 3 cm of thermal insulations has been added, and consequently an additional thermal resistance of 0.70 $W/m^2 K$ is achieved.

Table 3. Main features of Low-E and reflective windows.

Double glass (s = 28 mm) two 6 mm glass and 16 mm airspace					
Glazing U_g (W/m^2 K)	Frame U_f (W/m^2 K)	Window U_w (W/m^2 K)	Solar factor g (%)	Emissivity of glass ε (-)	Reflectance r (-)
1.30	2.89	2.00	42	0.1	0.9

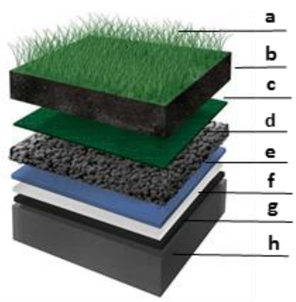
A ventilated façade is constituted by an air gap, with thickness of 10 cm, and Poroton blocks where is fixed the bearing structure of panels. Substantially, the ventilated facades act reducing the energy needs for cooling through the combined action of shading of the external walls, from the incident solar radiation, and the ventilation of the air channel due to the air buoyancy. The U-value was calculated by means UNI EN ISO 6946 [30] as reported in the following equation:

$$U = \frac{1}{\frac{1}{h_{oe}} + \sum_{i=1}^{n} \frac{s_i}{\lambda_i} + \frac{1}{h_{oi}}} \tag{11}$$

For the ventilated facades, the U-value is obtained neglecting the thermal resistance of the air gap and all layers that separate it from outdoor air. Consequently, the thermal resistance of the internal layer ($\sum s_i/\lambda_i$) and the two superficial thermal resistance, h_{oe} and h_{oi}, are included. Therefore the U-value of the ventilated facade results by 0.30 W/m^2 K. Moreover, the thermal mass (MS = 262 kg/m^2), Thermal Capacitance (C_i = 38.83 kJ/kg K) and Periodic Thermal Transmittance (Y_{ie} = 0.07 W/m^2 K) have been calculated.

The layers reported in Table 4 constitute the implemented extensive green roof, where mosses, an essence that guarantee a good coverage as well as roof membrane protection, constitute the vegetation layer [30].

Table 4. Main features of the green roof.

Layer	a	b	c	d	e	f	g	h
	Vegetation layer	Growing Medium (15 cm)	Filter layer (0.1 cm)	Drainage (10 cm)	Water proofing membrane	Thermal insulation (6 cm)	Moisture barrier (0.5 cm)	Roof deck (10 cm)

The thermo-physical features of the vegetation layer and substrate are reported in Table 5.

The U-value of the green roof is 0.20 W/m^2 K. Moreover, the thermal mass (MS = 602 kg/m^2), thermal capacitance (C_i = 70.20 kJ/kg K) and periodic thermal transmittance (Y_{ie} = 0.12 W/m^2 K) have been calculated in accordance to UNI EN ISO 13786:2008 [31].

Table 5. Thermo-physical properties of vegetation and substrate layer.

Vegetation layer						
Height of the plants (h_f) (m)	Leaf are index (LAI) (m^2/m^2)	Albedo (r_f)	Absorbance (α_f)	Transmissivity (t_f)	Emissivity (ε_f)	Minimum Stomatal Resistance (r_s) (s/m)
0.10	2.0	0.22	0.60	0.18	0.95	180
Substrate						
Thermal conductivity (λ_g) (W/m^2 K)	Density (ρ_g) (kg/m^3)	Specific heat (c_p) (J/kg K)	Absorbance (α_g)	Emissivity (ε_g)	Moisture Content (θ) (m^3/m^3)	Saturation Moisture (θ_{sat}) (m^3/m^3)
0.98	0.98	880	0.70	0.90	0.40	0.60

Table 6 summarize the U-value of the components of the envelope of the upgraded building for the two scenarios.

Table 6. Opaque envelope and glazing thermal features.

Type	U (W/m^2 K)	Ψ (W/mK)
Ventilated Facades	0.30	-
Green Roof	0.20	-
External Wall Insulation Systems	0.33	-
Low-E and Reflective Windows	2.00	-
Thermal bridge	-	0.15

Figure 3 shows the monthly energy saving $(ES_J)_I$ associated with each investigated energy efficient measure.

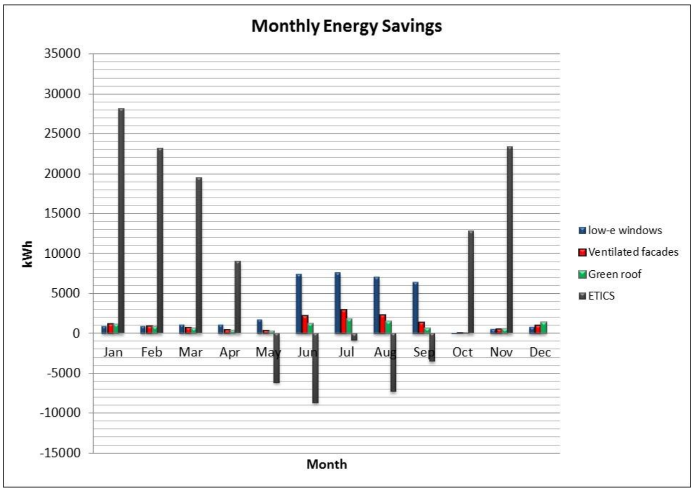


Figure 3. Energy saving attained by each building components.

It can be noted that the ETICS provides the highest energy savings during the heating period; otherwise, it implies the growth of the energy needs during the months of April, May, September and

October. This happens because of the indoor set point temperature, used in calculation, is fixed at 26 ℃ (according UNI TS 11300), that could be higher than the outdoor temperatures. Accordingly, the thermal flux goes from the indoor to outdoor environment and the increase of the thermal resistance impedes the cooling of the internal environment, especially during the night time. Otherwise, in July and August the outdoor air temperatures are highest than the indoor temperatures, therefore the increase of thermal insulation reduce the thermal flux form the outdoor to the indoor environment.

The low-e and reflective windows allow getting excellent performances during the cooling period contributing by 50% of the reduction of the cooling needs, thanks mainly to the reduction of solar gains.

The ventilated façades give a support to the energy saving all year around, and are most efficient during the summer months (June, July, August and September), contributing by 24% of the reduction of the cooling needs. Table 7 shows the reduction of the energy needs and specific primary energy associated with each energy efficient measure as well as the whole package.

Table 7. Reduction of the energy needs and specific primary energy.

Intervention	ΔQ_H (MWh)	ΔQ_C (MWh)	ΔPE_H (kWh/m^{2}y)	ΔPE_C (kWh/m^{2}y)
ETICS	80.97	+34.12	32.63	+10.70
Windows	4.27	28.35	1.72	8.89
Ventilated Facade	4.22	10.10	1.70	3.17
Green roof	2.75	4.25	1.11	1.33
Whole package of EEM	107.87	30.88	43.48	9.68

Globally, the proposed package of energy efficient measure reduces by 69% the energy needs for space heating, (107.87 MWh), and by 34% (30.88 MWh) for space cooling. This result is higher than the summation of the energy saving deriving from each energy efficient measure thanks to a “multiplicative Energy Saving Effects” (mESE).

Globally, the energy needs of the building envelope, which include the above described energy efficient measure are Q_H = 47.31 MWh; Q_C = 58.79 MWh. As regard the energy needs for DHW production there are not variation, Q_W = 55.19 MWh.

Thereby, the equation (1) for the upgraded building gives the following indexes of energy performance, which are PE_{gl} = 41.28 kWh/m^{2}y; PE_C = 18.43 kWh/m^{2}y. To further reduce the energy needs it is necessary improve the efficiency of the energy production system and foresee the exploitation of RES.

4.2. Energy production systems

The energy performance of building can be further increased through the introduction of generation systems with efficient higher than the traditional generation system that are a condensing boiler and one Heat Pumps.

Therefore, the energy needs of the upgraded building have been calculated installing an air source vapor compressed HP with a seasonal performance factor (SPF) of 3.45, or a condensing boiler (CB) with an efficiency of 99.0% are implemented as heating generation systems.

The specific primary energy PE_H becomes 11.52 kWh/m^{2}y and 14.03 kWh/m^{2}y in the case of a (HP) or a (CB) respectively.

The EU directive [32] recognizes Heat Pumps (HPs) as a technology that exploit RES from air, water and ground, when the efficiency of HP, calculated with reference to the primary energy, is higher than 115%. This means that the SPF must satisfy the follows condition:

$$\mathrm{SPF} > \frac{1.15}{\eta} \tag{12}$$

Where η is the efficiency of electricity production in the EU, here assumed equal to 0.4.

The annual renewable energy (E_{RES}) delivered by the HP, calculated by equation 14, is of 33.62 MWh, which is about the 71% of the thermal energy request for space heating.

$$E_{RES} = Q_{usable}\left(1 - \frac{1}{\mathrm{SPF}}\right) \tag{13}$$

Where (Q_{usable}) is total usable heat delivered by HPs for space heating and Domestic Hot Water (DHW).

However, the implementation of a heat pumps resets the fuel needs but involves a demand of electric energy that will be satisfied by the optimal management of various RES.

5. Renewable Energy

5.1. Solar thermal plant

The energy needs for DHW represents a significant percentage of the total energy demand of the building. Indeed, the primary energy for domestic hot water PE_W amounted to 22.22 kWh/m^{2}y that is about 50% of the global primary energy PE_{gl} in the case of the upgraded building envelope.

Thus, the installation of 39 thermal solar plants, with a gross area of 3.00 m^2, has been accounted for reducing the DHW energy requirement. The solar collectors are south oriented with a tilt angle of 35°, the collector's optical efficiency (τα) is of 86%, and the coefficient of thermal losses is 3.50 (W/m^2 K). Moreover, each solar plants equipped with a stratified storage tank with a capacity of 250.00l.

The monthly average daily values of solar radiation incident on the solar plants was evaluated by the National Institute for Alternative Energy (ENEA) software [33].

Starting by the previous mentioned data, the calculation developed by the "f chart" method [34] have shown that the surface of 3.00 m^2 is sufficient to satisfy by 80% of the DHW energy demand of each apartments. Figure 4 reports energy provided and the fraction of energy needs satisfied by each solar thermal plant.

In this way, the request of energy for DHW is 4.44 kWh/m^{2}y and, consequently the global specific primary energy PE_{gl} is drastically reduced to 17.70 kWh/m^{2}y when the heating system is a HP and 23.50 kWh/m^{2}y when the heating system is a CB. The effectiveness of these interventions on systems is an important issue for buildings that are located in temperate climates, for which the interventions on the building envelope are costly and not decisive in terms of energy savings.

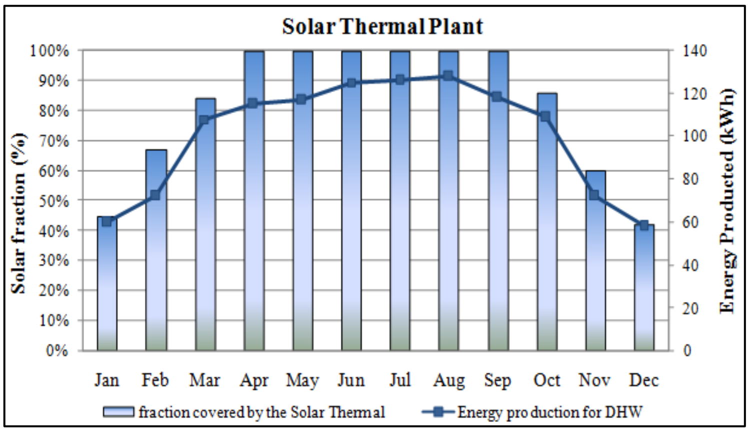


Figure 4. Solar fraction and energy produced for DHW by the solar thermal plant.

5.2. Nearly zero energy building

The target of a nZEB is not only to minimize all the energy consumption, including energy requirements for lighting and other use such as the plug loads, but also balances its energy requirements with the local production of energy through RES.

The total demand of electrical energy is about 117,000 kWh, which was calculated assuming an electricity energy consumption of about 3.000 kWh/y per apartment [35].

For this purpose, the implementation of a BIPV (Building integrated photovoltaic) plant has been evaluated. The PV panels are posed on the facades and on the parapets of the balconies (β = 90°) of each apartment, as well as on the roofs of the staircases (β = 15°). The PV technology used is the crystalline silicon and its characteristics and geometric data are reported in Table 8.

Table 8. Characteristics and geometric data of PV panels.

Efficiency PV (η_{PV})	Dimension (m × m)	Surface (m^2)	Peak power* (W)	Panel surface for kW_p installed power (m^2)	Number of panels for kW_p
14%	1.65 × 1.00	1.65	250	6.53	4

*The peak power is referred to a standard condition: temperature of 25 °C and solar radiation of 1000 W/m^2.

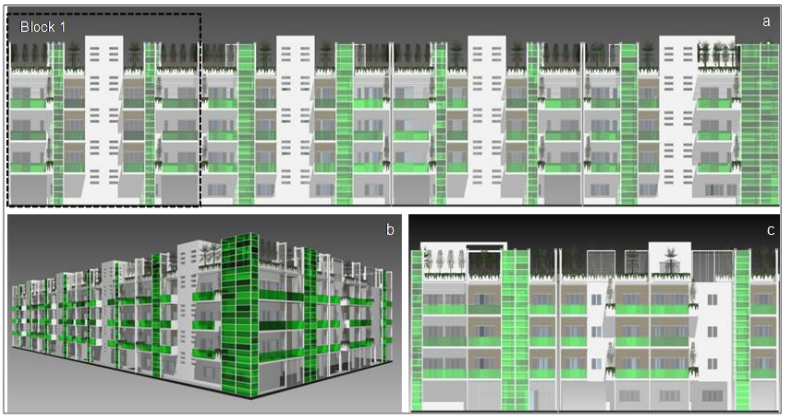


Figure 5. Building after renovation: a) West façade; b) 3D view and South façade; c) South facade.

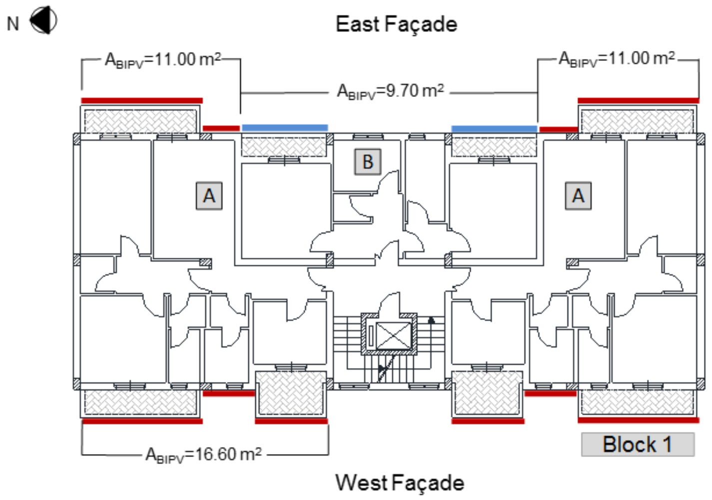


Figure 6. Plan of the typical block with available surface for the PV panels.

Figure 5 and 6 show the positioning of the PV panels in a representative block of the multistore building and a view of the building façade in which the BIPV plants are implemented.

5.3. PV energy yields

The PV energy yields has been calculated through the software platform PVGIS [36]. Figure 7 shows the monthly solar radiation, deriving by the database "climate SAF-PVGIS", incident on the different facing and surfaces.

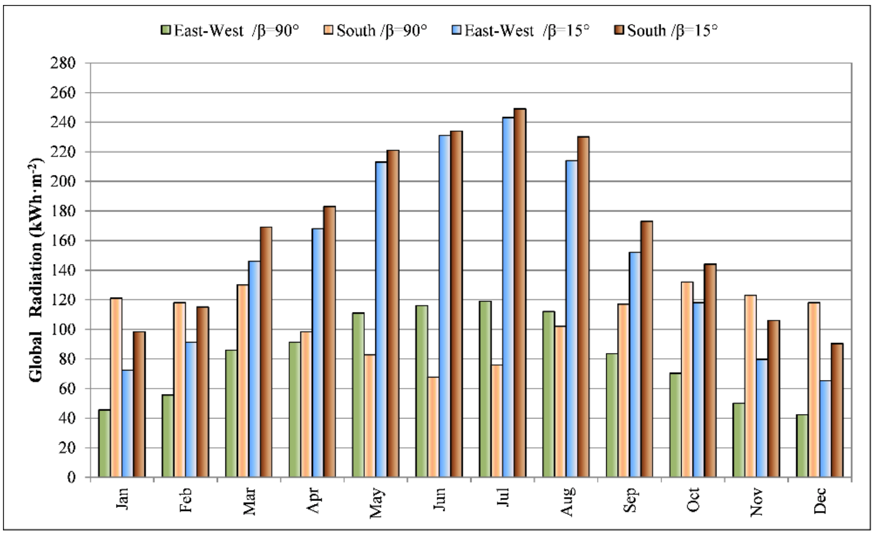


Figure 7. Monthly global irradiation (kWh/m^2).

The yearly global radiations at the different orientation are:
West-East façade (90°): 1,285 kWh/m^{2}y;
South façade (90°): 982 kWh/m^{2}y;

West Sloped roof (15°): 1,793 kWh/m^{2}y;
South Sloped roof (15°): 2,012 kWh/m^{2}y.

The following Table shows the available surfaces and their orientation on which to install the PV panels for each of the 39 apartments and on the staircase roof for each block.

The usable surface has been calculated considering the number of the PV panels that can be hosted in the available surfaces and the relative installed peak power (kW$_p$).

The yearly electricity production E_m (kWh) have been calculated through the PVGIS tool. The system energy loss has been assumed by 15.5%, for considering both shadowing effects and the degradation of the PV performance due to cell ageing.

Table 9. Available surface and yearly electricity production by the PV plant.

	Apartment	Number	Gross surface per apartment			Usable surface per apartment			Total usable surface		
			E	W	S	E	W	S	E	W	S
1	Type A	6	11.00	16.60	-	9.90	14.85	-	59.40	89.10	-
	Type B	3	9.70	-	-	8.25	-	-	24.75	-	-
2	Type C	6	8.10	16.60	-	6.60	14.85	-	39.6	89.10	-
3	Type A	6	11.00	16.60	-	9.90	14.85	-	59.40	89.10	-
	Type B	3	9.70	-	-	8.25	-	-	24.75	-	-
4	Type C	3	8.10	16.60	-	6.60	14.85	-	19.80	44.50	-
	Type D	3	-	23.50	9.70	-	23.10	8.25	-	69.30	24.75
	Type E	3	-	8.50	12.20	-	8.25	11.55	-	24.75	34.65
5	Type F	3	-	-	8.50	-	-	6.60	-	-	19.80
	Type G	3	-	8.50	10.20	-	8.25	8.25	-	24.75	24.75
	Stair case	4	-	29.20	-	-	26.04	-	-	105.60	-
	Roof (β = 15°)	1	-	-	29.20	-	-	26.04	-	-	26.04

	East (90°)	West (90°)	South (90°)	West (β = 15°)	South (β = 15°)
Total available surface (m^2)	227.70	430.65	103.95	105.60	26.04
Installed peak power (kW$_p$)	34.0	60.0	15.0	16.0	4.0
Energy yield (kWh)	24,475	43,239	18,908	21,286	5,986

Globally the building surface occupied by BIPV is 893.94 m^2, of which 762.30 m^2 on the building façade and 131.64 m^2 on the staircase roof. The total installed peak power is 129 kW$_p$, which provide a yearly electricity production of 113,895 kWh, almost totally satisfy the electrical energy needs (117,000 kWh) of the 39 apartments of the multi-floor building.

Definitively, the equation 1 gives a PE less than of 17.70 or 25.50 kWh/m^{2}y in function of the heating system adopted. However, when a Heat Pump is adopted as heating system its energy consumptions can be satisfied by the PV plant, guaranteeing almost zero energy balance.A possible strategy for further exploit the usable surface for installing renewable energy plant is the implementation of solar panels which allow the simultaneously production of electric and thermal energy, the so-called PVT panel [37].

6. Environmental Performances of the Implementation of the Green Roof

Green roofs are often pointed as an efficient technology that reduce solar gain, indoor and outdoor superficial temperature fluctuations, as well as indoor air temperature peaks.

The capability of the green roof to achieve the above mentioned performance it was analyzed through the DesignBuilder Software. In particular, the internal (T_{si}) and external (T_{so}) superficial temperatures were calculated in free running conditions (without ACs) for both a traditional roof (TR) and a green roof (GR). Figure 8 shows the trends of these temperatures during the period (15th July–15st August).

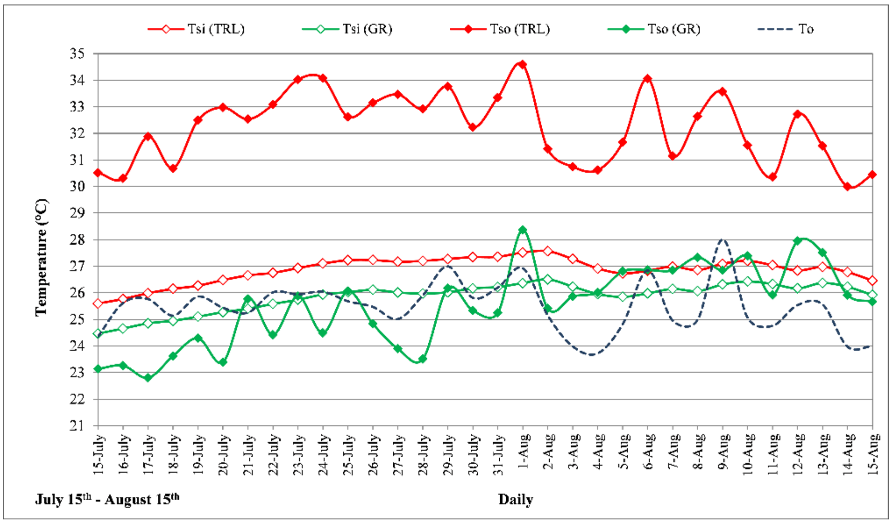


Figure 8. Daily profiles of outer and inner surface temperature.

It is possible to notice that throughout the period investigated the T_{so} of (TR) is always higher than T_{so} of (GR). The average difference between T_{so} (TR) and T_{so} (GR) is of about 7.0 ℃, with a maximum daily value of 9.50 ℃.

The trend of T_{si} (TR) keeps its profile averagely around 30 ℃ with peak values of 31 ℃ while T_{si} (GR) has values almost of 26 ℃. Therefore, a significant average difference equal to 4 ℃ and a maximum daily value of 5 ℃ between the values of T_{si} (TR) and T_{si} (GR) have been obtained. It is important to highlight which the profile of T_{si} (GR) is rather flat if compared to the T_{si} (TR), this indicates which the green roof reduces the hourly fluctuations of T_{si}. This is due to the soil layer which with its thermal mass and the water content it absorbs, stores and releases the heat in the nocturnal hours [38,39].

7. Economic Analysis Results

The above listed energy efficient measure of the building envelope and systems are now considered from the economic and financial perspectives, in order to compare the two options, new construction and retrofit, and select their optimal arrangement.

At first, the nZEB program costs and revenues have been represented separately, showing the associated costs and revenues related to each proposed interventions: thermal insulation (1.TI), windows (2.WI), green roof (3.GR), ventilated facades (4.VF), thermal bridges (5.TB), condensing boiler (6.CB), heat pump (7.HP), solar thermal (8.ST) and mono-cristalline photovoltaic (9.PV) (Table 10).

Table 10. Costs and revenues for each component of the nZEB program considering the cases of new building and retrofit (€).

New building	TI	WI	GR	VF	TB	CB	HP	ST	PV
Unitary cost	17	45	51	85	239	31815	46502	554	416
Investment cost (Stock)	48247	30034	52090	203162	58584	27915	46502	33246	336733
Maintenance (annuity for the whole life cycle)	420	56	514	0	282	500	360	300	324
Incentives (annuity for ten years)	0	0	0	0	0	0	0	0	16200
Savings (annuity for the whole life cycle)	6289	1978	690	-696	2280	2915	10502	3246	14148
Retrofit	**TI**	**WI**	**GR**	**VF**	**TB**	**CB**	**HB**	**ST**	**PV**
Unitary cost	70	507	51	85	-	31815	46502	554	462
Investment cost (Stock)	196299	338704	52090	203304	-	31815	46502	33246	374148
Maintenance (annuity for the whole life cycle)	420	654	514	0	-	500	360	300	324
Incentives (annuity for ten years)	12351	21887	3341	13260	-	1879	2340	3900	18000
Savings (annuity for the whole life cycle)	6289	1978	690	–696	-	2915	10502	6492	14148

Table 11 shows the NPV calculated for each energy efficient measure as well as the two scenarios, considering two life cycle of 30 (medium term) and 100 years (long term). The 100-years period is just an illustrative hypothesis for testing the convenience under the perspective of the willingness to expect.

Table 11. NPV (thousands €) for both new building and retrofit scenario in medium (30 years) and long (100 years) run.

		1.TI	2.WI	3.GR	4.VF	5.TB	6.CB	7.HP	8.ST	9.PV
30 years	New building	68	–5	–87	–239	–30	13	161	17	–85
	Retrofit	–29	–294	–57	–122	-	26	181	34	–94
100 years	New building	157	14	–109	–251	–5	44	315	54	–4
	Retrofit	28	–388	–80	–134	-	56	336	71	–5

The energy efficient measure 6.CB (HS_1) and 7.HP (HS_2) are alternative. Further the NPV of the whole energy efficient measure has been calculated for all the set of possible alternative: New building with CB ($S1_{HS1}$), New building with HP ($S1_{HS2}$), Retrofit with CB ($S2_{HS1}$), Retrofit with HP ($S2_{HS2}$).

Table 12. Total NPV (thousands €) for both new building and retrofit scenario in medium (30 years) and long (100 years) run.

	T = 30 y				T = 100 y			
	$S1_{HS1}$	$S2_{HS1}$	$S1_{HS2}$	$S2_{HS2}$	$S1_{HS1}$	$S2_{HS1}$	$S1_{HS2}$	$S2_{HS2}$
NPV	–263	–443	–201	–382	–95	–444	174	–168

It is possible notice that the minimum discounted payback period, even not economically significant, occurs in the new building scenario when the Heat Pump is chosen as heating system (lower left graph).

Then, the retrofit scenario, despite the availability of government incentives, cannot compensate the highest initial cost. The consolidated discounted cash flows—annual (blue) and cumulated (red) in the long term period are displayed in Figure 9.

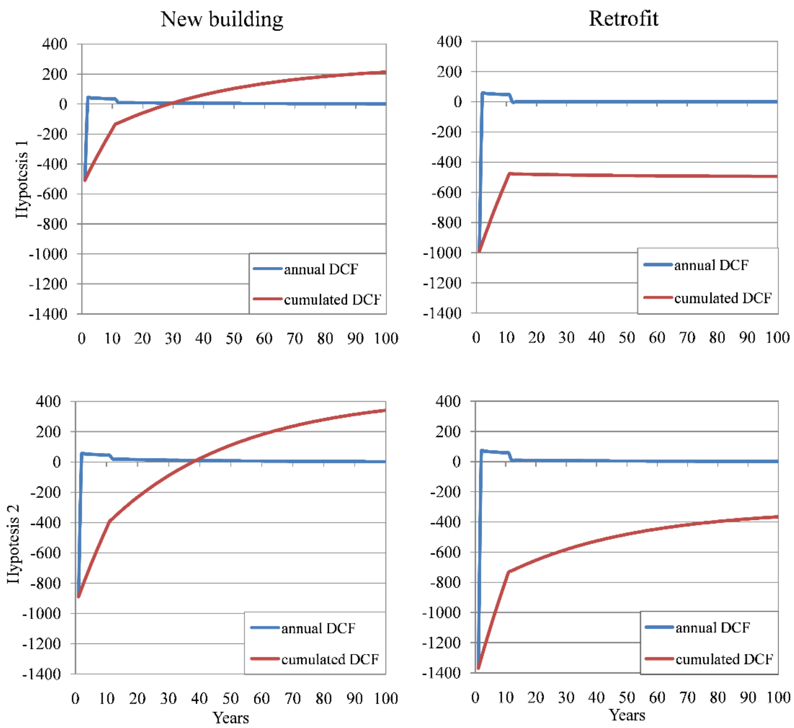


Figure 9. Discount cash flows (DCF) in M€.

Table 13. Economic results and financial indices.

	T = 30 y				T = 100 y			
	$S1_{HS1}$	$S2_{HS1}$	$S1_{HS2}$	$S2_{HS2}$	$S1_{HS1}$	$S2_{HS1}$	$S1_{HS2}$	$S2_{HS2}$
ERR (%)	–0.27	0.24	1.49	1.26	2.17	1.74	2.60	2.26
IRR (%)	–4.98	–10.91	–2.20	–3.89	–0.65	-	0.73	–0.74
DPP (years)	> 100	> 100	54	> 100	> 100	> 100	54	> 100

Table 13 shows the other financial indices that have been calculated. Despite the general scarcity of the economic performances displayed in Table 13, some remarks can be pointed out. The new building scenario, from all the perspectives, achieve the most attractive performance, despite the government incentives that significantly support energy retrofit and renovation. Furthermore, the implementation of the heat pump system for environmental heating provides the higher performance both in new building and in retrofit scenario.

The favourable results of the long term scenario allow us to appreciate the positive impact in terms of economic performances coming from the willingness to expect of the owners, that a situation of low inflation and low interest rates as the current one can encourage. The relevance of this result specifically concerns the environmental policy matters about the choices of the kind and the amount of the supports to implement.

Due to the poorness of the economic results of Ventilated Facades and Green Roof both in medium and long term, the financial indices have been recalculated excluding these energy efficiency measure (Table 14).

Table 14. Economic results and financial indices.

	T = 30 y		T = 100 y	
	New Building	Retrofit	New Building	Retrofit
NPV (k€)	139	–176	578	102
ERR (%)	3.21	1.83	3.13	2.50
IRR (%)	1.95	–1.96	3.44	0.49
DPP (years)	20	60	20	60

The red numbers indicate the values considered insufficient or exceeding the benchmarks. It is possible to point out the satisfying economic performances of this configuration especially in case of new building.

8. Conclusion

This study analyses the extra cost necessary to reach the nZEB target in the case of the energy retrofit of an existing multistore building (scenario 1) and in the case to directly realize a building with achieve the nZEB status (scenario 2). Further, the two scenarios have been compared under financial point of view.

For obtaining a nearly zero energy balance, it is necessary to upgrade the performance of the building envelope in combination with the energy generation system in comparison to a reference building. The analysed energy efficient measure under investigated are that one commonly used in the current building design: ETICS, Efficient windows, Ventilated façade, green roof, Heat Pump and condensing boiler.

However, only such strategy, which significantly contribute to diminish the energy demand of the building, is not sufficient to reach a nearly zero balance of the energy needs.

Therefore, it is compulsory the local production of energy through renewable source, which allows obtaining a nearly zero energy balance.

More specifically the implementation of a solar thermal plant of about 117 m^2, which satisfy by 80% of the energy needs for the production of DHW, and about 893 m^2 of PV panels, which satisfy almost totally the energy needs of both electric appliance and of the Heat Pump.

From these results, one can point outs the enormous requirements of available surfaces, more than 1000 m^2, where install the solar panels that can be satisfied only by exploiting the BIPV technology.

The implementation of the same energy efficient measure involves different cost for the two scenarios. Indeed, in the case of the refurbishment of an existing building extra costs are necessary for provisional scaffolders and to demolish the pre-existent components of the building envelope that needs to be upgraded.

The financial analysis shows that some of the energy efficient measures implemented for upgrading the building envelope are less cost-effective, (i.e. ventilated façade and green roof) in comparison with the upgrade of the energy generation system.

However, the implementation of a ventilated façade and of a green roof allows to obtain some other specific benefits that are not directly monetizable (aesthetic value, improve of the microclimate).

The economic-financial analysis confirmed the clear preferability of the first scenario, (i.e. new building) option envisaging sustainable constructive technologies, heat pump (HS2) and solar thermal system by most of the points of view.

The long-term strategy highlights the possibility to achieve positive financial indices thanks to the significantly cheaper environmental investments. Therefore, high initial costs and long payback periods, financial barriers, are the main obstacles for increase the spreading of the nZEB.

Conflict of Interest

All authors declare no conflicts of interest in this paper.

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