Definition of nearly zero energy building and cost-optimal energy performance in 2020

Francesco Madonna
RSE SpA,
Via Rubattino, 54
IT-20134 Milano
Italy
francesco.madonna@rse-web.it

Franco Ravasio
RSE SpA,
Via Rubattino, 54
IT-20134 Milano
Italy
franco.ravasio@rse-web.it

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Abstract

Directive 2010/31/EU (EPBD recast) introduces the concept of nearly zero energy building (NZEB) stating that all new buildings must be NZEB by the end of 2020. According to the Directive, a NZEB is a building that has a very high energy performance and its energy need is covered to a very significant extent by energy from renewable sources (RES). It is up to each Member State specify the meaning of "very high performance" and "very significant extent".

The same Directive mentions cost optimality as a driver in fixing building energy requirements. Particularly, the Commission established a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for building and buildings elements. So, NZEB energy performance should be equal or better than the cost-optimal level calculated with the comparative methodology applied in 2020.

In this paper we define two 2020 scenarios and then we apply the comparative methodology in order to derive the cost-optimal levels, i.e. the energy performance, in terms of primary energy, leading to minimum life cycle cost. These levels are benchmarks for NZEB definition.

In the first scenario we use current input values, with a slight improvement in the energy efficiency of building systems and a reduction of the primary energy and CO_2 factors for electricity. In the second scenario, in addition to the previous hypotheses, we assume cost reductions of RES technology and of new generation systems due to technological progress.

The study is focused on new residential buildings (two typologies) and takes into account the effect of two different climate conditions (northern and southern Italy). The considered energy efficiency measures cover different levels of thermal insulation, double and triple glazing, shading devices, condensing boilers, air and ground-source heat pumps, combined heat and power, photovoltaic and thermal solar collectors and mechanical ventilation with heat recovery.

Introduction

Buildings account for 40 % of total energy consumption in the European Union (European Union, 2010) and there is a huge potential for cost-effective energy savings in this sector. In order to achieve these savings, especially after the adoption of the Directive 2002/91/EC (European Union, 2002), authorities have introduced new and more stringent requirements in building regulations. In this process of making building more efficient, the forthcoming step will be the nearly zero energy building (NZEB).

According to EPBD recast – Article 2(2) – a NZEB is "a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby". The same Directive fixes 2020 as the deadline for all new buildings to be nearly zero energy (and even sooner for public buildings – by the end of 2018). For existing buildings, Member States are required to draw up national plans to increase the number of NZEBs, though no specific targets have been set.

The previous definition is quite general and qualitative, so each Member State has to give full detail and quantitatively specify which requirements a building has to fulfil in order to be classified as a NZEB. Probably there will be as many definitions as Member states, depending on the level of ambition as well as local conditions. In fact, the concept of very high energy performance is inherently relative and therefore subject to different interpretations. But a common driver in fixing targets is given by the EPBD recast which states that minimum requirements should be set, at least, with a view to achieve the cost-optimal balance between the investments involved and the energy costs saved throughout the lifecycle of the building. On this basis, it is clear that NZEB definition has a link with cost-optimality because the minimum energy performance requirements for new buildings after 2020 (i.e. NZEB) will have to be cost-optimal as well.

Methodology

The Commission Delegated Regulation No. 244/2012 (European Union, 2012a) established a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for building and buildings elements. With this methodology, Member States have to verify the strictness of their current requirements and periodically review their calculations in time for the review of their requirements.

In this paper we simulate the application of the comparative methodology framework in 2020. Then the obtained cost-optimal levels, i.e. the energy performance, in terms of primary energy, leading to minimum life cycle cost, should represent the minimum requirement in 2020, i.e. the upper limit for NZEB energy performance.

The methodology proposed by the Commission is articulated around 6 steps:

1. Establishment of reference buildings;
2. Identification of energy efficiency measures and measures based on RES;
3. Calculation of the primary energy demand;
4. Calculation of the global cost (in term of Net Present Value);
5. Derivation of a cost-optimal level of energy performance;
6. Sensitivity analysis on key parameters.

In this paper we follow Commission guidelines but our attention is focused on overall building performance. We limit our analysis to new residential buildings and, since we focus on very high performance, we consider only state-of-the-art or innovative measures avoiding solutions that are inefficient or not compliant with current requirements. In order to have 2020 as the starting year of the calculation, we build two scenarios that take into account the evolution of key parameters. Strictly speaking, we do not undertake any sensitivity analysis, even if comparing two scenarios could be seen as a sort of sensitivity analysis. In the next sections we will describe the methodology detailing buildings, measures, energy performance calculation, global cost calculation and scenarios.

BUILDINGS

The study is conducted on four different new residential buildings classified according to two typologies and two locations. The first typology is the single-family building. It consists of two heated storeys of 75 m^2 each, an unheated attic and an unheated basement. The compactness ratio[1] is 0.70 and the gross glazing area[2] amounts to 19.4 m^2 (44 % on the South façade, 28 % on the North façade, 19 % on the West façade and 9 % on the East façade). The second typology is a multi-family building consisting of 12 apartments distributed on 6»storeys, plus an unheated attic and an unheated basement. Each apartment is 80 m^2 and the compactness ratio of the building is 0.46. The gross glazing area amount to 129.6 m^2 (42 % on the South façade, 33 % on the North façade, 13 % on the West and 13 % on the East façades).

Taking into account different locations allows us to evaluate the influence of different climates. The climate strongly affects the energy performance of buildings and technical systems and, as a consequence, building techniques and materials are usually adapted to the local conditions. Italy experiences a variety of climates and, especially in winter, temperatures are very different between the North and the South of the country. The local legislation reflects these differences and splits the country into six heating climate zones (from A to F) depending on heating degree days (HDD) and provides different requirements for each zone. We choose the biggest cities belonging to climate zones B and E, respectively Palermo (751 HDD) and Milan (2404 HDD), in order to test different climates representative of the building stock. We do not consider climate zones A and F since less than 3 % of the population lives in these areas.

MEASURES

We identify seven measures among energy efficiency measures and measures based on renewable energy (Table 1). For each measure we consider up to five variants which may be different according to building typology and location. These variants are identified by the value of a parameter. The different values of each parameters correspond to different levels (intensity) of the measure.

The first package of measures refers to opaque envelope thermal insulation Table 2. To have a manageable calculation we combine wall, roof and floor insulation in a unique package: it means that the three measures vary together.

The second measure concerns the transparent envelope. In Palermo, we consider a simple double glazing, a double glaz-

Table 1. List of measures.

Measures or group of measures
Opaque envelope thermal insulation
Glazing systems
Shading devices
Mechanical ventilation with heat recovery
Heating and cooling systems
Solar thermal collector
Solar photovoltaic collector

1. The compactness ratio of a building is the ratio between the external surface area and the internal volume of a building.

2. These figures only include windows installed in heated areas.

Table 2. Opaque envelope thermal insulation.

	Parameter	Milan			Palermo		
		Level 1	Level 2	Level 3	Level 1	Level 2	Level 3
Wall, roof and floor thermal insulation	U-value [W/m^{2}K]	0.35	0.25	0.15	0.45	0.35	0.25

Table 3. Glazing systems characteristics.

Glazing system	Glazing U-value [W/m^{2}K]	Window U-value [W/m^{2}K]	g_n-value [-]
Double glazing	2.7	2.9	0.75
Double glazing with low-emissivity coating	1.8	2.3	0.63
Argon filled double glazing with low-emissivity coating	1.3	1.9	0.63
Argon filled triple glazing with low-emissivity coating	0.9	1.5	0.54

Table 4. Heating and cooling systems.

#	Systems	Services	Buildings
1	Condensing boiler coupled with a low-temperature floor heating distribution system	Space heating and domestic hot water production	All building typologies and locations
	Multi split air conditioning system	Space cooling	
2	Reversible air source heat pump coupled with fan coil units	Space heating and cooling and domestic hot water production	All building typologies and locations
3	Reversible ground source heat pump, exploiting a vertical geothermal borefield, coupled with fan coils units	Space heating and cooling and domestic hot water production	All building typologies and locations
4	Gas engine CHP system plus a condensing boiler coupled with a low-temperature floor heating distribution systems	Space heating and domestic hot water production	Multi-family building in Milan
	Multi split air conditioning systems	Space cooling	
5	Reversible multi split air conditioning systems	Space heating and cooling	All building typologies in Palermo
	Standard boiler	Domestic hot water production	

ing with low-emissivity coating and argon filled double glazing with low-emissivity coating. In Milan, we consider a double glazing with low-emissivity coating, argon filled double glazing with low-emissivity coating and argon filled triple glazing with low-emissivity coating. Glazing systems characteristics are described in Table 3[3]. All the glazing systems have a thermal break aluminum frame.

The next measures are the adoption of:

- a movable mid-pane shading device that, when in use, reduces total solar energy transmittance by 70 %;
- a mechanical ventilation with heat recovery compliant with "Passivhaus standard" (McLeod R. et al., 2012), i.e. heat recovery efficiency of 75 % and specific fan power of 0,4 Wh/m^3.

The fifth group of measures refers to heating and cooling systems. We consider five solutions adapted to building typology and location as described in Table 4.

Measure 6 consists in the adoption of glazed flat-plate collectors with selective absorber surfaces. We consider three levels, identified by a different collector area as illustrated in Table 5. Heat produced by thermal solar collectors is used for domestic hot water production in case of level 2, and both for domestic hot water production and for space heating in case of level 3.

The last measure concerns solar photovoltaic collectors (mono-crystalline silicon cells with an efficiency of 15 %). As shown in Table 5, three levels are taken into account.

ENERGY PERFORMANCE CALCULATION

The calculation of the buildings net thermal energy needs is performed with the hourly dynamic calculation method described in ISO standard 13790[4]. We assume a single thermal zone per building and a set point temperature of 20 °C in winter and 26 °C in summer (operative temperature). The Italian legislation regulates space heating periods, so, accordingly, the

3. Window U-value: for a window of 1.5 m × 1.2 m.

4. The model is based on an equivalent resistance-capacitance model 5R1C. An analysis of this method is proposed in (Millet J.-R., 2007) and a comparison with monthly methods is presented in (Van Dijk H.A.L. et al., 2004).

Table 5. Thermal and PV solar systems.

	Parameter	Single-family buildings			Multi-family buildings		
		Level 1	Level 2	Level 3	Level 1	Level 2	Level 3
Thermal solar systems	Collectors area [m²]	0	2	4	0	8	16
PV systems	Power output [kWp]	0	1.5	3	0	3	6

heating season starts the 1st of December and ends the 31st of March in Palermo and it lasts from the 15th of October till the 15th of April in Milan. For space cooling there are no prescriptions, so we decide to use cooling devices when weekly heat gains (internal and solar gains) exceed weekly thermal losses (transmission and ventilation). Using an hourly model requires weather data in the form of a typical year: for this purpose we use the IWEC files (International Weather for Energy Calculation) (ASHRAE, 2011).

Heating and cooling systems efficiencies are estimated on a seasonal basis, mainly using the UNI standard UNI/TS 11300 (Italian standard). Instead, thermal solar systems are simulated with a time-step of 1 hour.

Delivered energy per energy carrier is converted in primary energy using the following primary energy factor:

- 1 for natural gas (i.e. the current value used for energy performance certificate);
- 1.3 for electric energy (see section "Scenarios").

In compliance with (European Union, 2012b), the non-renewable part of primary energy is considered. Concerning exported energy, i.e. the energy produced by technical building systems through the system boundary and used outside the system boundary (e.g. the electricity produced by PV system and exported to the network), we use the same primary energy factor used for energy delivered to the building[5].

GLOBAL COST CALCULATION

The calculation of the global cost in term of net present value is done according to standard EN 15459. This calculation takes into account the initial investment, annual costs for maintenance and energy consumptions, disposal costs, replacements costs and residual values of equipment with longer lifetimes.

When valuating investment costs we consider installation costs too, and, particularly, for heating and cooling systems not only the costs of generators but also of storage tanks, distribution system and emitters. Cost data concerning energy efficiency measures and measures based on renewable energy sources have been derived by existing cost databases (DEI 2011); other sources are (Benini et al., 2011), (Grattieri et al., 2012) and (Madonna et al., 2013). We only omit costs that are the same for all the variants of a measure and costs related to building elements which have no influence on the energy performance of a building. For residual values we assume a straight line depreciation.

We use a calculation period of 30 years for all buildings and two perspectives: financial and macroeconomic. The financial perspective simulates the point of view of an investor: it takes into account prices as paid by consumer including taxes. However we do not consider any subsidies, because having 2020 as starting year prevents us from making any reliable prediction. In the macroeconomic perspective we adopt a societal point of view, so we exclude all taxes and we consider greenhouse gas emission costs. We use a discount rate, in real terms, of 5 % and 3 %, respectively for financial and macroeconomic perspectives.

SCENARIOS

Scenario 1

Although Member States are now urged to give their definition of NZEB, these buildings will become the minimum requirement only in 2020. Therefore it is important to estimate cost-optimal level in 2020, in order to compare this level with NZEB performance, and verify that the latter is better than the former. So, with the aim of simulating the application of "cost-optimal methodology" in 2020, we define a scenario to take into account how some parameters will change. Concerning the reduction of primary energy and CO_2 factors per electricity, we refer to a study (Gelmini et al., 2012) carried out to analyse the development of the Italian power system up to 2050. The main hypotheses of this study are the achievement of NREAP (National Renewable Energy Action Plan) targets in 2020 for electricity from RES production except for photovoltaic plants (because they have already exceeded the target set for 2020) and the abandonment of the Italian plan for nuclear power. Some results are shown in Figure 1, Figure 2 and Figure 3.

Particularly, we calculate the non-renewable primary energy factor per electricity f_E with the following equations (see the scheme in Figure 4):

$$f_E = \frac{\sum_i P_i}{E_F \cdot \alpha} \tag{1}$$

$$\alpha = \frac{E_{domestic}}{E_{domestic} + E_{imported}} \tag{2}$$

Where:

- P_i primary energy consumption for (non-renewable) source i in power generation (Table 6);
- E_F final electricity consumption;
- α correction factor for imported electricity;
- $E_{imported}$ imported electricity;
- $E_{domestic}$ electricity produced in Italy.

5. Currently in Italy there is a discussion concerning exported energy and, perhaps, in the future, Italian legislation will consider exported energy in energy performance calculation only if exported energy does not exceed delivered energy on a month by month and carrier by carrier basis.

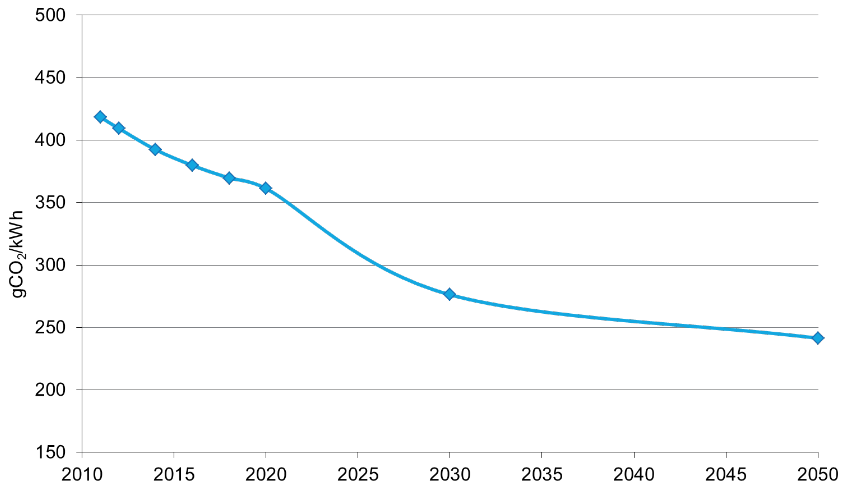

Figure 1. CO_2 emissions per kWh generated electricity.

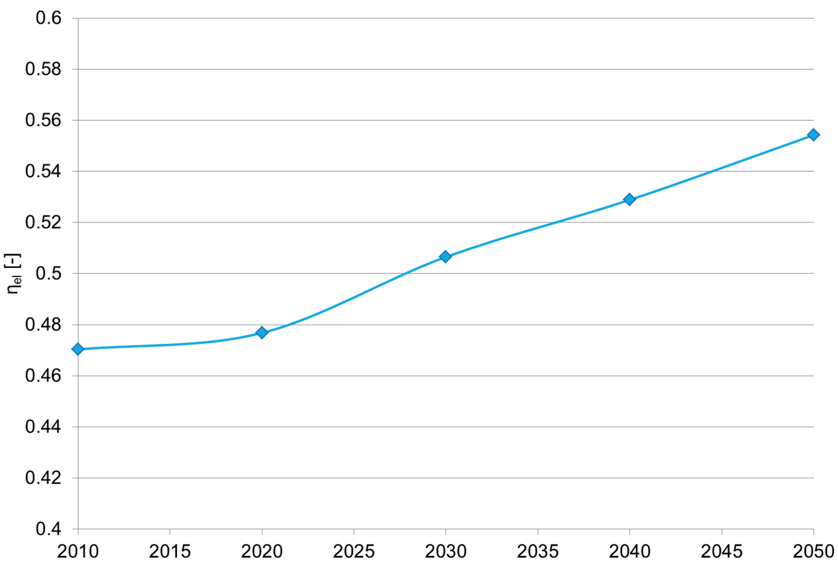

Figure 2. Thermoelectric power generation efficiency in Italy (excluding energy from waste).

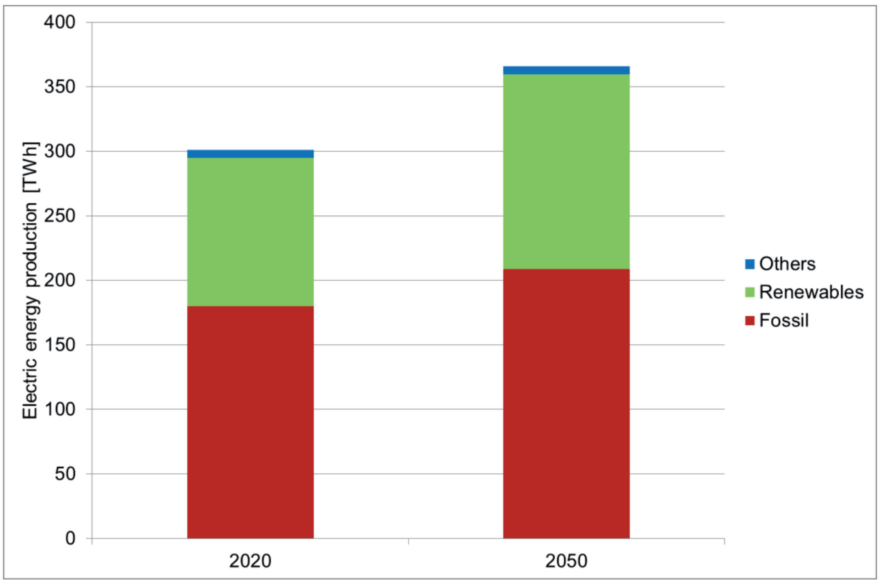

Figure 3. Sources of electricity in Italy in 2020 and 2050.

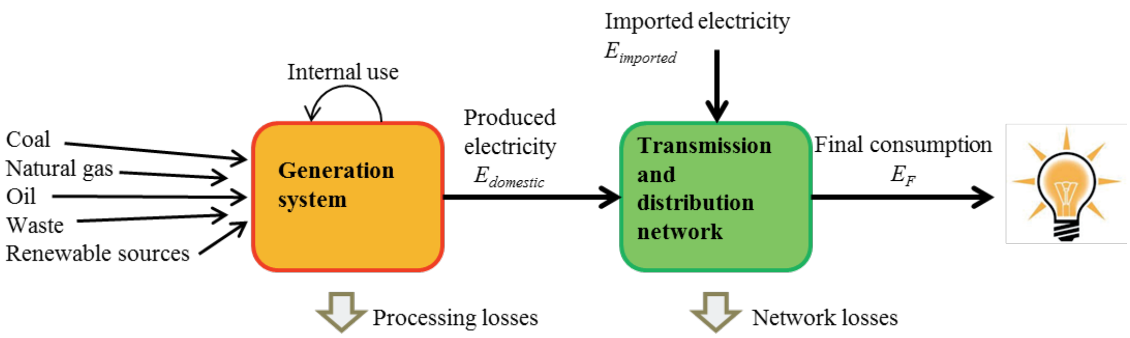

Figure 4. Simplified scheme of electrical system.

Table 6. Primary energy consumption in power generation in Italy (non-renewable sources) [TWh].

	2020	2030	2050
Coal	153	143	127
Natural gas	180	183	235
Oil	38	8	1
Waste	38	48	40

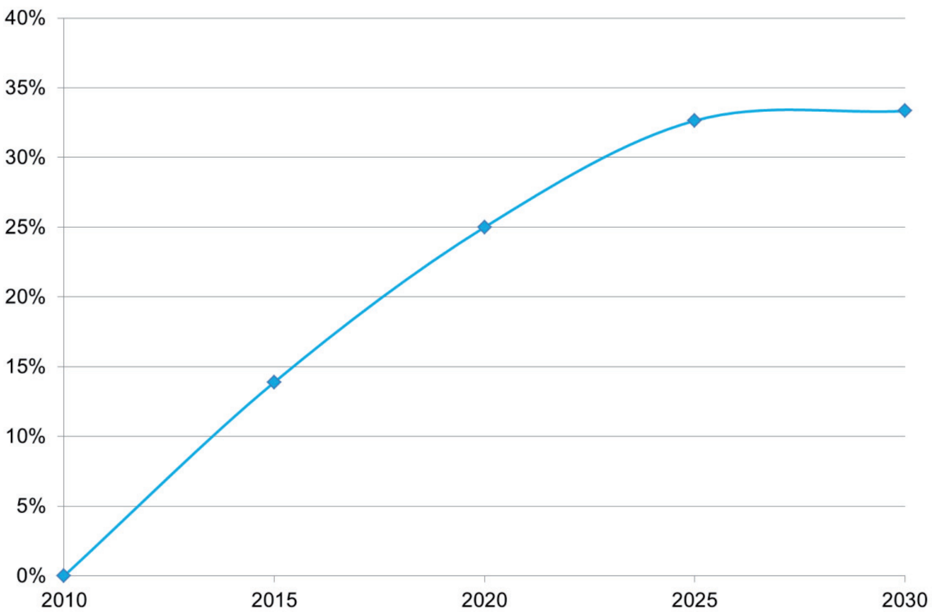

Figure 5. Increase in electricity price for households (real terms).

As a consequence of the rise of thermoelectric power generation efficiency and the increase of the share of electricity from RES, in the period 2020–2050 we expect an average non-renewable primary energy factor per electricity equal to 1.3.

We refer to the energy trend scenario developed with the PRIMES model (European Union, 2009) to quantify long term energy price developments. It implies, for gas prices, an annual increase of 2.8 % and, for electricity price, the variation shown in Figure 5. The price of European Union Emissions Trading Scheme carbon credits is taken from the values indicates by the Commission for this purpose (European Union, 2011).

Scenario 2

In scenario 2, we make the same assumption of scenario 1 and, furthermore, we consider a reduction of 10 % of the current costs of all the selected measures. In such a way we make a sort of sensitivity analysis on the cost of measures. However, it is likely a cost reduction of RES technology and of new generation systems due to technological progress.

Results

Testing all the combinations of measures for each building results in simulating each building thousands of times: the result is shown in Figure 6, where each point represents a combination of measures. To derive the cost-optimal level it is useful to define a specific cost curve (global cost vs energy performance) defined as the lower border of the area marked by the points.

Considering that we have two scenarios and two perspectives, for each building we have four curves. These curves are shown in Figure 7, Figure 8, Figure 9 and Figure 10.

It can be observed that, for each building, all the four cases analysed are very similar. We see that the curves are slightly shifted, particularly scenario 2 has lower global costs than scenario 1 and the macroeconomic perspective has lower global costs than the financial perspective. Considering that in scenario 2 we assume lower investment costs than in scenario 1, the trend is obvious. Instead, the fact that macroeconomic perspective curves are, in most of the cases, below the financial perspective curves means that taxes, VAT and charges have a larger weight than greenhouse gas emission cost.

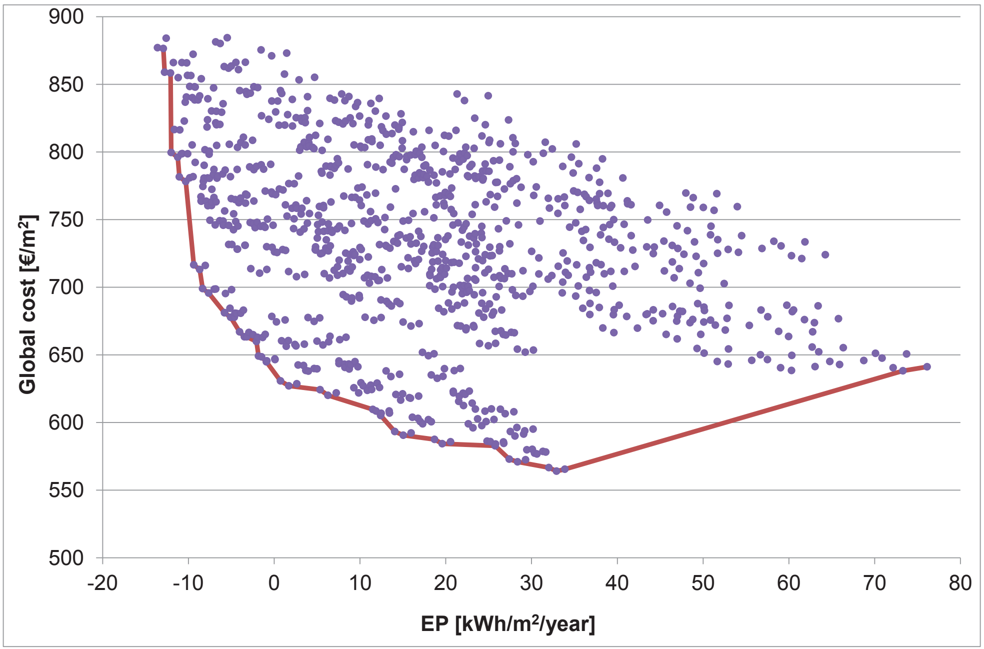

Figure 6. Global cost vs. energy performance. Each point represents a combination of measures, the curve is the lower border. Single-family building in Milan, scenario 1, financial perspective.

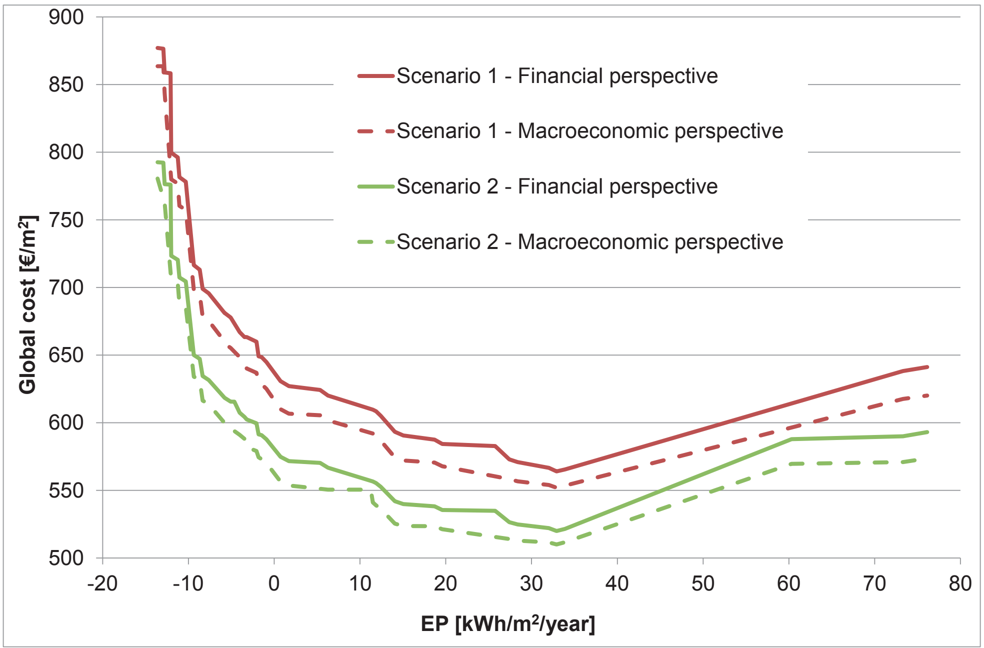

Figure 7. Global cost vs. energy performance curve for a single-family building in Milan.

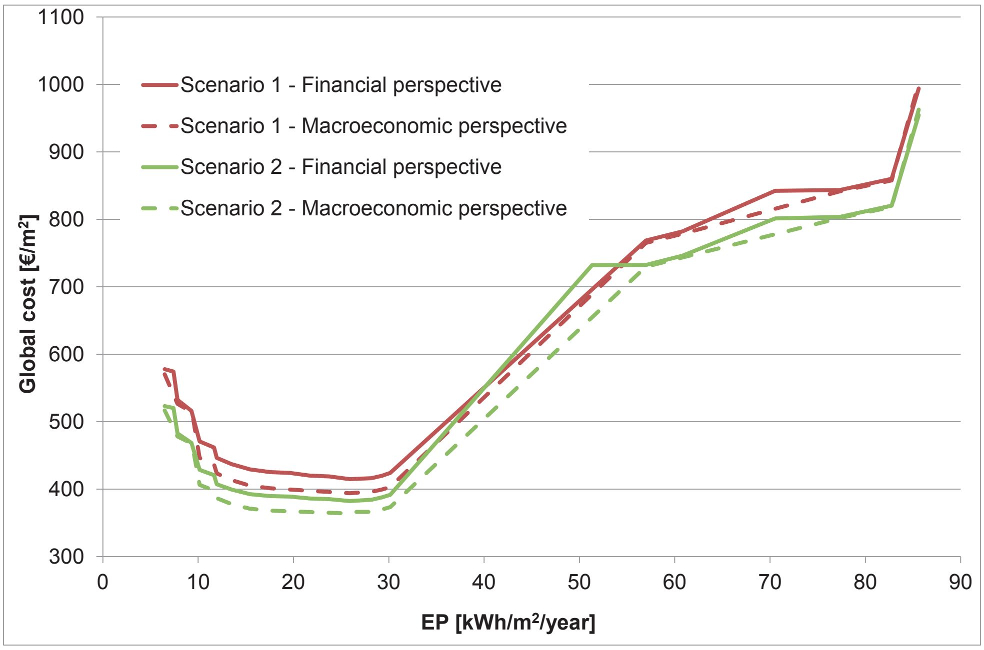

Figure 8. Global cost vs. energy performance curve for a multi-family building in Milan.

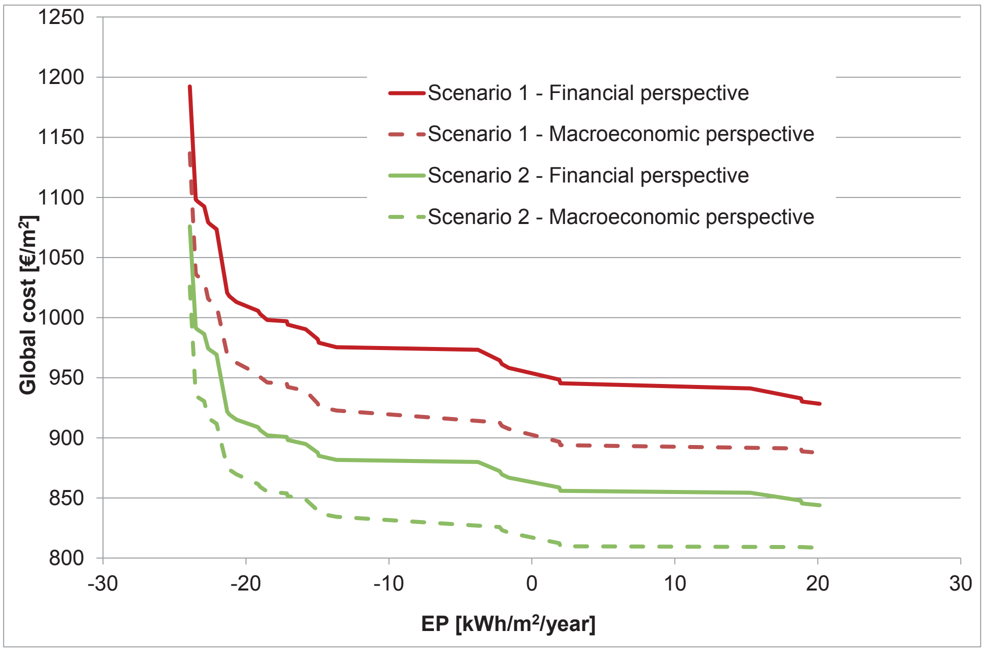

Figure 9. Global cost vs. energy performance curve for a single-family building in Palermo.

In spite of these little differences, the cost-optimal level, i.e. the energy performance corresponding to the minimum cost, is the same for all the curves belonging to same building (Table 7), except scenario 2 macroeconomic perspective in multi-family building in Palermo. In Table 8 we describe the measures corresponding to cost-optimal levels for scenario 1 macroeconomic calculation.

We can identify three zones in the previous graphs, even if not all of them are evident in each building:

1. The left-hand zone where curves have a negative slope. A negative slope means that the economic impact reduces with increasing EP. It implies that improving the energy performance – by adopting the most efficient measures – causes an increase in global costs.
2. The central zone is characterised by a sort of plateau with a little negative slope. The cost-optimal levels lie in this zone where the global cost varies very little. In such a case it is advisable to have an energy performance requirement in the left side of the plateau because with a little effort (cost) it is possible to have a great benefit in energy performance. In Table 9 we point out these points for all curves calling them "impact-optimal levels". Numerically, we found these

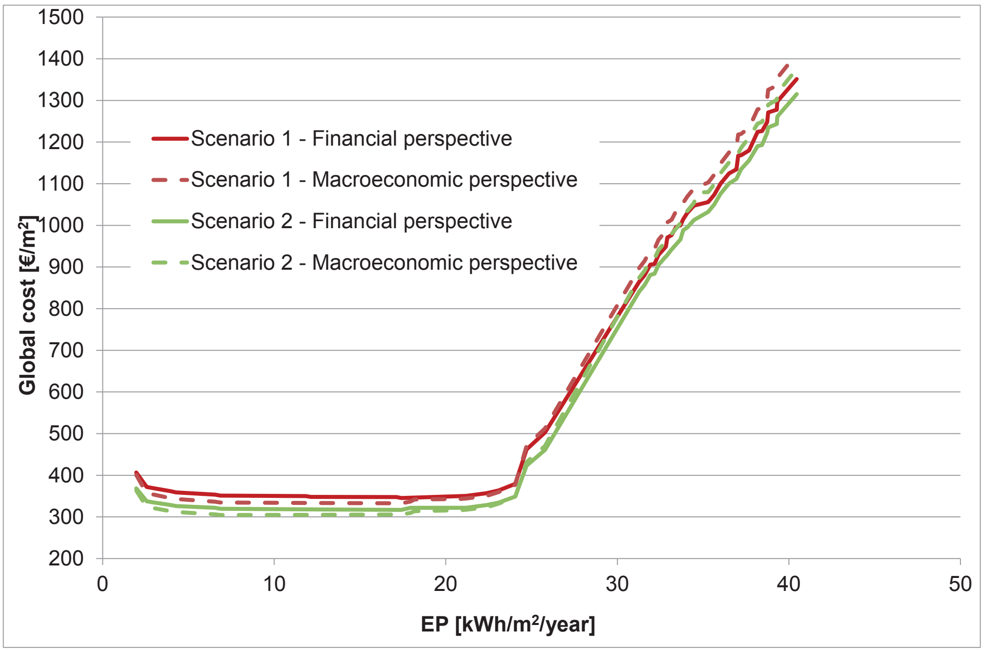

Figure 10. Global cost vs. energy performance curve for a multi-family building in Palermo.

Table 7. Cost-optimal levels [kWh/m²/year].

	Scenario 1 Financial	Scenario 1 Macroeconomic	Scenario 2 Financial	Scenario 2 Macroeconomic
Single-family Milan	33	33	33	33
Multi-family Milan	26	26	26	26
Single-family Palermo	20	20	20	20
Multi-family Palermo	17	17	17	7

Table 8. Description of the measures corresponding to cost-optimal levels (scenario 1 financial perspective).

	Single-family Milan	Multi-family Milan	Single-family Palermo	Multi-family Palermo
Opaque envelope thermal insulation	0,35 W/m^2K	0,35 W/m^2K	0,45 W/m^2K	0,45 W/m^2K
Glazing systems	Argon-filled double glazing with low-emissivity coating	Argon-filled triple glazing with low-emissivity coating	Double glazing	Argon-filled double glazing with low-emissivity coating
Shading devices	No	Yes	No	Yes
Mechanical ventilation with heat recovery	No	No	No	No
Heating and cooling systems	Reversible air source heat pump	Reversible air source heat pump	Reversible multi split air conditioning system & boiler (for domestic hot water)	Reversible air source heat pump
Solar thermal collector	0 m^2	0 m^2	2 m^2	0 m^2
Solar photovoltaic collector	0 kWp	0 kWp	0 kWp	0 kWp

Table 9. Impact-optimal levels [kWh/m2/year].

	Scenario 1 Financial	Scenario 1 Macroeconomic	Scenario 2 Financial	Scenario 2 Macroeconomic
Single-family Milan	15	14	14	14
Multi-family Milan	15	14	14	14
Single-family Palermo	-4	-15	-15	-16
Multi-family Palermo	4	4	4	4

Table 10. Description of the measures corresponding to impact-optimal levels (scenario 1 financial perspective).

	Single-family Milan	Multi-family Milan	Single-family Palermo	Multi-family Palermo
Opaque envelope thermal insulation	0,25 W/m^2K	0,25 W/m^2K	0,45 W/m^2K	0,45 W/m^2K
Glazing systems	Argon-filled double glazing with low-emissivity coating	Argon-filled triple glazing with low-emissivity coating	Double glazing	Double glazing with low-emissivity coating
Shading devices	No	Yes	Yes	Yes
Mechanical ventilation with heat recovery	No	No	No	No
Heating and cooling systems	Reversible air source heat pump	Reversible air source heat pump	Reversible multi split air conditioning system & boiler (for domestic hot water)	Reversible air source heat pump
Solar thermal collector	0 m^2	0 m^2	4 m^2	8 m^2
Solar photovoltaic collector	1,5 kWp	6 kWp	1,5 kWp	3 kWp

levels as the minimum energy performance with a global cost lower than the minimum global cost multiplied by 1.05. Viewing the NZEB as the most efficient building economically justifiable, it would be desirable for its energy performance to correspond to the impact-optimal level.

3. The right-hand zone where curves have a positive slope. This zone is to be avoided for minimum requirement, because increasing the economic impact results in a poorer energy performance.

In single-family building in Palermo we note that the presence a photovoltaic solar system combined with some measures allows to have a building with an energy performance lower than zero. It means that such a building is a positive one, i.e. it generates more energy than it consumes. Impact-optimal level refers to a positive energy building while the cost-optimal level does not. The description of measures corresponding to impact-optimal building is illustrated in Table 10.

COMPARISON WITH CURRENT MINIMUM REQUIREMENTS

A comparison with current requirements is unfair because we use a different primary energy factor per electricity. Therefore, with the sole purpose of a correct comparison with current minimum requirements we repeat simulations using the primary energy factor per electricity currently in use in Italy, i.e. 2.17.

To limit the number of cases we select only scenario 1 financial perspective and scenario 2 macroeconomic perspective. The comparison is shown in Figure 11: current minimum requirements have a primary energy consumption about double than the cost-optimal.

With the aim of comparing cost-optimal levels with current best practices, we point out the energy performance corresponding to the best class of energy performance certificate Italian scheme, namely "Classe A+". This scheme only includes space heating and domestic hot water production whereas cooling performance is evaluated only in term of thermal energy need. Therefore we add to the "Classe A+" energy performance a cooling primary energy consumption evaluated considering a reference cooling system efficiency. The result of this comparison is that "Classe A+" performance is between cost-optimal and impact-optimal levels.

Conclusion

In this paper we applied the cost-optimal methodology proposed by the European Commission in order to derive the energy performance leading to minimum life cycle cost. Considering that a NZEB has to have a performance equal or better than the cost-optimal level in 2020, in our study we use 2020 as starting year assuming two different scenario that account for the evolution of some input values. The main result consists in drawing the "global cost vs. energy performance" curves and then finding the cost-optimal levels. These levels lie in a plateau with a little negative slope, it means that, with a slightly higher cost (5 %), it is possible to improve the performance by at least

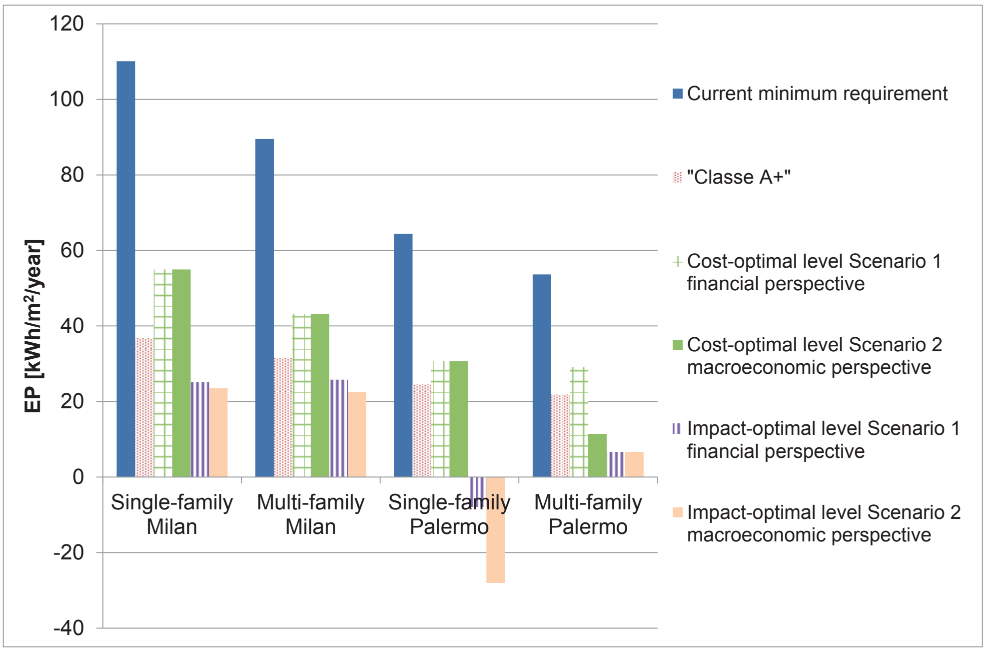

Figure 11. Comparison between current minimum requirements, "Classe A+" energy performance, cost-optimal levels and cost-effort levels.

40 %, and, particularly, single-family building in Palermo can become a positive energy building. We called impact-optimal level the left-side of the plateau and, according to our opinion, NZEB energy performance should be close to this level. However, an energy performance between impact-optimal and cost-optimal levels could be considered as adequate, even if less ambitious.

Concerning current minimum requirements, they would be not adequate in 2020 because with a lower global cost is possible to have an improved energy performance. Instead "Classe A+" performance could be a fairly good reference for NZEB.

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