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On the cost-optimal levels of energy-performance requirements for buildings: A case study with economic evaluation in Italy

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ABSTRACT

The European energy policies about climate and energy package, known as the "20-20-20" targets define ambitious, but achievable, national energy objectives. As regards the Directives closely related to the 2020 targets, the EU Energy Performance of Buildings Directive (EPBD Recast- DIR 2010/31/EU) is the main European legislative instrument for improving the energy performance of buildings, taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness.

The EPBD recast now requests that Member States shall ensure that minimum energy performance requirements for buildings are set "with a view to achieving cost-optimal levels". The cost optimum level shall be calculated in accordance with a comparative methodology framework, leaving the Member States to determine which of these calculations is to become the national benchmark against which national minimum energy performance requirements will be assessed.

The European standards (ENs- Umbrella Document V7 (prCEN/TR 15615) are intended to support the EPBD by providing the calculation methods and associated material to obtain the overall energy performance of a building. For Italy the Energy Performance of Building Simulations EPBS must be calculated with standard UNITS 11300. The energy building behaviour is referred to standard and not to real use, nor climate or dynamic energy evaluation.

Since retrofitting of existing buildings offers significant opportunities for reducing energy consumption and greenhouse gas emissions, a case study of retrofitting is described and the Cost-Optimal Level EU procedure in an Italian context is analysed.

Following this procedure, it is shown not only that the energy cost depends on several conditions and most of them are not indexed at national level but also that the cost of improvement depends on local variables and contract tender.

The case study highlights the difficulties to apply EU rules, and allows verifying whether this methodology could be used as thermo-economic analysis for investment decisions in energy efficiency improvements and refurbishment in Italy or similar regions.

In the case study here analysed, the choice of the best energy efficiency measures derived from the Cost Optimal level methodology underlined the importance of the building typology, the reference market and also the building location in applying this methodology.

Keywords:

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economic evaluation
cost-optimal level
Energy-building-performance evaluation

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1. Introduction

The buildings are responsible for approximately 40% of global energy consumption of European Union and about 36% of the European Union's carbon dioxide (CO_2) emissions, as highlighted in Directive 2001/91/EC [1] and Directive 2010/31/EU (recast) [2], followed by transport (32%), and industry (25%).

This means that the residential sector has a great energy saving potential with respect to the others and that all the subjects involved in the sector (owner, lessor, builder, designer, architect, engineer, thermo-technical engineer, real estate agency, energy trader, etc.) should be formed and coordinated in order to promote energy saving.

The Directive 2010/31/EU requires Member States to establish and apply minimum energy performance requirements for new and existing buildings, ensure the certification of building energy performance and require the regular inspection of boilers and air conditioning systems in buildings. About energy minimum requirements, the Directive introduces a further requirement: from 2020 all new buildings must be a nearly Zero Energy Building (nZEB).

The recast of the EPBD includes a provision that national energy performance requirements should be set with the view to achieving cost optimum levels by applying a harmonised calculation methodology defined in Annex III of the directive and also detailed in Delegate Regulation (EU) n. 244/2012 of 16 January 2012 [3] It prescribes the calculation of cost-optimal levels from both macroeconomic and financial viewpoints (ANNEX I of the present paper).

The aim of Cost-optimal-level is to set up a comparative methodology to compare minimum energy performance requirements between EU Member States. The new requirement must be ambitious and economical achievable.

In order to compare energy requirements all EU Member States are requested to define a "Reference Buildings" (RB), which could be individuated accordingly to European Intelligent Energy Efficiency (IEE) programs TABULA [4] and ASIEPI [5], whereas the international RB database and benchmarking is the Department of Energy (DOE) of United States.

The balance between cost and benefit is a key-factor of Cost Optimal Level, which could be evaluated by several methodologies, in order to conform each Member State legislation and real estate industry. The Cost-Optimal-Level approach should be therefore used throughout the design of new buildings or energy retrofits, in order to compare several options and solutions. In that case, all costs are included: building, energy and maintenance costs. The comparative methodology framework described in Delegate Regulation 244/2012 could be used by Member State not only to report to the European Commission but also by designers and builders to evaluate energy efficiency scenarios and increase real estate values. Several studies from Building Performance Institute of Europe report examples of adoption of the cost optimal level procedure [6, 7] for Italy and Estonia. Moreover, the energy efficiency measures for building may be considered as an increase of real estate value in relation to the Energy Classification improvement, for example from energy Class D to energy Class A, as described in [9, 10], or also in building and energy efficiency measure in national policies [11]. In this paper, we adopt the Delegate Regulation (EU) n.244/2012 procedure and do not consider real estate value.

The aim of this paper is presenting a case study for the energy retrofit of a residential building applying the Cost Optimal Level methodology and verifying if this methodology could be applied as thermo-economic analysis in order to decide whether or not to invest in energy efficiency improvements and refurbishment.

In particular, the following section 2 describes the framework methodology to identify Cost Optimal Level of energy performance summarizing the provisions or the EPBD recast DIR regarding calculating and achieving cost-optimal requirements.

In the section 3 a reference case study of energy retrofit for a bi-familiar villa is presented evaluating the Energy Performance Index (EPi) for each intervention following the Italian Standard UNITS 11300. Therefore the Cost Optimal level procedure has been applied. The section 4 presents the results of the cost optimal level methodology considering both the macroeconomic/financial viewpoint and the global EP. The final section 5 highlights the main recommendations and further research directions.

2. Comparative metodology framework for calculating cost optimal levels

The aim of Directive 2010/31/EU is to improve the energy performance of building in the EU, with new requirements for 'building elements', 'technical building system' and nearly zero energy building (only for new buildings). All these requirements must consider the related cost-effectiveness.

In Annex III a general methodological framework to evaluate cost and benefit is defined, and requires Member State to provide:

(1) definition of buildings reference for existing and new buildings, both dwellings and not dwellings, based on geographic and climate zone;
(2) definition of energy efficient improvement scenarios;
(3) evaluation of energy primary of all reference buildings, for all the scenarios;
(4) calculation of cost for each scenario expressed with Net Present value (NPV) during the Life Economic Cycle (or lifespan);
(5) evaluation of effectiveness minimum energy requirements and determination of cost-optimal-level.

The energy minimum requirement, defined by methodology framework of Annex III, is upgraded every 5 year, in order to follow the evolution of building construction.

The “Delegate Regulation (EU) 244/2012” and the “Guideline for calculation cost-optimal levels C 115-2012” [12] represent two frameworks that define cost-optimal levels for each EU Member State. The Delegate Regulation (EU) 244/2012 describes both method and procedure, whereas the “Guideline C 115–2012” reports some Delegate Regulation enlightenment and examples of calculation.

2.1. The reference building and energy efficiency scenarios

In order to report the Energy Efficiency Action Plans at EU Commission, EU Member States are requested to relate the minimum energy performance requirement with “Reference Building”. The “Reference Building” is a tool to compare all the European legislation as requested by EU Commission. They are defined in Annex III as “(…) representative of their functionality and geographic location, including indoor and outdoor climate conditions. The reference building shall cover residential and non-residential buildings, both new and existing ones”.

The reference building shall be defined for the following categories of buildings: (1) single-family buildings, (2) apartment blocks and multifamily buildings, (3) office buildings, and (4) other optional buildings: schools, hotels, restaurants, sport buildings, shopping centers or other buildings with relevant energy consumption.

The definition of Reference Building for Italy has been adopted by Italian Ministry of Economic Development [13] and ENEA (Italian National Agency for New Technologies Energy and Sustainable Economic Expansion) in order to define an Italian Reference Building [14].

The energy efficiency solutions are defined as “all input parameters for the calculation that have a direct or indirect impact on the energy performance of the building, including for alternative high-efficiency systems such as district energy supply systems” (Reg 244/2012, Annex I, point 2).

Each single measure (or scenario) should define the energy efficiency measures. For example, a new window constitutes a new scenario as well as a new package or new refurbishment of wall and roof, or the substitution of boiler.

The “Guideline C 115-2012” at point 4.2 reports: “the number calculated and applied to each reference building should certainly not be lower than 10 packages/variants plus the reference case.” and also: “Various techniques can be used to limit the number of calculations. One is to design the database of energy efficiency measures as a matrix of measures which rules out mutually exclusive technologies so that the number of calculations is minimized”. It is clear that the more are the scenarios, the more cost-optimal levels are feasible.

Moreover, the regulation provides the “*Reporting Template*” that Member States may use for reporting to the Commission data on calculation of cost-optimal levels and new building (Annex III).

The reference tables are:

- Table 1 - “Reference building for existing buildings (major refurbishment)”;
- Table 2 - “Reference building for new buildings”;
- Table 3 - “Example of a basic reporting table for energy performance relevant data”;
- Table 4 - “Illustrative table for listing selected variants/measures”, where are reported all ordinary and innovative energy efficient measure, for the same comfort level;
- Table 5 - “Energy demand calculation output table”, with in attachment a calculation

report and standard references used to evaluate energy performance of buildings;

- Table 6 - "Output data and global cost calculations";
- Table 7 - "Comparison table for both new and existing buildings".

The first table (reference building for existing buildings) is here reported. The case study described in this paper (simulated by means of specific spreadsheets), consists of the refurbishment of an existing building, and all the scenarios have been calculated for it.

2.2. Energy-building-performance evaluation

Once every package/measure for each scenario is defined, the further step consists on the energy-building-performance evaluation, in order to calculate the energy primary index, expressed in kWh/m^{2}year, for each scenario.

The Directive 2010/31/EU includes all energy services of buildings: heating, cooling, domestic hot water, ventilation and lighting.

In Italy the energy-performance methodologies follow ISO 13790 [16] with steady-state balance, based on monthly methodology. Actually the Italian standards UNITS 11300 part 1 [17], part 2 [18] and part 4 [19] consider only heating and domestic hot water evaluation and renewable energy sources. Other energy consumptions for cooling, ventilation and lighting or electricity use, are now being considered.

For these reasons, in Italy, the Energy consumption is related only to the thermal use and not to the electric use. This differs from the procedure (and example) reported in Delegate Regulation (EU) 244/2012, and it is not possible to evaluate the electric consumption and all the photovoltaic or window-shield benefits during cooling consumption.

These limitations influence the energy performance evaluation, the energy class, and nearly zero energy building defined, as described for Italian and English cases in [20, 21].

2.3. The cost-optimal-level

The cost-optimal-level means "the energy performance level which leads to the lowest cost during the estimated economic lifecycle" (DIR 2010/31 art.2). Moreover, "The cost-optimal level shall lie within the range of performance levels where the cost benefit analysis

Table 1: "Reference building for existing buildings (major refurbishment)".

	Building				Heating plant system					
	Roof thermal insulation	Wall insulation	Basement floor insulation	Windows replacement	Radiant heating (panel heating)	Boiler	Condensing boiler	Heat pump (air/water)	Renewable energy sources solar collector and photovoltaic	M = natural gas E = Elecricity
Scenario 0 - law requirements	X				X		X		X	M
Scenario 1	X	X	X		X		X		X	M
Scenario 2	X			X	X		X		X	M
Scenario 1+2	X	X	X	X	X		X		X	M
Scenario 3	X				X			X	X	E
Scenario 1+2+3	X	X	X	X	X			X	X	E

calculated over the estimated economic lifecycle is positive". Therefore, the cost-optimal-level identifies the technological solution, measure, package or scenario with shorter Global cost $C_g(\tau)$ (as reported in Annex 1 of this article).

The Regulation (EU) 244/2012 identifies five steps that are necessary to evaluate the cost-optimal-level:

(1) to define the start year and to evaluate an economic lifespan for buildings or 'building elements' or 'technical building system' following EN 15459 [15] ;
(2) to establish the "discount rate" for comparison the value of money at different times, and for both evaluation methodologies;
(3) to define the "energy carrier" or other energy cost (with and without tax), and other maintenance and operative cost;
(4) to evaluate the "energy-cost trend" for energy carrier (natural gas, electricity, etc.) relate to the national contest;
(5) to define the "primary energy factor".

The cost-optimal-level for the reference building could be evaluated following two economic viewpoints:

1. Financial viewpoint; it consists of evaluating the energy-efficiency-measure-cost, expressed in cost and benefits, at the investment year. In this case, it shall be considered all the real cost at the present, including tax and incentive or other financial support.
2. Macroeconomic viewpoint; it consists of evaluating the investment cost, including all environmental effects of energy efficiency measures. In this case, also the reduction of CO_2 in the atmosphere and the connected economic benefit shall be considered.

The optimum solutions are neither the scenario with the lowest energy-performance-index, EP, because in that case the starting cost has more relevant incidence than those of energy-cost reduction, nor the scenario with lowest starting investment cost, because in that case the energy annual cost are relevant.

The cost-optimal level is a "balance point" (figure 1 and 2) between Starting Investment Cost, SIC, and Annual Energy-Cost, AEC, during all the period of evaluation.

The evaluation of cost-optimal level does not depend on a single parameter, for example wall transmittance or energy-performance index. It is a tool that allows defining a "cost-optimal level zone" (figure 1).

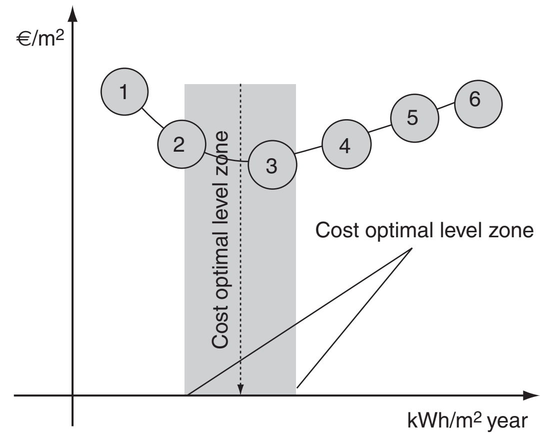

Figure 1: Cost optimal level zone.

3. The case study

The aforementioned method has been applied in a case study related to an energy-retrofit building. For this building and for each scenario measurement, the energy-performance index (EP_i) has been evaluated following Italian standard UNITS 11300. The evaluation period, here considered, is 30 years; the discount rate *r* is 1%, following the Italian ban-value, and the energy cost and tariff for natural gas and electricity, are based on the Italian Regulatory Authority for Electricity and Gas (Autorità per l'Energia Elettrica e per il Gas, AEEG) [23] value for 2012 (second quarter year). The building-material and the technical plant-cost, and also all relative costs about the designer and construction site, have been calculated considering the official price list by CNA of Ravenna, where the building is located [24]. In Italy, the building-material prices are normally evaluated for each province and for each year, because of their variability among the country. In order to define a national methodology, it might be possible to individuate a regional (or also a macro-regional) value. In this case study the national incentives about energy efficiency improvements are not considered.

3.1. The building

The case study is a bi-familiar villa on 3 levels, but the energy retrofit, here considered, is related only to half of the building. The structure is made of reinforced concrete and internal walls are made in bricks without thermal insulation; also the floors are made of reinforced concrete and bricks without any thermal insulation.

The windows frames are made of wood, having single glass layer. The heat generator is a traditional

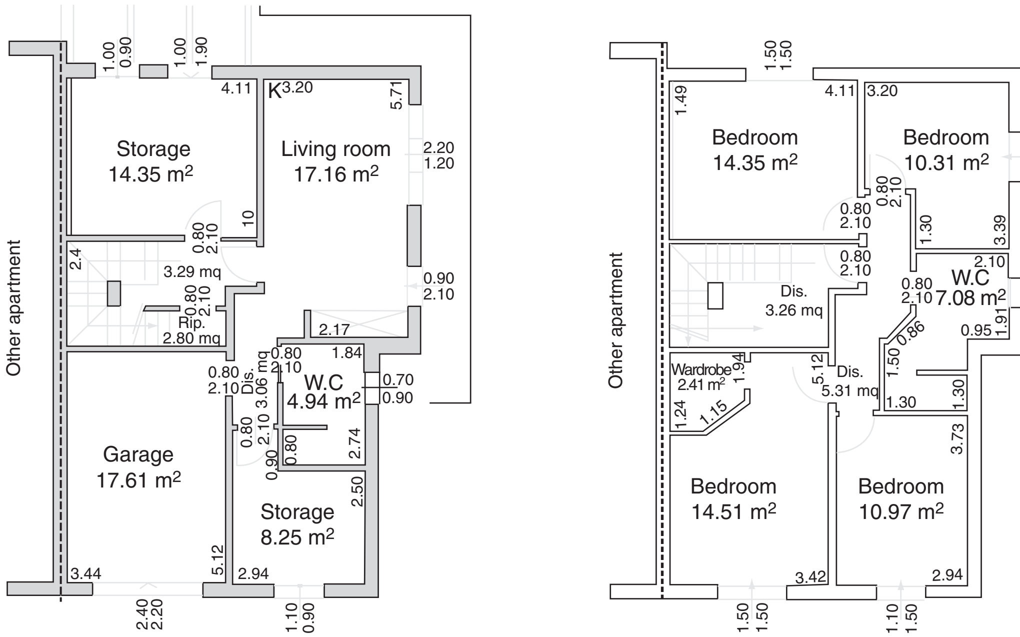

Figure 2: The case study–groundfloor (left) andfirst floor (right).

Table 2: Case study – technologies for each scenario.

Start existing building	Pitched roof (stratigraphy):	roofing tile ǀ 5 cm lightweight concrete ǀ 6 cm hollow gauged brick ǀ 14 cm air cavity ǀ 6 cm hollow gauged brick ǀ U = 1.274 W/m^{2}K
	Plan roof (stratigraphy):	tile ǀ 5 cm concrete ǀ 5 cm structural lightweight concrete (ISOCAL) ǀ 18 floor in concrete and brick ǀ 1.5 cm plaster ǀ U = 1.128 W/m^{2}K
	Wall type 1 (stratigraphy):	1.5 cm plaster ǀ 28 cm common brick ǀ 2 cm plaster ǀ U = 1.412 W/m^{2}K
	Wall type 2 (stratigraphy):	1.5 cm plaster ǀ 12 cm common brick ǀ 1.5 cm plaster ǀ U = 2.483 W/m^{2}K
	Basement floor (stratigraphy):	tile ǀ 5 cm concrete ǀ 12 cm structural lightweight concrete (ISOCAL) ǀ U = 0.643 W/m^{2}K
	Windows	wood frame ǀ single glass 4 mm ǀ U_{glas} 5.685. U_{frame} 2.541. U_{window} 4.434 (W/m^{2}K)
	Heating plant:	Traditional boiler (natural gas) ǀ radiator
	Domestic Hot Water (DHW):	produced by same boiler (natural gas) integrated
	Energy Carrier:	natural gas
Scneario 0 – law requirements	Pitched roof (stratigraphy):	roofing tile ǀ**10 cm polystyrene expanse** ǀ 5 cm lightweight concrete ǀ 6 cm hollow gauged brick ǀ 14 cm air cavity ǀ 6 cm hollow gauged brick ǀ U = 0.296 (minimum requirement 0.30 W/m^{2}K)
	Plan roof (stratigraphy):	tile ǀ 5 cm concrete ǀ 5 cm structural lightweight concrete (ISOCAL) ǀ 18 floor in concrete and brick ǀ 1.5 cm plaster ǀ **10 cm glass wool** ǀ **1.5 gypsum plasterboard** ǀ U = 0.299 W/m^{2}K (minimum requirement 0.30 W/m^{2}K)
	Wall type 1 (stratigraphy):	1.5 cm plaster ǀ 28 cm common brick ǀ **10 cm glass wool** ǀ1 cm plaster ǀ U = 0.303 W/m^{2}K (minimum requirement 0.34 W/m^{2}K)
	Wall type 2 (stratigraphy):	1.5 cm plaster ǀ 12 cm common brick ǀ **8 cm glass wool** ǀ **12 cm alveolater brick** ǀ **1.5 cm plaster** ǀ U = 0.328 W/m^{2}K (minimum requirement 0.34 W/m^{2}K)
	Basement floor (stratigraphy):	tile ǀ 5 cm concrete ǀ 10 cm radiant heating with thermal and acustic insulation ǀ U = 0.318 W/m^{2}K (minimum requirement 0.32 W/m^{2}K)
	Windows	PVC frame ǀ **low emission glass 6-20-4 with argon** ǀ U_{glas} 1.495. U_{frame} 1.800. U_{window} 1.874 (W/m^{2}K)
	Heating plant:	Condensing boiler (natural gas) ǀ radiators

Table 2: Case study – technologies for each scenario (Continued).

	Domestic Hot Water (DHW):	produced by same Condensing boiler (natural gas) integrated with solar collector
	Renewable Energy Sources:	2.50 m^2 solar collector (1727.78 kWh/year)
	Energy Carrier:	natural gas
Scenario 1	Pitched roof (stratigraphy):	roofing tile |**12 cm polystyrene expanse** | 5 cm lightweight concrete | 6 cm hollow gauged brick | 14 cm air cavity | 6 cm hollow gauged brick | U = 0.215 (minimum requirement 0.30 W/m^2K)
	Plan roof (stratigraphy):	tile | 5 cm concrete | 5 cm structural lightweight concrete (ISOCAL) | 18 floor in concrete and brick | 1.5 cm plaster |**12 cm polystyrene expanse** | **1.5 gypsum plasterboard** | U = 0.206 W/m^2K (minimum requirement 0.30 W/m^2K)
	Wall type 1 (stratigraphy):	1.5 cm plaster | 28 cm common brick |**12 cm polystyrene expanse** | 1 cm plaster | U = 0.206 W/m^2K (minimum requirement 0.34 W/m^2K)
	Wall type 2 (stratigraphy):	2.0 cm plaster | 12 cm common brick |**12 cm polystyrene expanse** | **12 cm alveolater brick** | **1.5 cm plaster** | U = 0.208 W/m^2K (minimum requirement 0.34 W/m^2K)
	Basement floor (stratigraphy):	*same scenario 0 – law requirement*
	Windows	*same scenario 0 – law requirement*
	Heating plant:	*same scenario 0 – law requirement*
	Domestic Hot Water (DHW):	*same scenario 0 – law requirement*
	Renewable Energy Sources:	*same scenario 0 – law requirement*
	Energy Carrier:	natural gas
Scenario 2	Pitched roof (stratigraphy):	*same scenario 0 – law requirement*
	Plan roof (stratigraphy):	*same scenario 0 – law requirement*
	Wall type 1 (stratigraphy):	*same scenario 0 – law requirement*
	Wall type 2 (stratigraphy):	*same scenario 0 – law requirement*
	Basement floor (stratigraphy):	*same scenario 0 – law requirement*
	Windows	PVC frame | **low emission triple glass 4-12-4-12-4** | U_{glas} 0.60 U_{frame} 1.00. U_{window} 1.10 (W/m^2K)
	Heating plant:	*same scenario 0 – law requirement*
	Domestic Hot Water (DHW):	*same scenario 0 – law requirement*
	Renewable Energy Sources:	*same scenario 0 – law requirement*
	Energy Carrier:	natural gas
Scenario 1+2	Pitched roof (stratigraphy):	*same scenario 1*
	Plan roof (stratigraphy):	*same scenario 1*
	Wall type 1 (stratigraphy):	*same scenario 1*
	Wall type 2 (stratigraphy):	*same scenario 1*
	Basement floor (stratigraphy):	*same scenario 0 – law requirement*
	Windows	*same scenario 2*
	Heating plant:	*same scenario 0 – law requirement*
	Domestic Hot Water (DHW):	*same scenario 0 – law requirement*
	Renewable Energy Sources:	*same scenario 0 – law requirement*
	Energy Carrier:	natural gas
Scenario .3	Pitched roof (stratigraphy):	*same scenario 0 – law requirement*
	Plan roof (stratigraphy):	*same scenario 0 – law requirement*
	Wall type 1 (stratigraphy):	*same scenario 0 – law requirement*
	Wall type 2 (stratigraphy):	*same scenario 0 – law requirement*
	Basement floor (stratigraphy):	*same scenario 0 – law requirement*
	Windows	*same scenario 0 – law requirement*
	Heating plant:	*same scenario 0 – law requirement*
	Domestic Hot Water (DHW):	*same scenario 0 – law requirement*
	Renewable Energy Sources:	2.50 m^2 solar collector (1727.78 kWh/year) | 3 kW_p Photovoltaic (1300.20 kWh/year)
	Energy Carrier:	natural gas
	Renewable Energy Sources:	2.50 m^2 solar collector (1727.78 kWh/year) | 3 kW_p Photovoltaic (1300.20 kWh/year)

Table 3: Case study – energy performance evaluation: results.

Variable		Start point existing building	Scenario 0 law requirements	Scenario 1	Scenario 2	Scenario 1+2	Scenario 3	Scenario 1+2+3
Building energy need (kWh/year)	Heating	22335	8768	7751	8088	7499	8679	7499
	Cooling	1380	1513	1596	1669	1331	1533	1331
	Domestic Hot Water	1272	1272	1272	1272	1272	1272	1272
Energy primary (kWh/m^{2}year)	Heating	139	55	48	50	47	54	47
	Cooling	9	9	10	10	8	10	8
	Domestic Hot Water	8	8	8	8	8	8	8
Energy carrier (kWh/year)	Electricity	985	1007	1007	1007	1007	1007	1007
	Natural gas	32813	8792	7767	8098	7519	8792	7519
Energy performance index EP (kWh/m^{2}year)			68	61	63	59	64	57
Percentage of EP reduction (kWh/m^{2}year)			148	156	154	158	153	160
		/	68.46%	72.02%	71.05%	72.75%	70.47%	73.79%

Table 4: Case study – cost evaluation (value in euro €).

Period of evaluation 30 year		Scenario 0	Scenario 1	Scenario 2	Scenario 1+2	Scenario 3	Scenario 1+2+3
INVESTMENT COST	Roof insulation	6775	/	6775	/	6775	/
	Roof insulation replacement (high performance)	/	7661	/	7661	/	7661
	Wall insulation	14866	/	14866	/	14866	/
	Wall insulation replacement (high performance)	/	16615	/	16615	/	16615
	Condensing boiler	3438	3438	3438	3438	3438	3438
	Radiant heating (panel heating)	6782	6782	6782	6782	6782	6782
	Solar collector	4800	4800	4800	4800	4800	4800
	Windows	7577	7577	/	/	7577	/
	Windows replacement (high performance)	/	/	9139	9139	/	9139
	Photovoltaic	/	/	/	/	1342	1342
	Total starting cost. €	***44238***	***46872***	***45800***	***48434***	***45580***	***50447***
	Total starting cost + VAT. €	***53527***	***56715***	***55418***	***58605***	***55152***	***61041***
ENERGY COST	Energy performance index EP (kWh/m^{2}year)	68	61	63	59	64	57
	Floor surface (m^2)	160	160	160	160	160	160
	Energy consumption (kWh/year)	10956	9719	10057	9466	10258	9104
	Energy carrier rate (€/kWh)	0	0	0	0	0	0
	Energy cost (€/year)	1004	891	922	868	940	834
	Energy cost + VAT (€/year)	1215	1078	1115	1050	1138	9104
	Energy cost (€/year)						
	Macroeconomic viewpoint	***25917***	***22991***	***23790***	***22392***	***24264***	***21535***
	Financial viewpoint	***31359***	***27819***	***28786***	***27094***	***29360***	***26057***
extra-ordinary maintenance (15th year)	Roof insulation	169	192	169	192	169	192
	Wall insulation	372	415	372	415	372	415
	Windows	189	189	228	228	189	228
	Photovoltaic inverter	/	/	/	/	38	38
	Periodic maintenance cost (€)	730	796	769	835	768	835
	Periodic maintenance cost + VAT (€)	884	964	931	1011	929	1056

Table 4: Case study – cost evaluation (value in euro €) (Continued).

Period of evaluation 30 year		Scenario 0	Scenario 1	Scenario 2	Scenario 1+2	Scenario 3	Scenario 1+2+3
	Extra ordinary cost (€/year)						
	Macroeconomic viewpoint	***629***	***686***	***663***	***720***	***661***	***752***
	Financial viewpoint	***921***	***1004***	***970***	***1053***	***968***	***1101***
Annual Maintenance	Boiler (€/year)	80	80	80	80	80	80
	Solar collector (€/year)	50	50	50	50	50	50
	Annual Maintenance cost (€/year)	130	130	130	130	130	130
	Annual Maintenance cost +VAT (€/year)	157	157	157	157	157	157
	Annual Cost (€/year)						
	Macroeconomic viewpoint	***3355***	***3355***	***3355***	***3355***	***3355***	***3355***
	Financial viewpoint	***4060***	***4060***	***4060***	***4060***	***4060***	***4060***
Emission CO_2 cost	Energy consumption (kWh/year)	10956	9719	10057	9466	10258	9104
	factor CO_2 conversion (Natural gas or Electricity)	0.277	0.277	0.277	0.277	0.277	0.277
	CO_2 Emssione (t_{CO2eq}/year)	3.03	2.69	2.79	2.62	2.84	2.52
	CO_2 emission cost (€)	3141	2786	2883	2714	2941	2610
MACROECONOMIC VIEWPOINT							
LIFE ECONOMIC COST (estimed)		77280	77280	76690	76491	77614	76801
GLOBAL MACROCONOMIC COST (€/m²)		***482***	***482***	***479***	***477***	***484***	***479***
FINANTIAL VIEWPOINT							
LIFE ECONOMIC COST (estimed)		89868	89868	89598	89234	90812	89539
GLOBAL FINANTIAL COST (€/m²)		***561***	***561***	***559***	***557***	***567***	***559***

Table 5: Case study – Graphics label: Energy index and global cost – Macroeconomic Viewpoint.

	Scenario	EP_i kWh/m²year	Global Cost €/m²
◆	***Scenario 1 + 2 + 3***	40.83	€ 434.82
■	***Scenario 3***	49.03	€ 428.25
▲	***Scenario 1+ 2***	51.16	€ 423.55
X	***Scenario 1***	54.74	€ 422.69
∗	***Scenario 2***	58.41	€ 426.34
●	***Scenario 0***	61.84	€ 425.09

Table 6: Case study – Graphics label: Energy index and Global cost – Financial Viewpoint.

	Scenario	EP_i kWh/m²year	Global Cost €/m²
◆	***Scenario 1+2+3***	40.83	€ 512.54
■	***Scenario 3***	49.03	€ 501.43
▲	***Scenario 1+2***	51.16	€ 495.67
X	***Scenario 1***	54.74	€ 493.34
∗	***Scenario 2***	58.41	€ 496.02
●	***Scenario 0***	61.84	€ 493.58

boiler (not condensing) for heating and domestic hot water combined production, with radiators. The floor surface is 160.25 m².

The graphics in figure 3 and 4 show an anomaly in cost-optimal level, because the global cost of the scenario 0, with minimum energy-requirement

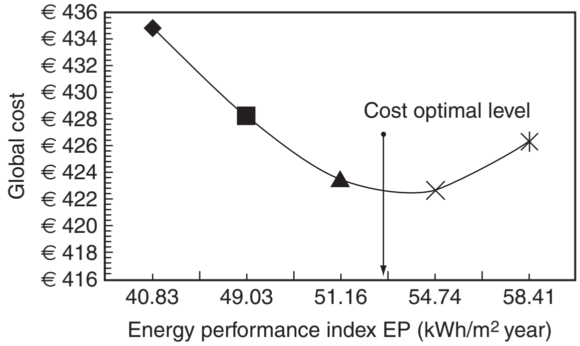

Figure 3: The case study–Macroeconomic viewpoint.

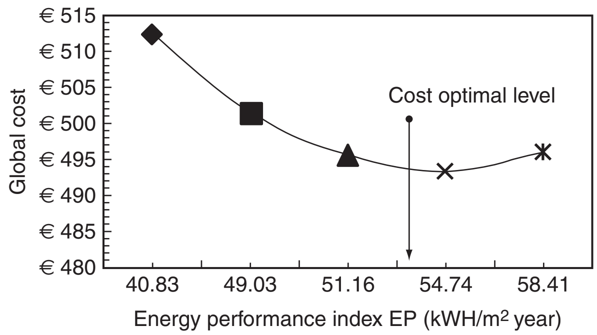

Figure 4: The case study–Financial viewpoint.

adjustment, is the lowest scenario. This result could depend on the initial costs, because the costs to realize the minimum energy-requirement adjustment do not have the extra-cost to improve energy performance, as in other energy- efficiency scenarios. If we do not consider the "zero scenario", the performance index EP, (which correspond the lowest Global Cost), is 54.74 kWh/m^{2}year. This could be considered the Cost-Optimal Level. In the following tables, the energy evaluation and the calculation of the costs are reported, considering 3 different scenarios. These three scenarios are proposed for this particular building and, if applied to a different typology of buildings, they could provide different results. However, this solution might be considered representative for a large number of existing buildings, especially if they are located in the centre or north part of Italy, where the climatic conditions are homogeneus, as well as in similar other areas in center Europe.

Considering the data reported in table 2-6, the Cost-Optimal-Level zone is located between the index EP 51.16 kWh/m^{2}year and 58.41 kWh/m^{2}year.

4. Discussion

In this case study, the cost-optima-level (which considered both the macroeconomic/financial viewpoint and the global EP) was obtained considering the scenario 1 + 2, described in the following table 7. This scenario 1 + 2 has resulted the best energy-efficiency-retrofit measure in terms of cost-efficiency for the building here considered.

However, it is important to underline that these results have been obtained in a bi-familiar villa located in the province of Ravenna (Italy), where the climate conditions differ considerably from the center-southern part of Italy. For example, in southern Italy the windows frame would not be necessarily composed by triple glasses as in the aforementioned

Table 7: Cost optimal level applied to the case study.

Pitched roof (stratigraphy):	roofing tile |**12 cm polystyrene expanse** | 5 cm lightweight concrete | 6 cm hollow gauged brick | 14 cm air cavity | 6 cm hollow gauged brick | U = 0.215 (minimum requirement 0.30 W/m^{2}K)
Plan roof (stratigraphy):	tile | 5 cm concrete | 5 cm structural lightweight concrete (ISOCAL) | 18 floor in concrete and brick | 1.5 cm plaster |**12 cm polystyrene expanse** | **1.5 gypsum plasterboard** | U = 0.206 W/m^{2}K (minimum requirement 0.30 W/m^{2}K)
Wall type 1 (stratigraphy):	1.5 cm plaster | 28 cm common brick |**12 cm polystyrene expanse** | 1 cm plaster | U = 0.206 W/m^{2}K (minimum requirement 0.34 W/m^{2}K)
Wall type 2 (stratigraphy):	2.0 cm plaster | 12 cm common brick |**12 cm polystyrene expanse** | **12 cm alveolater brick** | **1.5 cm plaster** | U = 0.208 W/m^{2}K (minimum requirement 0.34 W/m^{2}K)
Basement floor (stratigraphy):	tile | 5 cm concrete | 10 cm radiant heating with thermal and acustic insulation | U = 0.318 W/m2K (minimum requirement 0.32 W/m2K)
Windows	PVC frame | **low emission triple glass 4-12-4-12-4** | U_{glas} 0.60 U_{frame} 1.00. U_{window} 1.10 (W/m^{2}K)
Heating plant:	Condensing boiler (natural gas) | radiators
Domestic Hot Water (DHW):	produced by same Condensing boiler (natural gas) integrated with solar collector
Renewable Energy Sources:	2.50 m2 solar collector (1727.78 kWh/year)
Energy Carrier:	natural gas

solution. The solar radiation could compensate a large part of the energy requirements also in the winter seasons, since the average outside temperature in southern Italy is about 10–12 degrees higher than that in the northern Italy.

Moreover, changing the building type, these results again could vary considerably. As an example, typically a condominium could benefit of a more suitable external shape which reduces the global surface in contact with the external (cold) air, rather than a low emission glass as in the villa. Also the energy carrier (central unit) could enhance the global efficiency of the entire building. Therefore, the results, reported in the present article, could be considered as an application of the calculation of the cost-optimal level in a single, bi-familiar villa, located in northern Italy, and therefore compared with other similar buildings in other countries (especially in central Europe), where the technical solutions which would be necessary to optimise the "cost-optimal level" could be different from those here obtained in this evaluation.

5. Conclusions

The cost-optimal-level is an important tool which is useful to compare several scenarios for the same building, and the methodology framework could be applied for real buildings and not only for the reference building. The methodology framework could have some difficulties, as in the case study here presented. In existing buildings the relation between energy-efficiency improvement and energy cost is not linear. The cost of some technologies (for example thermal plant or renewable technologies), and also the energy carrier and tariffs might not be related to the results of their application. The same consideration could be adopted for walls or roof insulation. In the case study, described above, the insulation technologies were more expensive than plant technologies. This was caused by the starting costs, that did not have any extra-cost to improve energy performance, as well as in other energy-efficiency scenarios. For not standardized buildings, some aspect must be investigated.

As an example, it might be useful to:

- identify the national or regional standard costs for energy-retrofit-technology solutions. They depend on the construction sector and not on the related energy saving, therefore they do not include material or accessory costs;
- define standard criteria for "energy tariff", for example following AEEG, because each energy carrier differs considerably for annual energy costs and variable;
- include the increase of real estate values in the framework, one of the most important effect of energy improvement as described in [25, 26], with same criteria adopted for greenhouse emission costs. Finally, the results here obtained and presented, might be compared with similar buildings located in different European countries, where different solutions from this Italian case study could give optimal levels.

Nevertheless, by changing the building type, technical solutions could be different. Moreover, even if considering the same building typology and located in the same country, differences in the energy efficiency refurbishment measures may result by changing the location of the same building (e.g. from northern to southern Italy).

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Annex 1 Global Cost Calculation

The Global Cost (GC) is defined as "the sum of the present value of the starting investment costs, sum of running costs, and replacement costs (referred to the starting year), as well as disposal costs if applicable. For the calculation at the macroeconomic level, an additional category cost of greenhouse gas emissions, is introduced".

The Global Costs are based on the "Net Present Value" (NPV) of all costs during the reference period of each scenario, which is fixed in 30 year.

The categories for evaluation of cost-optimal-level could be divided into macroeconomic viewpoint or financial viewpoint. The macroeconomic viewpoint considers primary energy costs; besides, financial viewpoint could be based on energy primary or energy used (or energy carrier: natural gas, electricity etc.).

The Global Cost, expressed in NPV, is obtained summing these costs:

- starting investment cost (C_I); it means the summa of all the investment costs, that include for example the insulation cost, the design cost and all taxes, for each scenario;
- Annual Cost (C_a); it means the summa of annual Energy Cost (C_e) and maintenance cost (C_m);
- Energy Cost (C_e) (i.e. the most important variable). It means the scheduled annual energy costs and peak charges for energy, including national taxes;
- Replacement Cost (C_r); It means a substitute investment for a building element;
- Cost of Greenhouse gas emission (C_c); it means the monetary value of environmental damage caused by CO_2 emission related to energy consumption in buildings.

The Energy Costs (C_e) are calculated for each year and for all the period; they are actualized with NPV at the starting year.

The evaluation of NPV considers the discount factor R_d that is calculated for a generic year *i,* and a discount rate *r*, with the formula:

$$R_d(i) = \left(\frac{1}{1+(r/100)}\right)^i [\%] \tag{1}$$

The calculation period is scheduled in 30 year for residential and public buildings, and in 20 year for commercial and not residential buildings. The lifespan and Life Economic Cycle for each building element and for all building are based o EN 15459 standard.

Therefore, to evaluate Global Cost, the following steps are required:

(1) definition of each scenario measure or package;
(2) evaluation of the Starting Investment Cost (C_I);
(3) evaluation of the annual Energy Cost $(C_e)_j$ for each energy carrier;
(4) evaluation of the Maintenance $(C_m)_j$ and Functional annual cost $(C_f)_j$
(5) evaluation of the Substitution $(Cs)_j$ and Disposal Cost $(C_d)_j$ for relative year;
(6) calculation of the NPV for starting year
(7) evaluation of the CO_2 emission and relative emission cost for greenhouse emission (only for macroeconomic viewpoint);
(8) summa of all the NPV costs;
(9) calculation of Global Cost (C_g).

The formula to evaluate the Global Cost for financial viewpoint [€/period] is the following:

$$C_g(\tau) = C_i + \sum_j \left[\sum_{i=j}^{\tau} \left(C_{a,i}(j) \times R_d(i) \right) - V_{f,\tau}(j) \right] \tag{2}$$

and for macroeconomic viewpoint is [€/period] :

$$C_g(\tau) = C_I + \sum_j \left[\begin{array}{l} \sum_{i=1}^{\tau} \left(C_{a,i}(j) \times R_d(i) + C_{c,i}(j) \right) \\ -V_{f,\tau}(j) \end{array} \right] \tag{3}$$

Where:

$V_{f,\tau}(j)$ means the residual value of a measure or a set of measures *j* at the end of the calculation period (discounted to the starting year $\tau 0$);

$R_d(i)$ means discount rate for *j*-year;

$C_{a,i}(j)$ is the annual cost during year *i* for measure or set of measures *j* calculated with [4]:

$$C_{a(i)} = C_{e(i)} + C_{m(i)} + C_{f(i)} + C_{so(i)} \text{ [€/year]} \tag{4}$$

$C_e(i)$ means energy annual cost for each energy carrier including tax for *j*-year;

$C_m(i)$ means maintenance cost;

$C_f(i)$ means operational cost;

$C_{so}(i)$ means substitution cost;

$C_{c,i}(i)$ means greenhouse gas emissions cost;

C_I means starting cost for each scenario.

The Global Cost discounted to the starting year ($C_{g,\tau}$), shall be related to floor units surface (US) (m^2):

$$C_g = \frac{C_g(\tau)}{US} \quad \left[\in /\mathrm{m}^2 \right] s \tag{5}$$

Annual Energy Cost $(C_e)_j$

The annual Energy costs represent the main value of annual cost. They directly depend on energy primary building performance, energy carrier and also energy market (or energy fee and tax). The formula is:

$$C_{e(i)} = Q_p \cdot T \text{ [€/year]} \tag{6}$$

Where Q_p means energy performance of building expressed in primary energy (kWh/year), and T means Energy fee or tariff included tax and/or VAT for each energy carrier expressed in €/kWh with kWh of primary energy.

The Operational Cost includes all cost for assurance, rules upgrade or improvement, energy cost, tax and fee. The Maintenance Cost includes all cost for inspection, ordinary or extra ordinary repair and safety cost.

The Operational Cost is calculated for each year. The Maintenance Cost could be divided into annual or periodic cost, for extra ordinary repair. The periodic maintenance operation could be related to inverter substitution for photovoltaic, boiler-component substitution, etc. All these costs shall be anticipated and bringing up-to-date with the formula [7]:

$$C_{m(i)} \text{ Maintenance Cost} \cdot R_{d(i)} \; [€/\text{year}] \tag{7}$$

In case of macroeconomic viewpoint, it is necessary to evaluate the environmental impact of greenhouse-gas-emissions and its monetization, for each year. The CO_2 emissions are calculated from energy building performance in relation with energy carrier and CO_2 factor values described in EN 15603 [22] Annex E or in national value.

The monetization of CO_2 emission are scheduled for 2050 scenario in 20 €/tCO_2 until 2025, 35 €/tCO_2 until 2030 and 50 €/tCO_2 after 2030.

For example, considering the starting year 2012, the monetization, for residential building is:

$$\sum_{i=1}^{\tau} C_{c,i(j)} = t_{CO_2 eq,a,i(j)} \cdot \begin{bmatrix} (20€ \cdot 13\text{year}) + (35€ \cdot 5\text{year}) \\ + (50€ \cdot 12\text{year}) \end{bmatrix} \left[€ / \text{year} \right] \tag{8}$$

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