ePANACEA
Smart European Energy Performance Assessment & Certification

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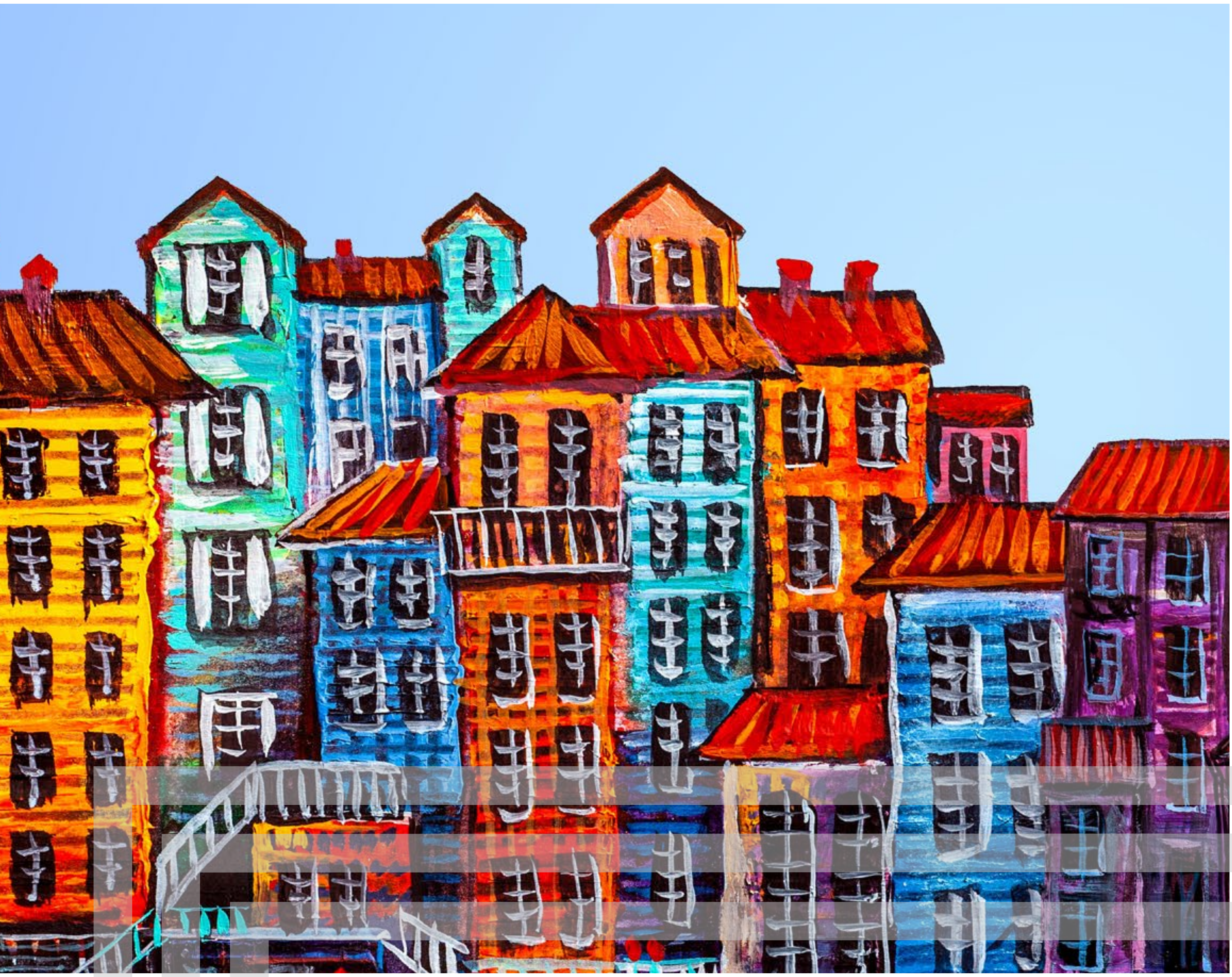

Economic feasibility of tailored energy efficiency recommendations for buildings

Report on the use of (cost-optimal) renovation business plans within EPC schemes
Version 1, May 2021

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HISTORY OF CHANGES

Version	Month Year	Organisation	Comments
1.0	20.05.2021	CENER	Draft ready for revision
1.1	25.05.2021	VTT	Draft including VTT comments
1.2	28.05.2021	EAst	Draft version including EAst comments
1.3	31.05.2021	CENER	Final version including internal review comments

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OVERVIEW OF THE ePANACEA PROJECT

After 10 years of track record, the current EPC schemes across the EU face several challenges which have led to a not full accomplishment of their initial objectives: lack of accuracy, a gap between theoretical and real consumption patterns, absence of proper protocols for inclusion of smart and novel technologies, little convergence across Europe, lack of trust in the market and very little user awareness related to energy efficiency.

The objective of the ePANACEA project is to develop a holistic methodology for energy performance assessment and certification of buildings that can overcome the above-mentioned challenges. The vision of ePANACEA is to become a relevant instrument in the European energy transition through the building sector.

ePANACEA comprises the creation of a prototype (the Smart Energy Performance Assessment Platform) making use of the most advanced techniques in dynamic and automated simulation modelling, big data analysis and machine learning, inverse modelling or the estimation of potential energy savings and economic viability check.

A relevant part of the project is to have a fluent dialogue with European policy makers, certification bodies, end-users and other stakeholders through two types of participatory actions: a feedback loop with policy makers, carried out through the so-called Regional Exploitation Boards (REBs) covering EU-27+UK+Norway on the one hand, and dialogue with end-users, established by means of specific thematic workshops, on the other.

Thanks to these participatory actions, the acceptance of the ePANACEA approach will be tested and validated in order to become aligned with and meet the needs of national public bodies, end-users and other stakeholders.

ePANACEA will demonstrate and validate reliability, accuracy, user-friendliness and cost-effectiveness of its methodology through 15 case studies in 5 European countries.

EXECUTIVE SUMMARY

Energy Performance Certificates (EPCs) inform building owners and users about the current energy efficiency of the building. They also include recommendations for the improvement of the energy performance of the building. They provide the efficiency classes associated with the different individual or package of energy efficiency measures (EEMs).

However, financial constraints are the main reason for people not to renovate or why building owners choose less efficient solutions, hampering the long-term transition.

The inclusion of a financing evaluation of EEMs into energy performance assessment methods and EPC schemes, based on the cost-optimal methodology, is a necessary instrument for building owners to take decisions regarding building renovation and to plan the staged deep renovations.

Harmonized economic and viability analysis based on energy saving estimation in EPC schemes will instil trust in the market and mobilize investments in energy efficiency based on energy renovations of existing buildings

ePANACEA project intends to integrate the cost-optimal methodology into energy performance assessment and certification schemes as a tool to evaluate the economic feasibility of integrated packages of business as usual (BAU) technologies and smart novel technical solutions.

Chapter 1 of this document introduces this report and summarizes political surroundings of the European Green Deal and the EPBD.

Chapter 2 includes the description of the ePANACEA cost-optimal methodology based on the adaptation of the CE cost-optimal framework defined in the EU Guidelines [EU 2012a] and Regulation (EU) N° 244/2012 [EU 2012]. A description of all considered BAU technologies and novel and smart technical solutions are also included in this section.

Chapter 3 shows the implementation of the cost-optimal methodology in two case studies: a new residential building and an existing office building.

Chapter 4 explores the integration of the economic assessment into staged deep renovation roadmaps and Building Renovation Passports (BRP).

Additionally, a database with costs of energy efficiency measures (EEMs), including current and main novel and smart technologies for target countries (AT, BE, EL, ES, FI) is been developing. This database will be included into the final ePANACEA methodology and its pilot Smart European Energy Performance Assessment and Certification Platform (SEPAP).

GLOSSARY

BAU technology – Business as usual technology, a current standard technology.

BMS - Building management system - Also known as building automation system (BAS) refers to a computer-based control system that needs to be installed within buildings to monitor and regulate the building's electrical and mechanical equipment such as cooling/heating generation, solar control, lighting, ventilation, etc.

BIPV - Building Integrated PhotoVoltaics system.

BRP - Building Renovation Passport - Although there is no common definition in the EU, according to [EPBD 2018/844/EU], the building renovation passport is generally considered as a "long-term, step-by-step deep renovation roadmap for a specific building based on quality criteria, following an energy audit, and outlining relevant measures and renovations that could improve the energy performance".

BACS - Building automation and control system – system comprising all products, software and engineering services that can support energy efficient, economical and safe operation of technical building systems through automatic control and by facilitating the manual management of those technical building systems.

Delivered energy – energy expressed per energy carrier, supplied to the technical building system through the assessment boundary, to satisfy the uses taken into account or to produce the exported energy. (Delivered energy can be calculated for defined energy uses or it can be measured)

DHW – Domestic hot water.

DSM – Lighting Demand Side Management

EEM – Energy efficiency measure.

Energy audit – An assessment of the energy needs and efficiency of a building, conducted by an energy expert.

Energy use for lighting – Electric energy input to a lighting system

Energy use for space heating or cooling or DHW – Energy input to the heating, cooling or DHW system to satisfy the energy need for heating, cooling (including dehumidification) or DHW respectively.

Energy use for ventilation - Electric energy input to a ventilation system for air transport and heat recovery.

EPBD - Energy Performance of Buildings Directive (EPBD) – The objective of this Directive 2010/31/EU] is to promote the improvement of the energy performance of buildings within the Community, taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness. The EPBD was amended [by way of Directive 2018/844/EU] in 2018.

EPC - Energy performance certificate – An EPC is a rating scheme indicating the energy performance of a building in the European Union. Each Member State (and, in certain cases, region) has developed its own EPC framework according to the framework given by the EPBD [2010/31/EU – Article 2 (12)].

EV – Electric vehicle.

NPV – Net present value

nZEB – nearly zero energy building

PEB – Positive energy building

Primary energy – Energy that has not been subjected to any conversion or transformation process. Primary energy includes non-renewable energy and renewable energy. If both are taken into account it can be called total primary energy

PV system - Photovoltaic system

PVT – Photovoltaic thermal collector - A hybrid photovoltaic-thermal collector integrates a solar thermal absorber and a PV into one unit.

RES – Renewable energy source

SEPAP – ePANACEA Smart European Energy Performance Assessment and Certification Platform.

Spanish TBC - Spanish Technical Building Code.

Staged deep renovation roadmap- step-by-step renovation plan with a horizon of up to 15–20 years that, by looking at the building as a whole, suggests the installation of selected measures in certain order (sequencing) [Fabbri M. 2017].

Logbook – A (digital) repository where all building information can be stored and continuously updated.

V2G – Vehicle to grid

1. INTRODUCTION

The European Green Deal establishes a common framework for transforming the EU's economy for a sustainable future. Among others, one of the new measures to achieve the European Green Deal objectives is increasing the EU's climate ambition for 2030 and 2050. As a part of the Green Deal objectives, the Renovation Wave strategy arises, whose key objectives are:

- At least double energy renovation rates
- Increase ambition and save energy
- Reduce GHG emissions
- Alleviate energy poverty
- Create jobs, aid economic recovery
- Undertake legislative reviews

However, financial constraints are the main reason for people not to renovate or why building owners choose less efficient solutions, hampering the long-term transition.

Energy Performance Certificates (EPCs) have the opportunity to play an important role in achieving the environmental objectives of the EU, as a useful element to support the energy transition in the buildings sector, motivating investment in new and existing buildings oriented to energy efficiency, integration of renewable energy sources and smart technologies that allow optimisation of buildings' performance.

Under the current EPBD revision, some key aspects related to EPCs are on the table:

- New EPC after every renovation project
- All buildings to have an EPC by 2030
- National databases to be accessible to stakeholders
- Link to achievement of long-term renovation strategies
- Link to building renovation passports and digital logbooks

EPCs inform building owners and users about the current energy efficiency of the building. They also include recommendations for the improvement of the energy performance of the building.

The inclusion of a financing evaluation of EEMs into energy performance assessment methods and EPC schemes, based on the cost-optimal methodology, is a necessary instrument for building owners to take decisions regarding building renovation and to plan the staged deep renovations.

Harmonized economic and viability analysis based on energy saving estimation in EPC schemes will instil trust in the market and mobilize investments in energy efficiency based on energy renovations of existing buildings

This report explores the inclusion of renovation business plans in EPCs, including business plans for staged deep renovations, based on the cost-optimal methodology. The minimum energy requirements for compliance included in Technical Building Codes should meet the cost-optimal requirements according to Article 5 of Directive 2010/31/EU. However, the assessments developed to define the minimum requirements at member state level only use to include current (and basic) technologies (e.g thermal insulation).

The integration of the cost-optimal methodology [EU 2012][1] into certification schemes would allow the evaluation of integrated packages of state-of-the-art and novel technical solutions from two points of view; energy consumption and global cost (i.e. including investments and operational costs associated with energy efficiency measures).

This report provides the methodology and guidance to include the economic viability assessment within the methodology development work package (WP4) focused on the quantitative assessment for the five pilot countries (AT, BE, EL, ES, FI).

This report provides the methodology and guidance to include the economic viability assessment within the ePANACEA approach for the next generation of energy assessment and certification, focused on the quantitative assessment for the five pilot countries: Austria, Belgium, Greece, Spain and Finland.

Additionally, a database with costs of energy efficiency measures, including main novel and smart technologies for target countries (AT, BE, EL, ES, FI) is being developing and including into the final ePANACEA methodology and its pilot Smart European Energy Performance Assessment and Certification Platform (SEPAP).

[1][EU 2012] Commission Delegated Regulation (EU) N244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements.

2. COST-OPTIMAL METHODOLOGY

2.1. Overview

The cost-optimal level is the energy performance (measured in kW*h/m² of primary energy[2]) that leads to the lowest cost during the estimated building life cycle. The cost calculations (expressed in net present value) include investment costs in energy efficiency and renewable energy measures, maintenance and operating costs, energy costs, earnings from energy produced and disposal costs (costs for deconstruction at the end of a building's life).

The following conceptual graph describes the primary energy use (x-axis: kW*h primary energy/ (m² useful floor area and year)) and global costs (y-axis: €/m² useful floor area) associated with different energy efficiency solutions. From a number of measures/ packages/variants, a specific cost curve (= lower border of the area marked by the data points of the different variants) can be developed. The cost-optimum is the lowest point on this graph and the cost-optimal energy performance is the one corresponding to that point.

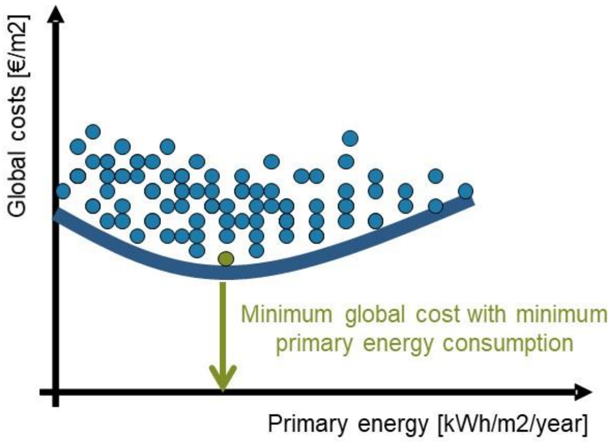


Figure 1: Cost-optimal definition. Source CENER

The cost-optimal framework methodology is based on a conventional cost-benefit analysis framework. It does not take into account all the external factors that can affect the building-use life cycle cost calculations. Similarly, the positive impacts for society of investments in energy efficiency and integrating renewable energy in buildings are also not accounted for by the cost-optimal framework methodology. These can include job and wealth creation, increased productivity, improved health of building occupants, and value of the buildings.

The cost-optimal framework methodology has been initially understood as a tool to support Member States in setting minimum energy performance requirements for buildings, based on national reference scenarios and current (and basic) technologies (e.g thermal insulation)[3].

[2] The calculation of primary energy includes the breakdown of energy needed for space heating, cooling, ventilation, domestic hot water and lighting systems. The resulting total primary energy is calculated using national primary energy conversion factors. The renewable energy produced on-site, if any, is deducted from the total primary energy consumption.

[3] Measures related to new technologies (e.g. on-site wind turbines and on-site cogeneration) and passive solutions (e.g. natural lighting and natural ventilation) are not considered in many national methodologies.

ePANACEA project intends to integrate the cost-optimal methodology into energy performance assessment and certification schemes as a tool to evaluate the economic feasibility of integrated packages of BAU technologies and novel and smart technical solutions. For this purpose, the proposed UE cost-optimal methodology has been adapted from the EU Guidelines [EU 2012a] and Regulation (EU) N° 244/2012 [EU 2012].

2.2. Methodology description

The cost-optimal ePANACEA calculation framework involves the following steps:

- Definition of baseline buildings;
- Identification of energy efficiency measures (EEMs) and packages of EEMs to be evaluated;
- Calculation of non-renewable primary energy of the baseline building with the identified energy efficiency measures;
- Calculation of global costs related to each energy efficiency measure and package, considering long-term expenditures and savings during the calculations period;
- Calculation of the cost-optimal package of EEMs and nZEB measures

Figure 2: Cost-optimal methodology phases. Source CENER

2.2.1. Baseline buildings

The first step in the calculations is the definition of the baseline building against to which compare the energy efficiency savings associated to specific EEMs or a combination of them.

Baseline building, in the case of evaluating a design project for the construction of a new building, could be the preliminary design project.

In the case of renovation, the basic refurbishment works only for aesthetic, functional and safety reasons could be the reference against to which compare the energy savings.[4]

2.2.2. Energy Efficiency Measures (EEMs) and packages of EEMs

The second step in the calculations is the identification of energy efficiency measures –EMMs-. This improvement measures can involve elements of the building envelope (e.g. triple-glazed windows with a certain U-value[5]), measures based on renewable energy (e.g. solar energy for domestic hot water (DHW)) and/or relevant alternative high-efficiency systems (e.g. cogeneration, district energy supply systems, condensing boilers and heat pumps). All of them have an impact on the energy

[4] In the case of defining minimum energy performance requirements for national energy policies, reference buildings should be representative of the national building stock.

[5] U-value is a measure of the thermal insulation performance of construction materials and building elements.

performance of the baseline building. These measures are then applied to the baseline building, and the resulting energy performance and global cost are calculated.

Individual energy efficiency measures can be combined into packages (e.g. triple-glazed windows, condensing boiler and solar energy for DHW). The evaluation of EEMs packages instead of individual EEMs is more advantageous because synergies can be added between them and obtain more efficient and cost-effective combinations than an individualized analysis.

Envelope Variants	1. Opaque elements parameters (Roof additional Insulation [cm]; Wall additional Insulation [cm]; Basement additional Insulation [cm]; Thermal bridges [% increase U value])	2. Window parameters (Glass U-value [W/m²K]; Frame U-value [W/m²K]; Air permeability: m³/hm² at 100)	3. Heat Recovery for ventilation system (Heat recovery Efficiency)	4. Cooling parameters (Shading control device optimization; Extra natural ventilation in Summer)
Variant 1	0	0	0	0
Variant 2	0	0	0	1
Variant 3	0	1	0	0
Variant 4	0	1	0	1
Variant 5	0	1	1	0
Variant 6	0	1	1	1
Variant 7	1	0	0	0
Variant 8	1	[illegible]	0	1
Variant 9	1	1	0	0
Variant 10	1	[illegible]	0	1
Variant 11	[illegible]	[illegible]	1	0
Variant 12	1	1	1	1
Variant 13	[illegible]	[illegible]	0	0
Variant 14	1	2	0	1
Variant 15	1	2	1	0
Variant 16	[illegible]	2	1	1
Variant 17	2	0	0	0
Variant 18	2	0	0	1
Variant 19	2	1	0	0
Variant 20	2	1	0	1
Variant 21	2	1	1	0
Variant 22	2	1	1	1
Variant 23	2	2	0	0
Variant 24	2	2	0	1
Variant 25	2	2	1	0
Variant 26	2	2	[illegible]	1
Variant 27	3	1	0	0
Variant 28	3	1	0	1
Variant 29	3	1	1	0
Variant 30	3	1	1	1
Variant 31	3	2	0	0
Variant 32	3	2	0	1
Variant 33	3	2	1	0
Variant 34	3	2	1	1

4 thickness levels of thermal insulation
3 types of windows
Strategies to reduce cooling demand
Heat recovery

Figure 3: Example of combination of EEMs. Source REVILICIA project. CENER

A detailed description of EEMs is provided in section 2.2 of this document.

2.2.3. Calculation of non-renewable primary energy indicator

The third step is the calculation of the energy performance of the various measures or packages of EEMs for the baseline building using the series of ISO 52000 standards[6], or an equivalent national calculation methodology. The results of the energy performance calculation are presented in annual non-renewable primary energy use per square metre of useful floor area (in kW*h/m²).

The detailed calculation methodology for energy performance can be summarized via the following Figure. Note that the time interval on which the balance is calculated (e.g. a day, a month, a year) should always be explicitly stated. In ePANACEA project a yearly energy balance is considered.

[6] According to Annex I of Directive (EU) 2018/844, *Member States shall describe their national calculation methodology following the national annexes of the overarching standards, namely ISO 52000-1, 52003-1, 52010-1, 52016-1, and 52018-1, developed under mandate M/480 given to the European Committee for Standardisation (CEN).*

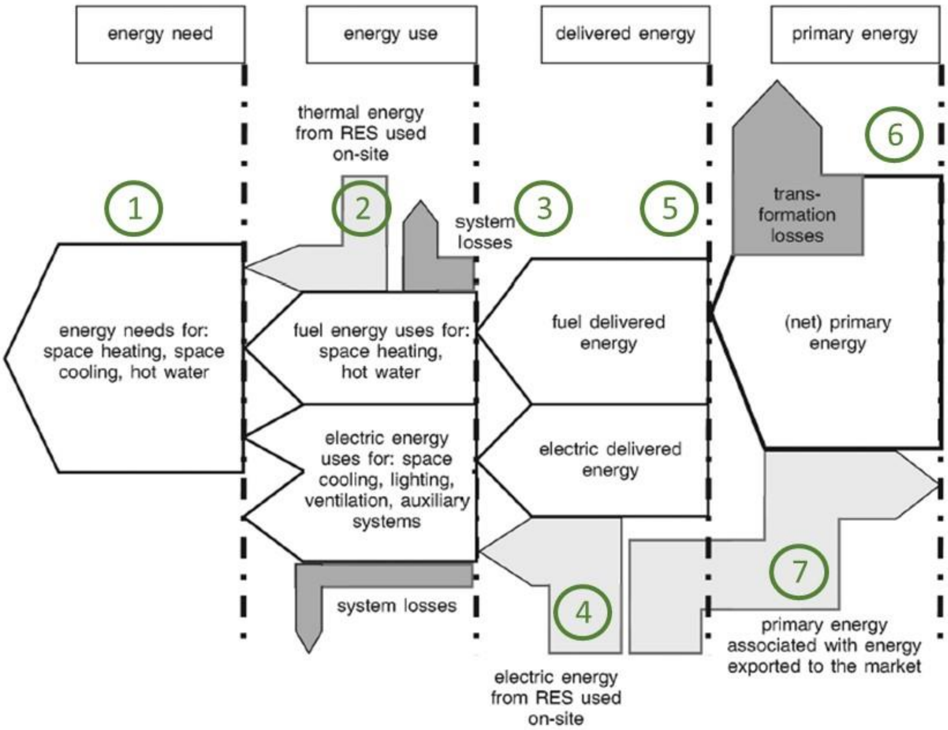


Figure 4: Scheme of calculation of the (net) primary energy resulting from the application of measures and packages of measures to a baseline building. Source CENER based on EU guidelines [EU 2012].

- **(1)** Calculation of **energy needs** associated with heating, cooling and DHW services for all energy models where the selected packages of EEMs have been implemented. Dynamic simulations based on series of ISO 52000 standards are recommended to carry out this quantitative assessment.
- **(2)** Subtraction of **thermal energy from renewable energy sources** produced and used on-site (e.g. solar thermal panels).
- **(3)** Calculation of **energy use** (space heating, space cooling, DHW, lighting, ventilation) for each energy carrier (electricity, fuel) taking into account the performance (characterized by seasonal efficiencies) of the generation, distribution, emission and control systems.
- **(4)** Subtraction of the electricity from renewable energy sources produced and used on-site (e.g. photovoltaic panels)
- **(5)** Calculation of **the delivered energy** for each energy carrier resulting as the sum of energy consumption.
- **(6)** Calculation of the **primary energy** associated with the delivered energy, using national/regional conversion factors per energy carrier.
- **(7)** Calculation of **primary energy associated with energy exported to the market** (e.g. generated by RES or co-generators on-site).
- **(8)** Calculation of **(net) primary energy** as the difference between the two previous calculated amounts: (6) **-** (7).

Hence, considering selected climate conditions and building case study, the energy needs for heating, DHW and cooling, the delivered energy for heating, cooling, DHW, lighting and ventilation, and finally the net primary energy, are calculated for each package of EEMs and variants.

This methodology allows expressing all energy uses with a single primary energy indicator. Thus, active measures based on renewable energy sources enter into direct competition with measures on the demand side, in line with the objective of the optimal-cost methodology of identifying the package of EEMs that represents the lowest overall cost without discriminating in favour or against any technology.

National/regional conversion factors are necessary to calculate primary energy from the delivered energy. In ePANACEA project the following non-renewable primary energy conversion factors are considered:

Table 1: Non-renewable primary energy conversion factors in the target countries/regions.

fPE_{nren} [kWh/kWh]	AT	BE	ES	FI	GR
Electricity	1,0189	2,035*	1,954	1,2	2,9
Gas	1,1	1	1,19	1	1,05
Biomass	0,1	0	0,085	0,5	0
Heating oil	1,2	1	1,179	1	1,1
District heating (non-renewable based)	1,37	1,3	-	0,5	-
District heating (renewable based)	0,28	0	0,85	0,5	0,7
District cooling	-	-	-	0,28	-

*Common use in Belgium fPE_{tot} = 2,5 kWh/kWh

2.2.4. Calculation of global cost

The next step is the calculation of the global cost for the various measures or packages of EEMs, based on net present value using a full cost approach. This means that for each measure or package applied to a baseline building, the full cost of construction (or major renovation) and the subsequent use of the building was taken into account.

The calculation periods considered in ePANACEA project is 30 years for residential and public buildings, and 20 years for non-residential buildings.

The global costs can be calculated from two different perspectives: financial (i.e. building owner and investor perspective) and macroeconomic (i.e. societal perspective). For the financial perspective, the costs include the prices paid by the final consumer, including all applicable taxes, including VAT, and charges. For the macroeconomic perspective, the prices exclude all applicable taxes, VAT, charges and subsidies. However, for the latter, the cost of greenhouse gas emissions is included. In addition, one, of the at least two, discount rates to be used for the sensitivity analysis for the macroeconomic perspective is 3 % expressed in real terms. For the financial perspective, discount rates should reflect national financing environments and mortgage conditions.

ePANACEA implements the financial perspective of individual building owners and/or private investors.

As mentioned before, all taxes (VAT), subsidies, and the interest rate (as adjusted to inflation) are usually included for considering the prices as paid by private customers and reflecting the real financial situation. However given the speed with subsidies and incentives change, it is possible to perform the calculation without considering them to obtain the point of view of a private investor.

The calculation of global cost (see the following Figure) considers the initial investment (material and labour costs, business profit and general expenditure etc.), substitution costs, annual maintenance costs over the calculated period, all with reference to the starting year. Note that embedded energy (also called grey energy) is not included in the calculation.

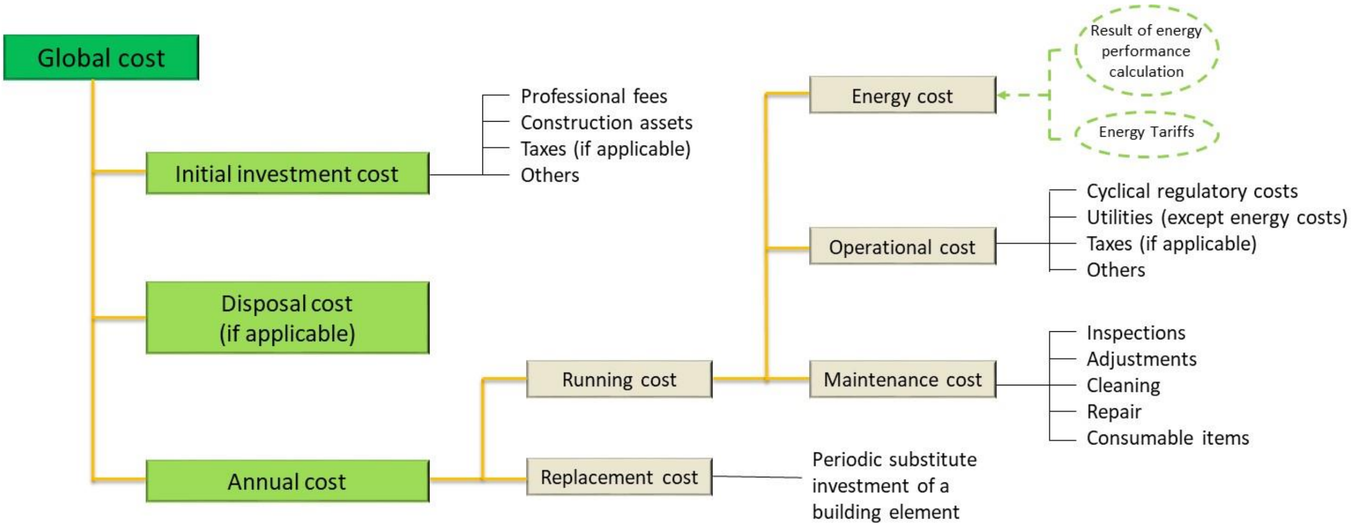


Figure 5: All costs considered in the performed global cost calculations. Source: CENER, adapted from EU guidelines [EU 2012a].

It is important to note the global cost, as intended for cost-optimal calculation, takes into account only energy-related costs.

Costs of construction not directly related to energy (structure, etc.) are not considering in this analysis. Costs of land, property taxes etc. are not included.

The following tables shows the professional fees and business profit & general expenditure percentages considered in ePANACEA project.

Table 2: Percentage of professional fees considered in the target countries/regions.

Percentage of professional fees considered [%]	**AT**	**BE**	**ES**	**FI**	**GR**
Professional fees percentages of whole building renovation (material costs + labour costs)	10-15%*	14-16%	10-12%	9%	5-10%

* [ENTRANZE project 2014]

Table 3: Percentage of business profit & general expenditure considered in the target countries/regions.

Business profit & general expenditure [%]	**AT**	**BE**	**ES**	**FI**	**GR**
Business profit & general expenditure percentages of whole building renovation (material costs + labour costs)	14-22%*	22%	15%	10%	15-20%

* [ENTRANZE project 2014]

As mentioned before, calculating the global cost means defining a net present value of all costs occurring during a defined calculation period τ, considering also the residual values of components with longer lifetimes. Components with shorter lifetime are replaced during the selected calculation period.

As a general rule, the replacement cost will be the same as the initial investment cost. E.g an element whose estimated life cycle is 15 years has to be included twice in the global cost calculation, once as initial investment cost and a second as replacement cost after 15 years.

The residual value of a building element with a longer lifetime than the calculation period can be calculated with straight-line depreciation and this value hast to be discounted to the beginning of the calculation period.

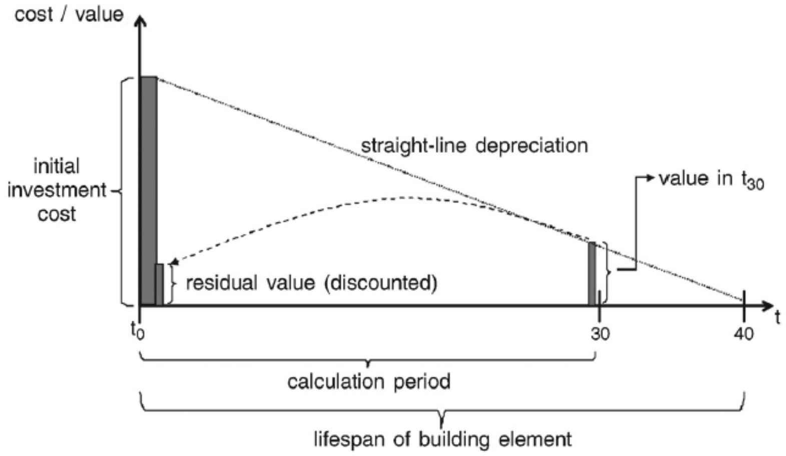


Figure 6: Calculation of the residual value of a building element which has a longer lifetime than the calculation period. Source: EU guidelines [EU 2012].

Figure 7 shows how the residual value has to be calculated for a building element which has a shorter lifespan than the calculation period (e.g. heating boiler). With an assumed lifespan of 20 years the element has to be replaced after that period of time. Once the element has been renewed a new depreciation period starts. In this case, after 30 years (end of the calculation period) the residual value of the element is 50 % of the replacement cost. Once again this value has to be discounted to the beginning of the calculation period.

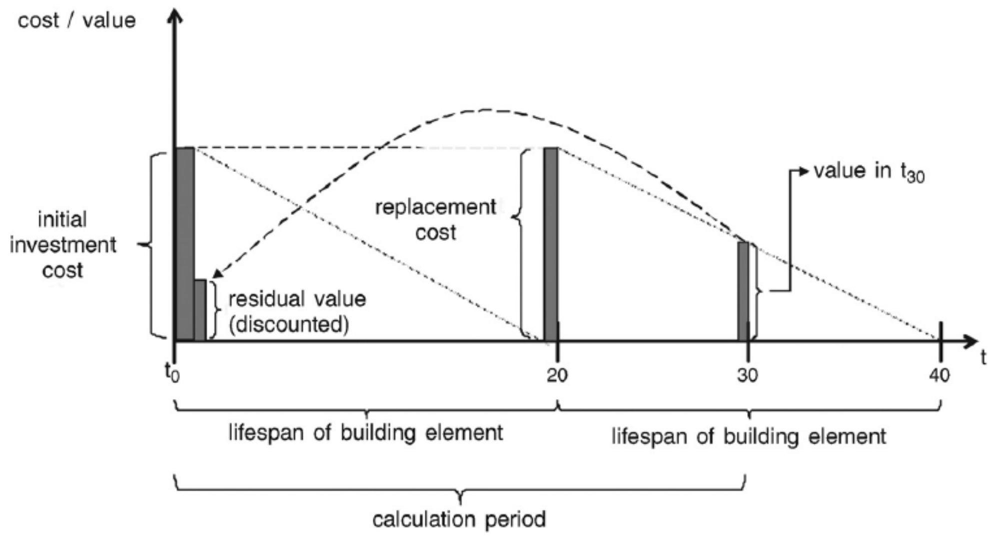


Figure 7: Calculation of the residual value of a building element which has a shorter lifetime than the calculation period. Source: EU guidelines [EU 2012].

ePANACEA method considers components lifespan according to standard EN15459-1: 2017.

As introduced, the cost-optimal calculations are based on financial assumptions concerning inflation, interest rates and the evolution of energy and products prices.

Hence main financial parameter is the discount rate, which is crucial to determine the discount factor for actualizing each cost that is considered within the global cost to the starting year.

Discount factor:

$$R_d(p) = \left(\frac{1}{1 + r/100}\right)^p$$

Where:

p is the number of years from the starting period

r is the real discount rate

The following values are considered in ePANACEA project for the target countries:

Table 4: Discount rates as reference for the target countries/regions.

Discount rate [%]	AT	BE	ES	FI	GR
Discount rate	2,19%	3%	1,4%	2%	3%

The discount rate used in discounted cash flow analysis to determine the present value of future cash flows. The discount rate takes into account the time value of money (the idea that money available now is worth more than the same amount of money available in the future because it could be earning interest) and the risk or uncertainty of the anticipated future cash flows (which might be less than expected).

Discount rate: the amount charged, expressed as a percentage of principal, by a lender to a borrower for the use of assets.

The other important financial parameter that may be considered in the calculation, the rate of evolution of energy prices, based on the different energy vectors.

Table 5: Energy prices considered for the target countries/regions.

Prices of energy carriers [€/kW*h]	AT		BE		ES		FI		GR	
	NoTax	Taxes	NoTax	Taxes	NoTax	Taxes	NoTax	Taxes	NoTax	Taxes
Electricity	0,195	20%	0,2386	17%	0.109	27%	0,11	30%	0,114	6%
Natural gas (*)	0,078	20%	0,0424	17%	0,055	21%	0,04	36%	0,019	6%
Biomass (*)	0,048	20%	0,0547	6%	0,038	21%	0,05	19%	0,049	6%
District heating	0,14/0,16(**)	20%	0,034	21%	-	21%	0,06	19%	0,053	6%
Heating oil(*)	-	20%	0,0475	21%	0,087	21%	0,04	47%	0,072	24%

(*) Referred to ICV (Inferior Calorific Value)

(**)Austria: Price of district heating (renewable base) 0,16 €; Price for district heating (CHP default)0,14€.

Table 6: Annual increase of energy costs considered for the target countries/regions.

Annual increase of energy cost per energy vector [%]	AT	BE	ES	FI	GR
Electricity	2,40%	0%	4%	1,5%	2,8%
Fossil fuels	3,60%	0%	4%	0%	2,8%
Biomass	2,10%	0%	2%	1,5%	2,8%

2.2.5. Identification of cost-optimal package of EEMs and nZEB measures

Finally, the procedure results in a cost-optimal graph where the building primary energy use is on the horizontal axis and the global cost is on the vertical axis, as in the following Figure.

Depending on the variety of packages considered, it is usually unlikely to form an exact curve, but rather a "cloud" of points, each corresponding to a different package of EEMs, that is a different building design alternative. The cost-optimum is the lowest point on this graph and the cost-optimal energy performance is the one corresponding to that point.

The Figure below depicts, within the cost-optimal curve, the gaps for both at financial and energy level, from the cost optimal level, the nZEB requirement, and the potential future PEB.

ePANACEA project identifies the cost-optimal package of EEMs and the corresponding nZEB set of EEMs. Depending on the particular conditions of the project the more appropriate set of measures will be chosen between a range of set of EEMs (cost-optimal and nZEB points).

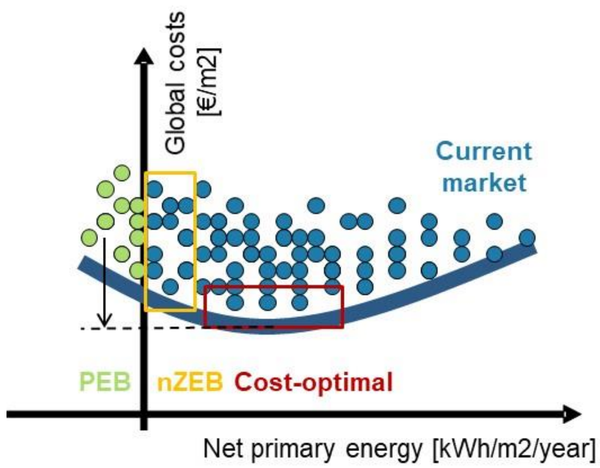


Figure 8: Cost-optimal curve for different packages of EEMs. Source CENER

2.3. Energy Efficiency Measures and smart technologies

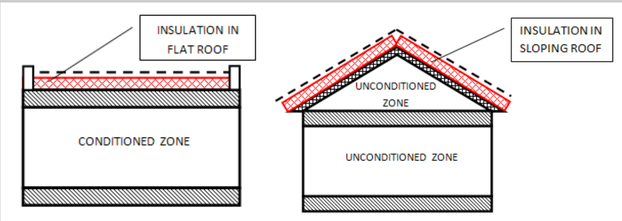
2.3.1. Building envelope

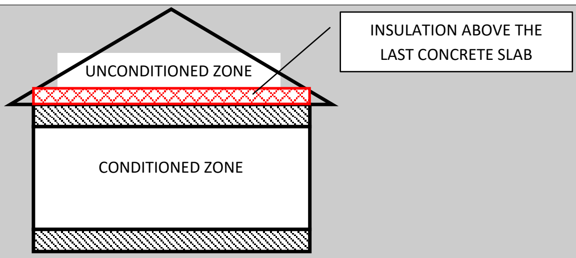
To reduce energy losses through the envelope, it is necessary to retrofit the building's envelope, either by adding thermal insulation or improving the thermal quality of windows. The replacement of openings will also allow the reduction of infiltrations in the building.

There are many interventions that are carried out in buildings, including those required for their maintenance, which can be used to improve their energy performance (for example, when painting the facade, waterproofing the roof, etc. an opportunity to add thermal insulation and thus reduce energy demand).

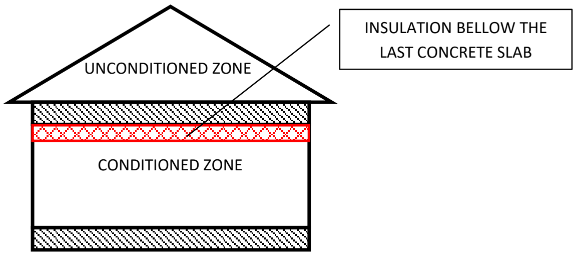
This subsection is focused on the definition of energy efficiency measures concerning the thermal envelope of the buildings.

Table 7: Roof measures.

EEM	Description
Roof refurbishment, adding a new layer of insulation from the outside. 	Renovation works of sloping or flat roofs: - In flat roofs: This measure includes the removal of all layers up to arrive the position of thermal insulation (over the waterproofing layer), the installation of the new thermal insulation layer, the protecting layer and the finishing layer (gravel, paving...). - In sloping roofs: This measure includes the removal of the roof tiles, battens and the waterproofing layer, the installation of the additional insulation layer over the slab/framework, the installation of the new waterproofing layer and vapor barrier, battens and tiles over the insulation. (*) Nominal Thermal Conductivity of the insulation layer λ=0,034 W/m*K
Pitched roof refurbishment, adding a new layer of insulation from the inside.	This measure includes the removal of all layers to arrive the position of thermal insulation; removal of existing layer of insulation and vapor barrier; installation of new thermal insulation and vapor barrier; installation of new finishing layer (plasterboard, etc). (*) Nominal Thermal Conductivity of the insulation layer λ=0,034 W/m*K
Addition of a **thermal insulation layer over the last slab in contact with an unconditioned space** (attic).	This measure includes the installation of a thermal insulation layer in the floor of unconditioned spaces, over the last horizontal concrete slab/framework. It is only possible in buildings with unconditioned space (attic) above the concrete slab/framework of the higher floor. This space

<table>
<tr>
<td>


</td>
<td>
is supposed to be no transit, so the insulation layer doesn't need to be protected by another fabric layer.

(*) Nominal Thermal Conductivity of the new insulation λ=0,034 W/m*K Insulation below the last concrete slab.
</td>
</tr>
<tr>
<td>
Insulation below the last concrete slab


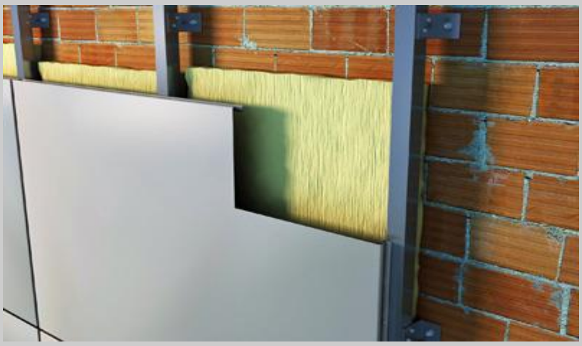
Source: CENER.
</td>
<td>
This measure includes the installation of a layer of thermal insulation in the false ceiling of the last (the highest) conditioned floor of the building (spaces below the roof or unconditioned attic).

In existing false ceiling it will be necessary replace it to install the insulation. When there isn't false ceiling it will be necessary create it.

For this option it is necessary to have enough ceiling height because it could be reduced.

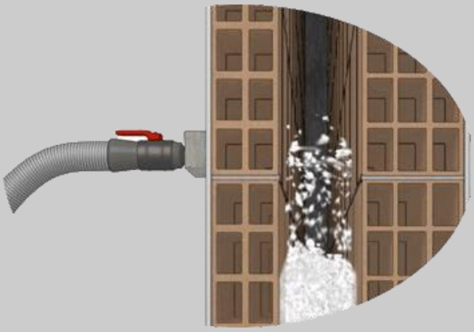
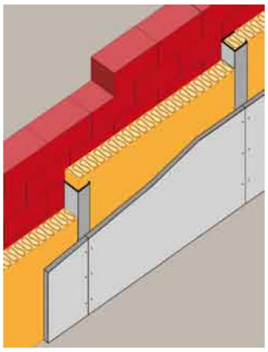
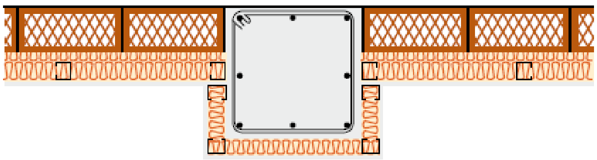
(*) Nominal Thermal Conductivity of the new insulation λ=0,034 W/m*K
</td>
</tr>
</table>

Table 8: Façade measures.

<table>
<tr>
<th>EEM</th>
<th>Description</th>
</tr>
<tr>
<td>
Façade, external insulation (ventilated façade)

Source: [PW 2021]
</td>
<td>
This measure includes the insulation of the building façade is made adding thermal insulation on the external surface of the façade. Thermal insulation will be protected by a new external layer attached, through a substructure, to the existing structure or building façade. Between the insulation and the external layer there will be a highly ventilated air chamber which will protect the building from solar radiation.

The material for the external layer could be; metal panels, natural stone, mortars panels...)

(*) Nominal Thermal Conductivity of the new insulation λ=0,037 W/m*K
</td>
</tr>
<tr>
<td>
Façade, External Insulation Finishing System (EIFS)
</td>
<td>
EIFS is a non-load bearing, exterior wall cladding system that consists of an insulation board attached
</td>
</tr>
</table>

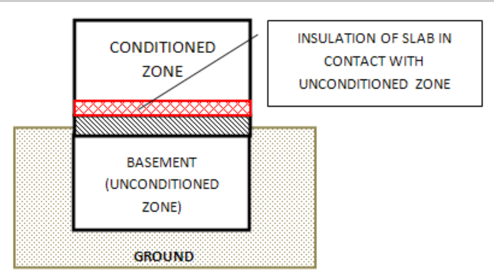
 Source: *CENER, EU-GUGLE project.*	either adhesively or mechanically, or both, to the substrate; an integrally reinforced base coat; and a textured protective finish coat. Nominal Thermal Conductivity of the new insulation λ=0,037 W/m*K
Façade, filling air chamber with thermal insulation  Source: *[Humenor 2021]*	This measure includes the installation of the thermal insulation injected into the existing air chamber. The thickness of the thermal insulation will depend on the air chamber thickness. (*) Nominal Thermal Conductivity of the new insulation λ=0,037 W/m*K
Façade, internal insulation (adding thermal insulation on the internal face of the wall)   Source: *[IDAE 2008]*	This measures includes the addition on the internal surface of the wall, the thermal insulation, vapor barrier and a new inner plaster layer. The more thermal insulation thickness, the less useful floor area of the building. (*) Nominal Thermal Conductivity of the new insulation λ=0,037 W/m*K
Façade, internal insulation (remove inner skin of the cavity wall and replace it by a new skin with thermal insulation)	Remove the inner skin of the cavity wall and then create a new skin, separated by an air chamber from

	the external skin, and composed by thermal insulation, brick masonry and plaster inside. (*) Nominal Thermal Conductivity of the new insulation λ=0,037 W/m*K

Table 9: Floor measures.

<table>
<tr><th>EEM</th><th>Description</th></tr>
<tr><td>

Floor in contact with outdoors or unconditioned spaces, insulation over the floor slab or framework.



Source: CENER.

</td><td>

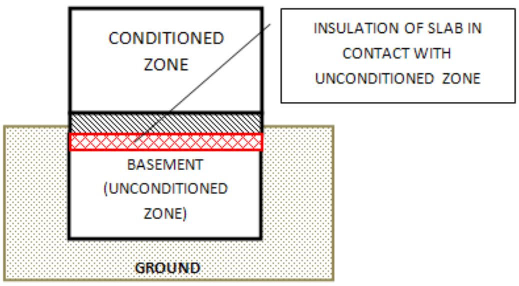
Remove the existing layers over the concrete slab. Install the thermal insulation, over the insulation a concrete screed, a vapour barrier and finally the finishing layer/s (ceramic tiles, wood,...)

For this solution is necessary to have enough ceiling height because it could be reduced and (in general) it could be necessary to adapt the height of all doors and french doors and to raise parapets and electric sockets.

(*) Nominal Thermal Conductivity of the new insulation λ=0,034 W/m*K

</td></tr>
<tr><td>

Floor in contact with outdoors or unconditioned spaces, insulation in the outer of the floor slabs.



Source: CENER

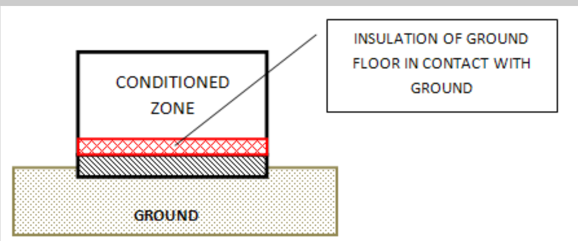
</td><td>

This measure includes the installation of layer of thermal insulation below the first conditioned plant of the building and a plaster or gypsum layer.

(*) Nominal Thermal Conductivity of the new insulation λ=0,034 W/m*K Floor in contact with the ground, insulating layer on top of concrete ground floor in contact with the ground.

</td></tr>
<tr><td>

Groundfloor slab, insulation on top of the ground floor concrete slab in contact with the ground.



</td><td>

This measure consists of removing the existing layers over the concrete slab. Install the thermal insulation, over the insulation a concrete screed, a vapor barrier and finally the finishing layer/s (ceramic tiles, wood,...)

For this solution is necessary to have enough ceiling height because it could be reduced and (in general) it could be necessary to adapt the height of all doors and to raise parapets and electric sockets.

</td></tr>
</table>

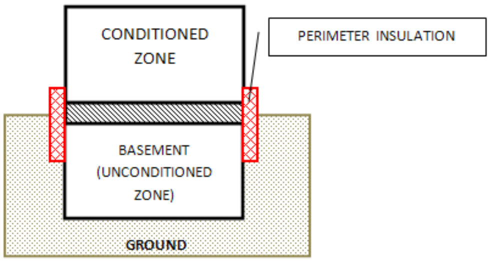
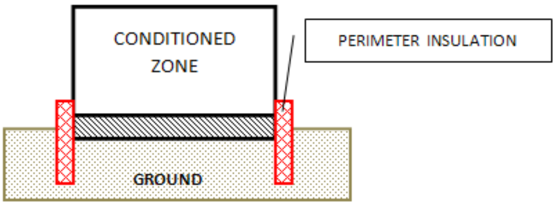
Source: *CENER*	(*) Nominal Thermal Conductivity of the new insulation λ=0,034 W/m*K
Perimeter, installation of vertical perimeter insulation   *Source*: *CENER*	This measure includes the installation of vertical perimeter insulation on the façade to a depth of approximately 1m (according to the plans). For this solution it is necessary to make a trench at a sufficient depth, insert the insulation panels over the waterproofing layer, add a drainage layer, perimeter drainage pipe and finally fill the trench with rockfill.

Table 10: Sealing measures.

EEM	**Description**
Sealing, improvement for traditional masonry (brick/concrete constructions).	This measure includes the addition of a new internal plaster layer (min 1 cm) over the existing + air stop bands in correspondence of the connection element ("wall-ceiling", "wall-floor", "wall-wall (angular)") + air stop elements where the building plant cross the building element (pipe, ventilation, etc...) + sealing electric boxes and tubes. After works, verification costs are applicable (e.g. blower door test, Air Leakage Testing Audits, etc.).
Sealing, improvement for wood/prefabricated wall.	This measure consists of replacement the internal layer + air stop bands in correspondence of the connection element ("wall-ceiling", "wall-floor", "wall-wall (angular)") + air stop elements where the building plant cross the building element (pipe, ventilation, etc...) + sealing electric boxes and tubes. After works, verification costs are applicable (e.g. blower door test, Air Leakage Testing Audits, etc.).

2.3.1.1.1. Windows measures

Table 11: Windows measures.

<table>
<tr><th>EEM</th><th>Description</th></tr>
<tr><td>Window glazing substitution</td><td>
This measure includes the replacement of the glazing of the existing windows where the frame allows (more usually in wooden frames), by double-glazing maintaining the frames that are in proper operating conditions.
Variants characteristics of glazing. Replacement of glazing in windows:
<table>
<tr><th>Variants</th><th>U_g (W/m^2K)</th><th>g</th><th>T_{vis}</th></tr>
<tr><td>Double glass with air cavity (16mm)</td><td>2,7</td><td>0,78</td><td>0,82</td></tr>
<tr><td>Double glass with air cavity (16mm) and a low-e glass</td><td>1,4</td><td>0,61</td><td>0,79</td></tr>
</table>
</td></tr>
<tr><td>Window replacement.</td><td>
This measure includes the replacement of old windows by windows with high or better energy efficiency properties.
Variants characteristics of replacement of windows:
<table>
<tr><th>Variants</th><th>U_g (W/m^2K)</th><th>g</th><th>T_{vis}</th><th>U_f (W/m^2K)</th><th>Air Per. (m^3/hm^2)</th></tr>
<tr><td>Double glass with air cavity (16mm)</td><td>2,7</td><td>0,78</td><td>0,82</td><td>2,2</td><td>≤27</td></tr>
<tr><td>Double glass with air cavity (16mm) and a low-e glass</td><td>1,4</td><td>0,61</td><td>0,79</td><td>1,4</td><td>≤9</td></tr>
<tr><td>Double glass with argon cavity (16mm) and a low-e glass</td><td>1,1</td><td>0,61</td><td>0,79</td><td>1,4</td><td>≤9</td></tr>
<tr><td>Double glass with argon cavity (16mm), solar control and a low-e glass</td><td>1,1</td><td>0,41</td><td>0,68</td><td>1,4</td><td>≤9</td></tr>
<tr><td>Triple glass with argon cavity (16mm) and a low-e glass</td><td>0,9</td><td>0,56</td><td>0,73</td><td>1</td><td>≤3</td></tr>
<tr><td>Triple glass with argon cavity (16mm), solar control and a low-e glass</td><td>0,8</td><td>0,26</td><td>0,55</td><td>1</td><td>≤3</td></tr>
<tr><td>Triple glass with argon cavity (18mm) and a low-e glass</td><td>0,65</td><td>0,6</td><td>0,733</td><td>0,95</td><td>≤3</td></tr>
</table>
</td></tr>
<tr><td>Double window (adding a new window to the existing).</td><td>This measure includes the addition of a new window in the wall thickness maintaining the existing. The new window will be installed in the opposite alignment of the wall to the existing one.</td></tr>
<tr><td>Windows, joints sealed.</td><td>The weather-stripping around the perimeter of the frame seals the window, eliminating drafts and creating a thermal barrier.</td></tr>
</table>

Table 12: Solar shading devices

EEM	Description
Drop-arm awnings installation.  *Source: CENER.*	Drop-arm awnings offer the ideal solution for providing shade for windows and balconies only in summer periods. Opacity coefficient of the awning material 0,7.
External window blinds.  *Source:[Shadefactor 2021]*	
BACS, automation of solar shading devices.	This measure includes the installation of electrical motors, electrical control for shading devices, solar radiation sensors, etc.
Solar Control Film.	This measure includes the installation of a solar control film bonded on the window glass in order to reduce the cooling demand of buildings by reducing solar gains.

Table 13: Natural ventilation

EEM	Description
Automatised natural ventilation	This solution includes electrical motors, electrical control for opening, internal partitions grids, outdoor temperature sensor, etc.

 Source: CENER.	

2.3.2. Heating and cooling systems

This subsection is focused on the definition of energy efficiency measures concerning the energy performance of the heating and cooling systems.

Table 14: Generation measures

EEM	Description
Condensing gas boiler	Replacement of the old heating generation system by condensing gas boiler(s). This measure includes the replacement of generator (including burner), fittings, generator pumps, smoke evacuation system and basements.
Biomass boiler	Installation of biomass boiler(s) to meet heating loads. This measure includes installation of generator (including burner), fittings, internal pumps, smoke evacuation system, basements, and storage pellet silo.
High efficiency heat pump	Replacement of the old heating/cooling generation system by a heat pump(s) (Air to water technology) with high COP (heating) and EER (cooling). Individual (P<35kW) or collective installation (P>35kW). This measure includes the installation of the heat pump, internal pumps, condensate tank and evacuation systems, basements, control system.
Rooftop	Installation of a Rooftop unit(s) including the whole HVAC system; heating, cooling and ventilation, based on air-to-air heat pump technology. Typical application: retail & department stores, warehouses & Industry This measure includes the installation of the equipment(s), installation, wiring, air duct connections, control integration and configuration.
CHP - Combined Heat and Power	Installation of a cogeneration equipment (gas turbine or I.C. engine) to meet DHW loads and/or a fraction of heating loads. This measure includes the installation of the equipment, fittings, internal pumps, smoke evacuation system, basements, electrical wiring, metering. Cogeneration is the

	sequential generation of two different forms of useful energy from a single primary energy source. The two different forms of energy in this case are electrical energy and thermal energy.
GSHP - Ground Source Heat Pump	Installation of a ground source heat pump system (water to water, with high COP) to meet base thermal load. This measure includes the installation of the heat pump, internal pumps, condensate tank and evacuation systems, basements, borehole perforation (considering double U pipes with lengths according to the power plant and climatic severity).
VRF - Variable Refrigerant Flow	Installation of a high efficiency VRF system. This measure includes the installation of the equipments, apart from exterior and interior units, pipes and control system.
CO2 Heat Pump (Air-Water) for DHW	This measure consists of the installation of a CO_2 heat pump for DHW. COP>3 for Outdoors Tª:0ºC, water in Tª=10º, water production Tª=70ºC. This measure includes the installation of the heat pump, internal pumps, storage tank, basements and control system.
Solar thermal system	Solar Thermal system to meet DHW loads and/or a fraction of heating loads. This measure includes the installation of a solar thermal system, apart from thermal panels, storage, circulation pumps, and expansion vessel.
Connection to a district heating	This measure includes the typical initial costs for getting connected to a district heating system
Air cooled water chiller	Replacement of the old cooling generation system by a chiller with medium EER. This measure includes the installation of the chiller, internal pumps, condensate tank and evacuation systems and basements.
Water cooled water chiller	Cooling generation system based on chiller(s) with high EER (including cooling tower). This measure includes the installation of the chiller, internal pumps, condensate tank and evacuation systems, basements, cooling tower…

Table 15: Emission measures

EEM	Description
Installation of insulated radiant floor emission system	It consists of preformed panel including piping, insulation material (2-4 cm) for slabs facing to unheated rooms.
Installation of insulated radiant ceiling system.	It consist of preformed panel including piping, insulation material (2-4

	cm) for slabs facing to unheated rooms.
Installation of radiators emission system.	It consists of radiator and valves and piping if it is necessary.
Installation of Fan coils emission system.	It consists of fan coil, fixing systems.
Installation of Air diffusers emission system.	It consists of air diffusers, air ducts, air handling units, false ceiling.
Installation of active chiller beams.	It consist of chiller beams, air ducts, air handling units, false ceiling.

Table 16: Distribution measures

EEM	Description
Pipe insulation.	Insulation of current water pipe distribution according to current regulation requirements (xx cm of insulation material according to pipe diameter)
Substitution of the old column distribution by a bi-pipe installation (ring distribution).	Substitution of the current column distribution system (pipes) by a ring (bi-pipe) distribution system. This allows the improvement of the hydraulic balance, better heat distribution and better control.

Table 17: Control measures

EEM	Description
Installation of a climatic control system.	It consists of 2 temperature sensors, a 3-way mixing valve with actuator, control system (supply temperature will vary according to outside temperature).
Installation of Thermostatic Radiator Valves (TRVs).	Installation of the equipment and installation of a TRV per radiator. The valve turns on and off the radiator based on the temperature of the room.
Installation of a indoor thermostatic control system.	This measure consists of the installation of the room thermostat, a two 2-way valve with servo (system is on according to the thermostat set point temperature).
Thermal Energy metering.	This measure consists of installation of a compact thermal energy meter for heating/cooling systems, including plumbing, wiring and monitoring platform or connection to a BMS.

2.3.3. Mechanical ventilation system

This section is focused on the definition of energy efficiency measures concerning the energy performance of mechanical ventilation systems.

2.3.3.1. Heat recovery.

It includes the installation of high-efficient heat recovery unit/s and fixing system (Note that installing a heat recovery unit requires extraction and impulsion air flow ducts. If the system of ducts doesn't exist on the baseline building, next measure "air distribution systems" should be added in order to evaluate the global cost of the measure).

2.3.3.2. Air distribution system

This measure includes the installation of the ducts and grilles to do the distribution of mechanical ventilation system (Notice that a "heat recovery installation" requires extraction and impulsion air flow ducts).

2.3.3.3. Control

Table 18: Ventilation systems. Control measures

EEM	Description
Free-cooling	This measure includes the installation of the specific control system, apart from the sensors and actuators that are needed in order to allow variable outdoors air flow rate according to energy need and air temperature.
Variable outdoors air rate according to building occupancy	This measure includes the installation of the specific control system, apart from the sensors and actuators that are needed in order to allow variable outdoors air flow rate according to occupancy.

2.3.4. Auxiliary systems

This subsection is focused on the definition of energy efficiency measures concerning the auxiliary systems.

2.3.4.1. Pumps

This measure consists of removing old pumps and installing new equipments with high efficiency rate.

2.3.4.2. Fans

This measure consists of rremoving old fans and installing new equipments with high efficiency rate.

2.3.5. Lighting systems

This subsection is focused on the definition of energy efficiency measures concerning the improvement of the energy performance of the lighting systems.

Table 19: Lighting systems. Equipment efficiency

EEM	Description
Substitution of old lamps (e.g. incandescescent, fluorescent, halogen...) by LED lamps compatible with the current luminaires.	
Remove the old luminaires and install new luminaires for LED lamps	This measure includes the installation of new luminaires for LED lamps with electronic ballasts (apart from LED lamps). For systems which provides 500-550 lux per m2, the new devices will be compatible with daylight dimming control.

Table 20: Lighting systems. Control

EEM	Description
Switch on/off by Occupancy.	This measure includes the installation of occupancy sensors and electrical wiring.
Automatic continuous daylight dimming in daylighted areas.	This measure includes the installation of sensors, electrical wiring, and configuration.

2.3.6. Smart technologies

This subsection is focused on the inclusion of RES-based technologies.

Table 21: Smart technologies. On-site electricity production

EEM	Description
PV Installation on the roof.  *Source: [PV magazine 2021]*	With regular inverter: Installation of a photovoltaic system on the roof, including PV panels, support structure, electricity meters, electrical wiring and a regular inverter. With smart inverter: Installation of a photovoltaic system on the roof, including PV panels, support structure, electricity meters, electrical wiring and a smart inverter with the possibility of configuration and control of grid-home-storage.

BIPV Installation of a Building Integrated PhotoVoltaics system (BIPV).  *Source: [SPW 2021]*	This measure includes the installation of the integrated PV into the building element (glass and/or roof), including material, inverter, wiring, etc.
PVT Installation of PVT system for simultaneously generation of electricity and DHW.  *Source: [DS 2021]*	This measure includes the installation of PVT panels on the roof, storage, circulation pumps, expansion vessel, inverter, wiring, plumbing, etc.
Rooftop wind turbine to generate electricity  *Rooftop wind turbine in residential building Source: [EXCESS project 2021]*	This measure includes the installation of the wind turbine, support structure, electricity meter and electrical wiring.

This subsection is focused on the definition of energy efficiency measures concerning the inclusion of energy storage equipments.

Table 22: Smart technologies. Energy storage

EEM	Description
Stationary battery OPzS	This measure consists of the installation of electric batterie(s) for electric storage and optimization of the electricity use and energy tariffs in combination with on-site RES, based on OPzS technology. This measure includes the installation of electric battery/ies, installation, electric wiring and electronic control.
Lithium-ion battery.	This measure consists of the installation of electric batterie(s) for electric storage and optimization of the electricity use and energy tariffs in combination with on-site RES, based on Li ion technology. This measure includes the installation of electric battery/ies, installation, electric wiring and electronic control.

2.3.6.1. DSM

This subsection is focused on the definition of energy efficiency measures concerning the inclusion DSM devices.

Table 23: Smart technologies. DSM

EEM	Description
Electricity meter	This measure consists of the installation an electricity meter per consumption circuit (e.g. lighting, appliances…), including device, installation and wiring.
Electrical contactor (with switching/Measurement functionality)	This measure consists of the installation of an electric contactor (normally open) for switching an electrical circuit on or off, including device, installation, and configuration. (Notice that the proportionally cost of the BMS of which it takes part will be considered).

2.3.6.2. BMS

This measure consists of the installation of BMS (management level) which includes the PC server, software, configuration, wiring, communications, etc.

2.3.7. E-vehicle charging infrastructure

This subsection is focused on the inclusion of e-vehicle charging infrastructure in the building.

Table 24: E-vehicle charging infrastructure.

EEM	Description
EV charging point – Wallbox.	This measure consists of the installation of an EV charging point including electric wiring, metering and control. CA Aprox. 5kW. Connector Type 1 (Yazaki) or Type 2

	(Mennekes).
V2G/V2H charging point.	This measure consists of the installation of a V2G or V2H EV charging point including electric wiring, metering and control. Charging outputs: DC 10kW. Connector CHAdeMO or Combo CCS.
EV fast charging point.	This measure consists of the installation of a EV fast charging point, including electric wiring, meters, and control. CC Aprox. 50kW, connector CHAdeMo and/or Combo CCS.

3. IMPLEMENTATION

In order to demonstrate the implementation of the cost optimal methodology, two case studies (new residential building and renovation of tertiary building) will be described in this section.

3.1. New buildings

3.1.1. Case study 1: Residential building

3.1.1.1. Introduction

This fist case study consists of a new residential building located in Madrid (Spain). The project implies a large multifamily block with around 40.000m^2 distributed in 8 floors, including 334 dwellings.

Based on an architectural predesign project, different alternative packages of energy measures related to the building envelope, thermal systems and renewable energy technologies has been proposed and compared from the optimal cost-effective perspective.

3.1.1.2. Baseline building

Baseline building in this case would be the preliminary design project, the baseline against to which compare the energy savings associated with the packages of energy efficiency measures.

Open Studio tool has been used to build the model and EnergyPlus has been the dynamic calculation engine to evaluate during 8760 yearly hours the energy performance of the baseline building and different combinations of the energy efficiency measures.

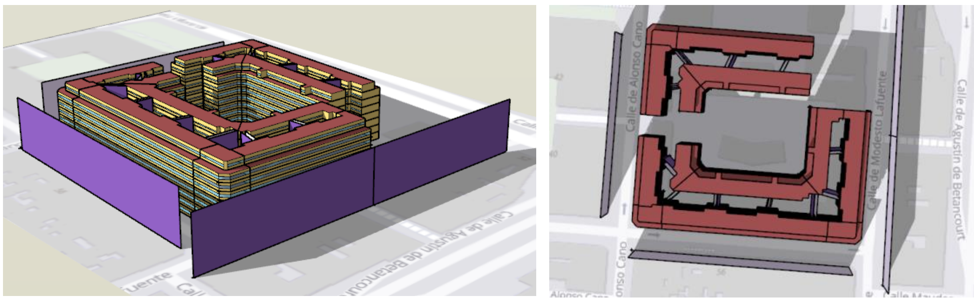


Figure 9: View of the 3D model. New residential building case study.

Table 25 includes the description of the different elements of the baseline building (variants WL-1, R-1, W-1 for the building envelope, HVAC-0 and RES-1) which non-renewable primary energy is in 57.82 kW*h/ m^2*year and its global cost for 30 years is 272.54 €/m2. Figure 38 shows additional information regarding energy needs and energy use breakdown for the baseline building.

3.1.1.3. Energy Efficiency Measures and packages of EEMs

The following table shows the individual EEMs proposed for the residential building and the characterization of the baseline building.

Table 25: List of EEMs. New residential building case study.

1. Thermal insulation in façades	1	Baseline building: 10 cm of external thermal insulation (EIFS) with thermal conductivity of 0.035 W / m²K
	2	10 cm of external thermal insulation (EIFS) with thermal conductivity of 0.021 W / m²K
	3	15 cm of external thermal insulation (EIFS) with thermal conductivity of 0.021 W / m²K
	4	The placement of the insulation is changed (10 cm on the outside layer and 5cm on the inside one) to check the impact of the thermal inertia of the façade.
2. Thermal insulation in roofs	1	Baseline building: 10 cm of external thermal insulation with thermal conductivity of 0.035 W / m²K
	2	10 cm of external thermal insulation with thermal conductivity of 0.021 W / m²K
	3	15 cm of external thermal insulation with thermal conductivity of 0.021 W / m²K
	4	20 cm of external thermal insulation with thermal conductivity of 0.021 W / m²K
3. High energy efficient windows	1	Baseline building: Double glazing with air cavity and a low-e glass; aluminium frame with thermal break
	2	Triple glazing with two argon cavity; PVC frame with at least 6 cavities
High energy efficient thermal systems (HVAC)	0	Baseline building: Heating: Centralized condensation gas boiler system DHW: Gas boiler Cooling: Individual equipments AC split type
	1	Heating: Centralized condensation gas boiler system DHW: Gas boiler Cooling: Chiller or roof air-water heat pumps (centralized system)
	2	Heating and cooling: Roof air-water high-efficiency heat pumps DHW: Roof CO_2 high-efficiency heat pumps optimized for DHW production
	3	Heating, cooling and DHW: Geothermal high-efficiency heat pumps (water-water), placed in the basement and connected to vertical boreholes under the building (ground heat exchanger).

	4	Centralized mixed solution: Geothermal 60% design power + condensation gas boiler (40% heating design power) + chiller (40% cooling design power)
	5	Centralized mixed solution: Geothermal 60% design power + Heat pumps (40% heating design power)
Renewable energy contribution (RES)	1	Baseline building: Solar thermal installation for covering 70% of the DHW according, to the minimum share established in the Technical Building Code
	2	PV roof installation (30º inclination, 223 kWp)
	3	PV roof installation (15º inclination, 311 kWp)

The individual measures have been combined in 448 packages of energy efficiency measures.

3.1.1.4. Analysis of energy consumptions and global costs

The calculation of the energy performance of the 448 packages of EEMs for the baseline buildings show for each case the associated annual energy needs, the operational profiles, the stationary energy performances of the different technologies, and the breakdown of energy use per service and energy carrier.

The following graphics show as an example, the shares of energy needs and the breakdown of energy use for the baseline building (package 1-1-1-0-1)

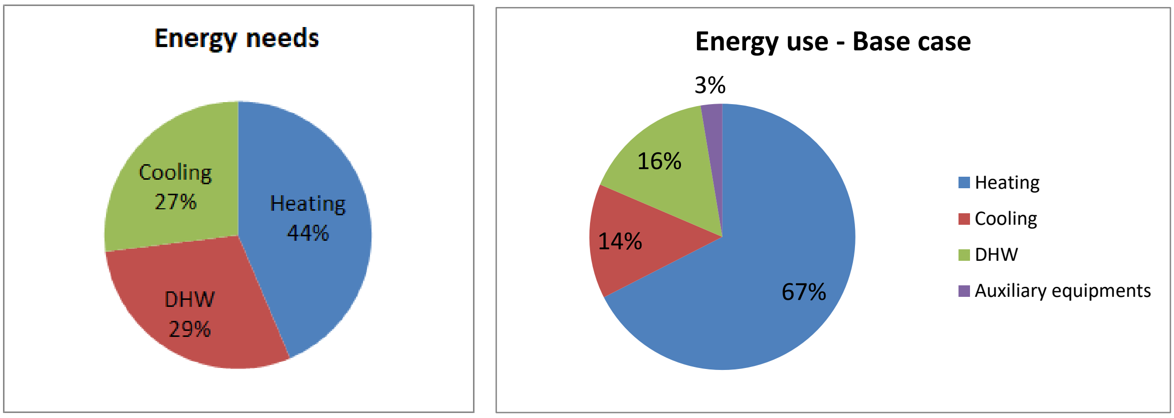


Figure 10: Energy needs and energy use breakdown of the baseline building. New residential building case study.

The final energy assessment by energy carrier of each package of measures allows the calculation in terms of the non-renewable primary energy indicator and the forecast in 30 years of the operational cost related to the energy use.

The minimum energy consumption is obtained from the combination of the 100% geothermal system (HVAC-3 measure) and the most efficient PV roof installation (RES-3 measure). 75% reduction is estimated respect to the baseline. 40% for the case without PV installation.

Considering the high investment cost of the geothermal system, a mixed solution with 60% of the design power and a cheaper one covering the 40% of the design power, will be more cost-effective.

3.1.1.5. Calculation of renewable energy contribution

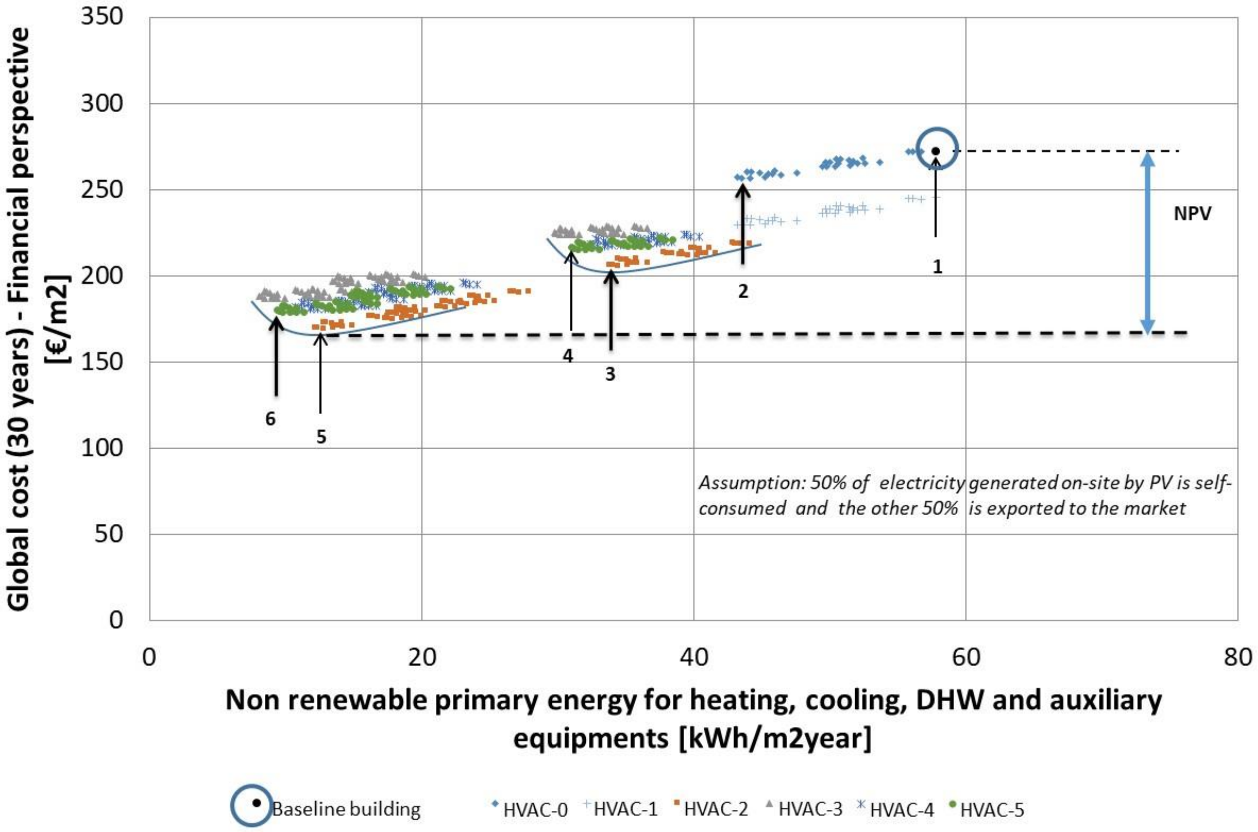
As already mentioned, three EEM variants for RES contribution have been considered. The first one, (RES-1) consist of the 70% solar thermal energy of the DHW demand, according to the Spanish TBC. The other two variants (RES-2 and RES-3) include on-site PV installations for self-consumption and paid delivery of the surplus of energy to the grid.

According the Spanish TBC, the minimum solar thermal share for DHW is required when conventional fossil fuel technologies are used for heat generation (heating and DHW), such as condensation gas boilers. However, the alternative option of using high-performance aerothermal and geothermal systems is possible if the same reduction of CO_2 emissions and the primary energy is achieved.

In conclusion, packages of EEMs including conventional technologies require additional solar thermal installation whereas packages including aerothermal or geothermal systems do not require additional installations. This alternative option combine easily with PV installations. This improves significantly the global energy performance of the integrated system.

3.1.1.6. Cost-optimal level: minimum global cost

The following graphic represents the non-renewable primary energy of the 448 implemented packages of EEMs and the associated global costs which includes the investment costs and the used energy costs during the 30 years of life span.



1-Baseline building; 2, 3, 5: cost-optimal points of each EEMs package families; 2, 6, 4: nZEB points of each EEMs package families

Figure 11: Analysis of energy consumptions and global costs graph. New residential building case study.

The cost-optimal level (minimum global cost) is obtained with the following set o EEMs:

- FAÇADES (WL-3 measure): 15 cm of external thermal insulation (EIFS) with thermal conductivity of 0.021 W / m2K

- ROOFs (R-2 or 3 measure): 10 or 15 cm of external thermal insulation with thermal conductivity of 0.021 W / m2K
- WINDOWS (W-2 measure): Triple glazing with two argon cavity and PVC frame with 6 cavities (U<1W/m2K)
- THERMAL SYSTEM (HVAC -2 measure): Air-water heat pump for heating and cooling and CO2 heat pumps for DHW
- RENEWABLE ENERGY CONTRIBUTION (RES-3 measure): PV roof installation (15º inclination, 311 kWp)

The minimum consumption solution among the studied options is associated with the following set of measures

- FAÇADES (WL-3 measure): 15 cm of external thermal insulation (EIFS) with thermal conductivity of 0.021 W / m2K
- ROOFs (R-3 or 2.4 measure): 15 or 20 cm of external thermal insulation with thermal conductivity of 0.021 W / m2K
- WINDOWS (W-2 measure): Triple glazing with two argon cavity and PVC frame with 6 cavities (U<1W/m2K)
- THERMAL SYSTEM (HVA-3 measure): Geothermal heat pump (water-water) for heating, cooling and DHW
- RENEWABLE ENERGY CONTRIBUTION (HVAC-3 measure): PV roof installation (15º inclination, 311 kWp)

3.1.1.7. Conclusions

From a qualitative point of view, the different technologies present certain strengths and weaknesses (e.g. aesthetically pleasing, maintenance, roof space, maintenance, one or more energy contracts, etc.).

From a strictly quantitative point of view, derived from the evaluation carried out using the cost-optimal methodology, the following insights and conclusions are collected:

Only the building envelope -walls, roofs and windows- improvement (preserving the reference thermal system) provides an overall global cost reduction of 5.7% and an estimated initial investment increase of € 607.341 (package 22 in table below).

Table 26: Comparative analysis of packages of EEMs related to the improvement of the building envelope. New residential building case study

	1	2	3	4	5	Non renewable primary energy	GLOBAL COSTS	Increase of initial investment	Energy costs savings 30 years	NPV
	Walls	Roofs	Windows	HVAC	RES	kWh/m2year	€/m2 30years	€	€	€
1	1	1	1	0	1	57.82	272.54			
5	1	3	1	0	1	56.11	272.09	117,621.00 €	135,034.83 €	17,413.83 €
2	1	1	2	0	1	51.77	266.36	329,340.59 €	565,301.23 €	235,960.64 €
6	1	3	2	0	1	50.03	265.81	446,961.59 €	703,876.52 €	256,914.92 €
17	3	1	1	0	1	51.47	263.99	160,380.00 €	486,783.14 €	326,403.14 €
21	3	3	1	0	1	49.78	263.58	278,001.00 €	620,321.03 €	342,320.03 €
18	3	1	2	0	1	45.26	257.45	489,720.59 €	1,065,977.36 €	576,256.77 €
22	3	3	2	0	1	43.52	256.90	607,341.59 €	1,204,547.11 €	597,205.52 €

Columns 1-5 shows the different EEM variants for Façades/Walls, Roofs, Windows, HAVC and RES described in Table 25.

Package 1 (WL-1, R-2, W-3, HVAC-4, RES-1) defines the baseline building. Its non-renewable primary energy is estimated in 57.82 kW*h/ m^2*year and its global cost for 30 years is 272.54 €/m2

Package 22 (WL-3, R-3, W-2, HVAC-0, RES-1) is one of the cost-optimal combination of EEMs, so its associated NVP is positive and reaches a value of 597.205€.

The following table shows the cost-optimal solutions regarding thermal installations and renewable energy systems (preserving the just mentioned cost-optimal envelope EEMs):

Table 27: Comparative analysis of packages of EEMs related to the improvement of thermal systems and RES contribution.

	1	2	3	4	5	Non renewable primary energy	GLOBAL COSTS	Increase of initial investment	Energy costs savings 30 years	NPV
	Walls	Roofs	Windows	HVAC	RES	kWh/m2year	€/m2 30years	€	€	€
374	3	3	2	5	0	31.20	216.21	-680,995.33 €	1,469,667.41 €	2,150,662.74 €
86	3	3	2	2	0	34.08	206.13	-1,374,334.21 €	1,161,157.82 €	2,535,492.02 €
406	3	3	2	5	2	14.93	188.27	-311,824.33 €	2,187,736.30 €	3,217,629.51 €
438	3	3	2	5	3	9.52	179.56	-167,086.33 €	2,426,353.78 €	3,550,126.47 €
118	3	3	2	2	2	17.81	178.19	-1,005,163.21 €	1,879,226.70 €	3,602,458.79 €
150	3	3	2	2	3	12.40	169.48	-860,425.21 €	2,117,844.18 €	3,934,955.75 €

All proposed alternative EEMs reduce the initial investment costs apart from providing an annual economic saving as they are more efficient solutions. As already explained, the reference thermal system implies the implementation of a solar thermal system to cover the standard minimum requirement, which entails higher investment costs comparing to the alternative solutions.

All proposed installation alternatives are based on centralized systems. In addition to reducing investment cost per installed kW, they allow to decrease maintenance costs and costs from energy supply contracts.

There are no disadvantages of a centralized system respect to an individual system thanks to the installation of individual meters (per dwelling) and thermostatic control devices required in the national regulation. On the contrary,

With the installation of individualization of consumption and thermostatic control required by RITE, individual control (at home level) of a centralized installation does not present any disadvantage compared to an individual installation. On the contrary, costs are optimized and energy performance is improved if the water distribution network and their discontinuities (cut-off valves, dilators ...) are properly isolated.

The option that presents the best economic result is the 100% aerothermal installation (HVAC-2 variants –cells in green-), with or without the support of a photovoltaic installation. However, this option involves a lot of equipment on roof.

Increasing the investment costs, it is possible to opt for a more efficient solution (HVAC-5 variants), which involves a mixed geothermal and aerothermal solution, reducing the roof space occupation.

The drop in investment prices in photovoltaic technology produced in recent years implies the viability and economic profitability of any installation, especially if it is possible to maximize energy self-consumption. Logically, although the photovoltaic installation represents an always favorable economic impact, it must be taken into account that it will occupy all or most of the roof area (approximately the same roof area with the solar thermal installation). Although the study considers the total occupation area of the roof, resulting high powers, it is possible to opt for a lower power installation in order to maintain the profitability of the investment.

As conclusion, given the size of the building and the great power of the systems (and its big influence in cost-optimal level), it is highly recommended a specific analysis of the investment costs of the two most favorable solutions and PV installation to make a final decision. Hence, detailed budgets of these thermal installations should be requested to building companies.

In the case of geothermal installations, the high cost of the vertical borehole heat exchangers field must be taken into account. The final dimensioning should be carried out after conducting a thermal response test of the ground by a specialized company to determine the thermal conductivity of the land.

3.2. Existing buildings

3.2.1. Case study 2: Tertiary building

3.2.1.1. Introduction

This section aims to describe the implementation of the cost-optimal methodology in an existing tertiary building located in Valencia (Spain).

The public office building, which is a listed one, is a five-story isolated construction with an area of 12.500 m^2, erected in the second half of the 18th century. Hence, the selection of the EEMs has to take into account the protection restrictions checked out by the Architectural Heritage Office.

3.2.1.2. Baseline building

This building is defined as the baseline against to which compare the energy and economic savings associated with the packages of energy efficiency measures. In this case, basic refurbishment works for aesthetic and/or functional reasons will be the reference combination of measures. This set incorporates the following ones:

- WALLS, ROOFS and FLOORS (variants 0 in Table 28): retrofitting of the building elements without the incorporation of thermal insulation.
- WINDOWS (variant 0): double glazing with 12mm air cavity (Uv= 2.8 W/m^2K, g=0.747 and Tvis=0.802)
- SOLAR PROTECTION (variant 0): light smooth interior roller blind.
- FORCED VENTILATION SYSTEM (variant 0): constant flow mechanical ventilation system according to national regulation.
- LIGHTING SYSTEM (variant 1): lighting system with VEEI = 2.5.
- THERMAL SYSTEMS (variant 1): Heat pump (air-water) and cooling chiller.
- RENEWABLE ENERGY SYSTEMS (variant 0): without incorporation of the photovoltaic installation.

Open Studio tool has been used to build the model. SGSave, based on Energy Plus v9.1, has been the dynamic software to evaluate during 8760 yearly hours the energy performance of the baseline building and the different combinations of the energy efficiency measures.

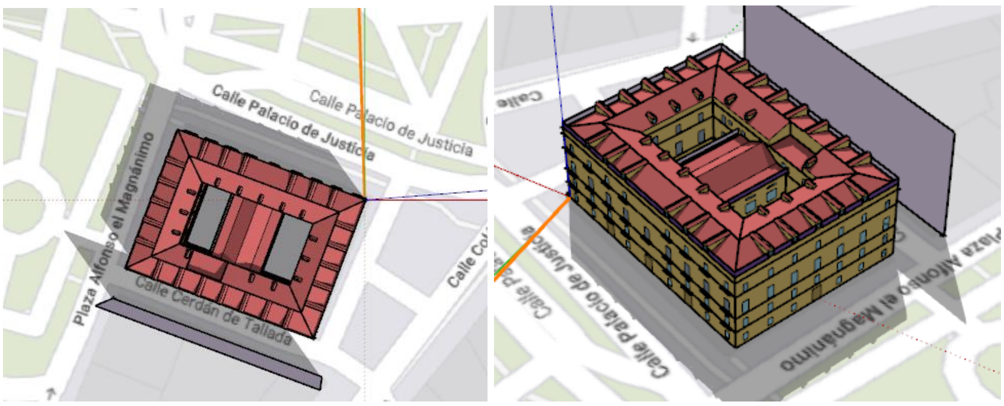


Figure 12: View of the 3D model. Existing tertiary building case study

Table 28 includes the description of the different elements of the baseline building (variants Env-1, W-0, SL-0, IT-1, Vent-0, LH-1, PV-0). Its non-renewable primary energy is estimated in 102.72 kW*h/ m^2*year and its global cost for 30 years is 470.58 €/m2.

3.2.1.3. Energy Efficiency Measures and packages of EEMs

Based on the architectural design project, different alternative packages of energy measures related to the building envelope, thermal systems and renewable energy technologies has been analyzed in order to propose a feasible cost-optimal packages of them. The intention is to include them in the detailed working project.

The following table shows the individual EEMs proposed for the refurbishment of the building. This includes the characterization of the baseline building as well.

Table 28: List of EEMs. Existing tertiary building case study

1. Thermal insulation in façades	0	Baseline building: basic refurbishment works for aesthetic and/or functional reasons without the incorporation of thermal insulation.
	1	Addition of 6 cm of thermal insulation in the inner layer of façades and internal walls in contact with uncondicionated spaces; λ=0.035 W / m^{2}K, according to TBC requirements.
	2	Addition of 8 cm of thermal insulation in the inner layer of façades and internal walls in contact with uncondicionated spaces; λ=0.035 W / m^{2}K
	3	Addition of 10 cm of thermal insulation in the inner layer of façades and internal walls in contact with uncondicionated spaces; λ=0.035 W / m^{2}K
2. Thermal insulation in roofs	0	Baseline building: basic refurbishment works for aesthetic and/or functional reasons without the incorporation of thermal insulation.
	1	Baseline building: Addition of 8 cm of thermal insulation in the inner layer of roofs; λ=0.035 W / m^{2}K, according to TBC requirements.
	2	Addition of 10 cm of thermal insulation in the inner layer of roofs; λ=0.035 W / m^{2}K
	3	Addition of 15 cm of thermal insulation in the inner layer of roofs; λ=0.035 W / m^{2}K
3. High energy efficient windows (W)	0	Baseline building: Double glazing with 12 mm air cavity and wooden frame (U_g=2.8035 W/m2K, g=0.747, T_{vis}=0.802, U_m=2.1 W/m_2K)
	1	Double low-e glazing with 14 mm air cavity and wooden frame (Ug=1.49 W/m^{2}K, g=0.61, Tvis=0.772, Um=2.1 W/m^{2}K)
	2	Double low-e glazing with 16 mm argon cavity and wooden frame (Ug=1.1 W/m^{2}K, g=0.61, Tvis=0.772, Um=2.1 W/m^{2}K)
	3	Double low-e glazing with 16 mm argon cavity + solar control, and wooden frame (Uv=1.1 W/m^{2}K, gv=0.41, Tvis=0.68, Um=2.1 W/m^{2}K)

	4	Triple e-low glazing with 16 mm argon cavity and wooden frame (Uv=0.9 W/m²K, gv=0.56, Tvis=0.73, Um=2.1 W/m²K)
	5	Triple e-low glazing with two argon cavity + solar control, and wooden frame (Uv=0.8 W/m²K, gv=0.26, Tvis=0.55, Um=2.1 W/m²K)
4. Internal solar protection (SL)	0	Baseline building: Clear smooth interior roller blind (mobile solar protection device on / off control)
	1	Iinterior roller blind with horizontal slats (mobile solar protection device on / off control + oriented slat to block direct solar radiation)
5.Ventilation (VEN)	0	Baseline building: Conventional ventilation system according to national regulation (12.5 l/s per person, considering 508 people capacity)
	1	Double constant-flow mechanical ventilation system with heat recovery (70% recovery performance)
6.Lighting (LH)	1	Baseline building: High-efficient Lighting system, VEEI= 2.5 (better than minimum required by national regulation)
	2	Very high-efficient lighting system, VEEI= 1.5
7.High energy efficient thermal systems (IT)	1	Baseline building: Heat pump (Carrier 30RQP380 model) and cooling chiller (Carrier 30KAV0500 model)
	2	4T Air-water Heat pump system with simultaneous production of heat and cooling (NECS-Q CA 1614 model)
8.Renewable energy contribution (PV)	0	Baseline building: Aerothermal system (energy extracted from the environment for heating and DHW
	1	47.12 kWp On-site PV installation for self-consumption 63.330 kW*h/year and delivery of surplus energy to the grid (124 PV modules, 248.9 m² field area)

Hence, the distribution of EEMs can be organized in the following families:

- Walls: Basic renovation + 3 variants (4 EEMs in total)
- Windows: 6 variants
- Dynamic solar protection : 2 variants
- Mechanical ventilation system: 2 variants
- Lighting system: 2 heat pump variants
- PV systems: 2 variants (with and without PV installation)

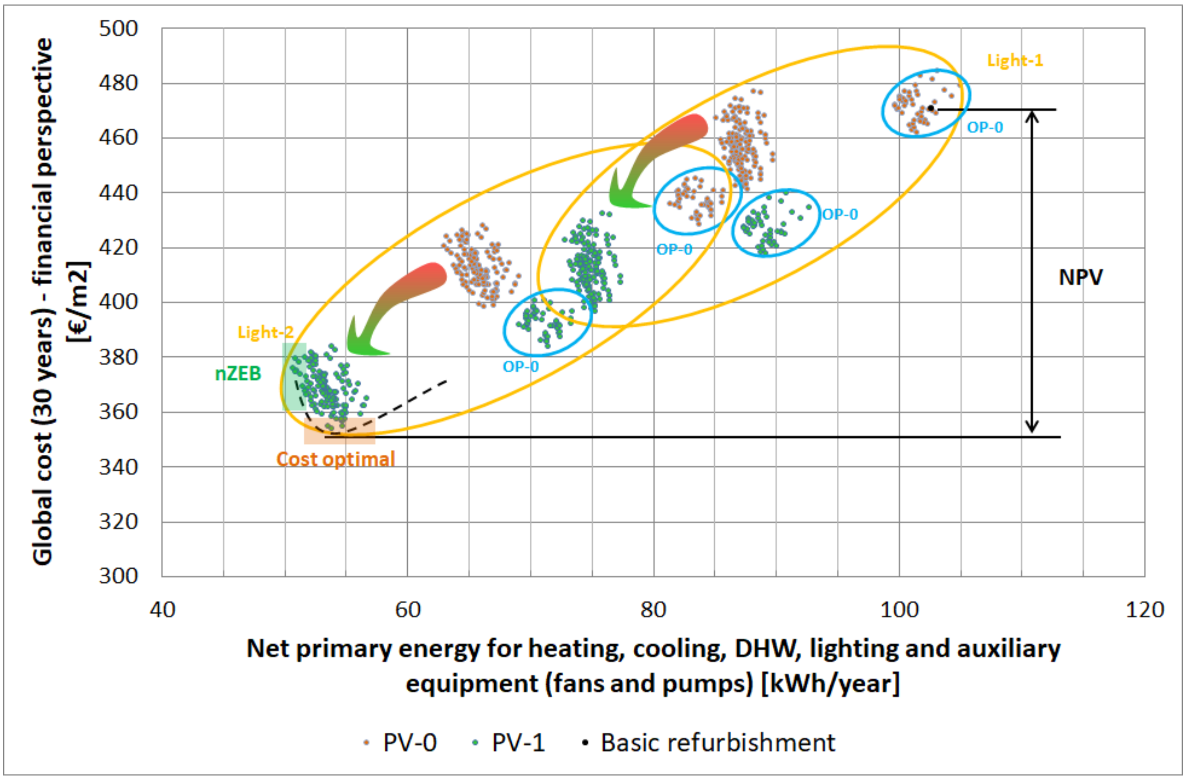
In total: **4 x 6 x 2 x 2 x 2 x 2 x 2 = 768 packs of EEMs**

3.2.1.4. Analysis of energy consumptions and global costs. Cost-optimal level: minimum global cost

Energy performance calculations for the quantitative comparison have been based on dynamic models capable of evaluating the loads on an hourly basis, under the operational profiles entered and the climate file considered (climate zone B3 of reference for Valencia).

The calculation procedure includes the non-renewable primary energy indicator [kW*h/m^{2}year] and the associated global cost indicator [€/m^2] for each case, which takes into account both the investment cost, the replacement cost and the operational cost, including the cost of energy during the calculation period (30 years), all updated to the current year.

The global graphic representation of the optimal-cost methodology applied to the analysis of the case study is shown in the following figure, where the 768 combinations of measures have been represented based on their consumption of non-renewable primary energy and their global cost:



Light-1 relates to the packages of measures which include variant 1 of Lighting EEMs; Light-2 relates to the packages of measures which include variant 2 of Lighting EEMs; OP-0 relates to the package of measures including variants 0 of Envelope measures –Façades, Roofs, Floors- which means no addition of thermal insulation.

Figure 13: Analysis of energy consumptions and global costs graph. Existing tertiary building case study

Two regions have been highlighted: in red the cost-optimal area and in green the minimum consumption area. Related packages of measures include a high-efficient lighting system (Light-2), and roof PV installation for self-consumption (PV-1) and addition of thermal insulation in the building envelope.

The combination called “basic retrofitting”, which serves as a reference point in the chart, has been defined as a basic refurbishment works for aesthetic or functional reasons.

The baseline (basic retrofitting or reference) implies a positive NPV of the investment, that is, the increase in investment necessary to rise the quality of the measures from an energy efficiency point of view, is amortized with the saving of the cost of the generating energy year after year during the calculation period, even generating positive cash flows (NPV> 0).

Minimum global cost or optimal-cost package of EEMs

The optimal-cost set of measures (minimum global cost), which justifies the investment based on the energy and economic savings that will occur throughout the building's lifetime, involves the following EEMs:

- WALLS, ROOFS, FLOORS (Variant 1): 6 cm of thermal insulation on the facade, 8cm on the roof and 4cm on the groundfloor element (λ=0.035 W/m*K).
- WINDOWS (Variant 3): Double low-e glazing with 16 mm argon cavity + solar control, and wooden frame (Uv=1.1 W/m^{2}K, gv=0.41, Tvis=0.68, Um=2.1 W/m^{2}K)
- SOLAR PROTECTION (Variant 1): Interior roller blind with horizontal slats
- FORCED VENTILATION INSTALLATION (Variant 0): constant flow mechanical ventilation system according to national regulation.
- LIGHTING SYSTEM (Variant 2): lighting installation with an average VEEI of 1.5.
- THERMAL SYSTEM (Variant 2): 4T Air-water Heat pump system with simultaneous production of heat and cooling.
- RES CONTRIBUTION (Variant 1): 47.12 kWp on-site PV installation

Minimum consumption or nZEB package of EEMs

The minimum consumption set of measures among the studied options is associated with the following package of EEMs:

- WALLS, ROOFS, FLOORS (Variant 3): 10 cm of thermal insulation on the facade, 15cm on the roof and 8cm on the groundfloor slab (λ=0,035 W/m*K).
- WINDOWS (Variant 3): Double low-e glazing with 16 mm argon cavity + solar control, and wooden frame (Uv=1.1 W/m^{2}K, gv=0.41, Tvis=0.68, Um=2.1 W/m^{2}K)
- SOLAR PROTECTION (Variant 0): light smooth interior roller blind.
- VENTILATION SYSTEM (Variant 1): Double constant-flow mechanical ventilation system with heat recovery (70% recovery performance)
- LIGHTING SYSTEM (Variant 2): lighting installation with an average VEEI of 1.5.
- THERMAL SYSTEM (Variant 1): Heat pump (air-water) and cooler chiller from Carrier.
- RES CONTRIBUTION(Variant 1): 47.12 kWp on-site PV installation

Comparative analysis of the investment profitability

Table 29: Comparative analysis of the cost-optimal package of EEMs vs minimum consumption package of EEMs

Nº	IT	Envelope	Windows	Solar	Vent.	Light	PV	Non-renewable PE	Global costs	TOTAL investment cost	Increase of initial investment costs	Energy cost savings 30 years	NPV
								kWh/m2year	€/m2 30 years	€/m2	€	€	€
1	1	0	0	0	0	1	0	102,72	470,58	118,88	-	-	-
556	1	3	3	0	1	2	1	50,59	376,27	179,01	603.999,08 €	1.679.543,19 €	947.248,83 €
654	2	1	3	1	0	2	1	53,80	354,38	153,96	352.372,31 €	1.584.908,58 €	1.167.059,06 €

Fist columns shows the different EEM variants for IT (Thermal systems), Envelope (Façades +Roofs), Windows, Solar devices, Ventilation, Lighting, and PV described in Table 28

.

After the implementation of the energy efficiency measures, the building's consumption could be reduced in terms of the non-renewable primary energy consumption indicator from 102.72 kW*h/m^2 year (Nº. 1, "basic retrofitting") to 53.80 kW*h/m^2 year which refers to the package of measures with the lowest overall cost (Nº654). The minimum consumption, 50.59 kW*h/m^{2}year, is obtained with the set of measures Nº556.

The minimum consumption package of measures implies an increase in the initial investment of 251.626,77 compared to the cost-optimal combination. The economic savings in the lifetime period of 30 years increases € 94,634.61.

Hence, the region of interest for decision making would be situated between these two cases, with a consumption of between 50.59 and 53.80 kW*h/m^{2}year and an interval in terms of global cost between 354.38 and 376.27 €/m^2.

Regarding final energy use, the following bar graph shows the positive effect of the implementation of the packages of measures related to cost-optimal combination and the cost minimum consumption one. All energy use consumptions decrease except the consumption of the primary air ventilation fans, which presents a slight increase in the case of minimum consumption package of EEMs, by incorporating double flow mechanical ventilation system with heat recovery.

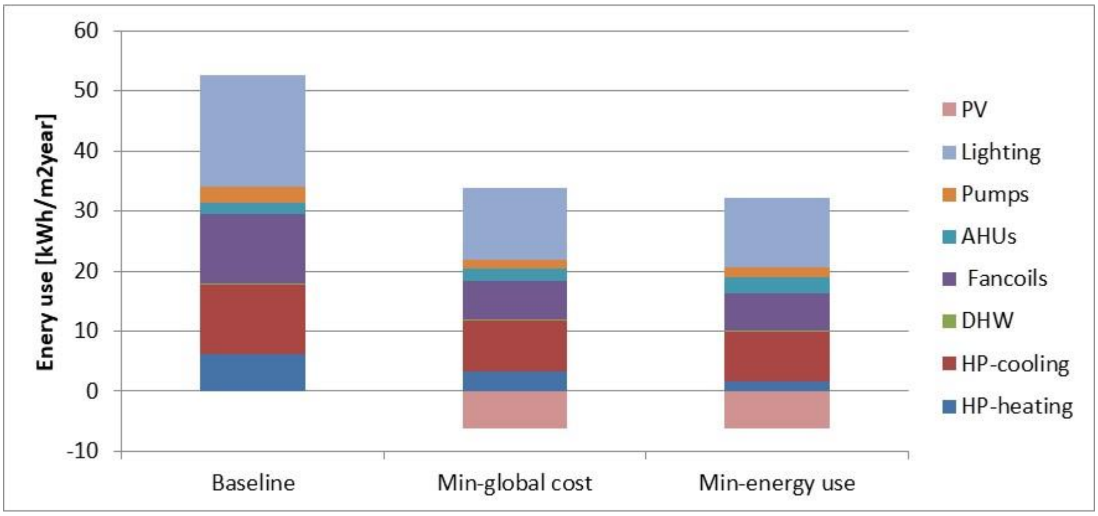


Figure 14: Breakdown in terms of energy use of the most relevant packages of EEMs

3.2.1.5. Conclusions

From a strictly financial point of view, the recommendation is <u>at least the implementation of the cost-optimal package of measures,</u> that is, the one that entails a greater payback on investment in energy efficiency (a higher NPV).

On the other hand, from a strictly energy and environmental point of view, the minimum consumption solution would be recommended, although this entails a higher initial investment and a lower payback.

Hence, the final recommendation should seek a compromise between these two aspects, finding economic viability based on the available budget and choosing a solution within this region (see table). The following table shows the package of measures that present the values in the recommended range (non-ren PE and Global Cost), with their associated economic characteristics.

Table 30: Comparative analysis of the recommended packages of EEMs

								Non-renewable PE	Global costs	TOTAL investment cost	Increase of initial investment costs (Cost-optimal related)	Energy cost savings 30 years (cost-optimal 654 related)
Nº	IT	Envelope	Windows	Solar	Vent.	Light	PV	kWh/m2year	€/m2 30 years	€/m2	€	€
654	2	1	3	1	0	2	1	53,80	354,38	153,96	-	-
650	2	1	3	0	0	2	1	53,44	355,26	155,92	19.646,84 €	10.856,29 €
462	1	1	3	1	0	2	1	54,13	357,51	155,26	13.055,85 €	-9.516,14 €
458	1	1	3	0	0	2	1	53,76	358,38	157,22	32.702,69 €	1.355,30 €
702	2	2	3	1	0	2	1	53,00	359,29	161,22	72.967,13 €	23.703,60 €
698	2	2	3	0	0	2	1	52,64	360,20	163,18	92.613,97 €	34.223,94 €
656	2	1	3	1	1	2	1	52,50	361,32	159,34	54.000,00 €	38.343,10 €
510	1	2	3	1	0	2	1	53,23	362,15	162,52	86.022,98 €	16.846,40 €
652	2	1	3	0	1	2	1	52,19	362,34	161,29	73.646,84 €	47.673,97 €
506	1	2	3	0	0	2	1	52,87	363,05	164,48	105.669,82 €	27.453,67 €
464	1	1	3	1	1	2	1	52,40	363,20	160,64	67.055,85 €	41.299,09 €
460	1	1	3	0	1	2	1	52,08	364,23	162,59	86.702,69 €	50.648,32 €
750	2	3	3	1	0	2	1	52,08	365,75	170,38	164.924,08 €	50.733,64 €
746	2	3	3	0	0	2	1	51,73	366,69	172,34	184.570,92 €	60.946,11 €
704	2	2	3	1	1	2	1	51,90	366,83	166,60	126.967,13 €	55.979,56 €
700	2	2	3	0	1	2	1	51,58	367,84	168,56	146.613,97 €	65.399,38 €
512	1	2	3	1	1	2	1	51,70	368,42	167,90	140.022,98 €	61.864,54 €
558	1	3	3	1	0	2	1	52,26	368,44	171,68	177.979,93 €	45.615,86 €
554	1	3	3	0	0	2	1	51,90	369,35	173,64	197.626,77 €	56.086,01 €
508	1	2	3	0	1	2	1	51,38	369,42	169,86	159.669,82 €	71.409,15 €
752	2	3	3	1	1	2	1	51,18	373,86	175,76	218.924,08 €	77.310,79 €
748	2	3	3	0	1	2	1	50,87	374,90	177,71	238.570,92 €	86.451,38 €
560	1	3	3	1	1	2	1	50,91	375,25	177,06	231.979,93 €	85.197,53 €
556	1	3	3	0	1	2	1	50,59	376,27	179,01	251.626,77 €	94.634,61 €

Finally, it must be taken into account that due to the quick technological development and the increasing regulatory requirements in buildings, as well as the long lifetime of a building, it is recommended to be as ambitious as possible in this sense, so that the building (and project) will not become obsolete from an energy point of view, in the short term.

4. LINK TO STAGED DEEP RENOVATION AND BUILDING RENOVATION PASSPORTS

There is a longstanding debate on whether the EU and Member States should favour one-step or staged deep renovation approaches. Both variants have their advantages and disadvantages.

One-step deep renovations can achieve energy savings faster than staged renovation, but excluding the possibility of staged renovations would increase the barrier for people to invest in any energy saving measures. This can be alleviate introducing supporting policies to guarantee the same level of savings over time, e.g. financial schemes, promoting staged deep renovation with the condition that the renovation follows the steps outlined in a roadmap, or a building renovation passport (BRP), and is completed within an agreed number of years [EU 2020].

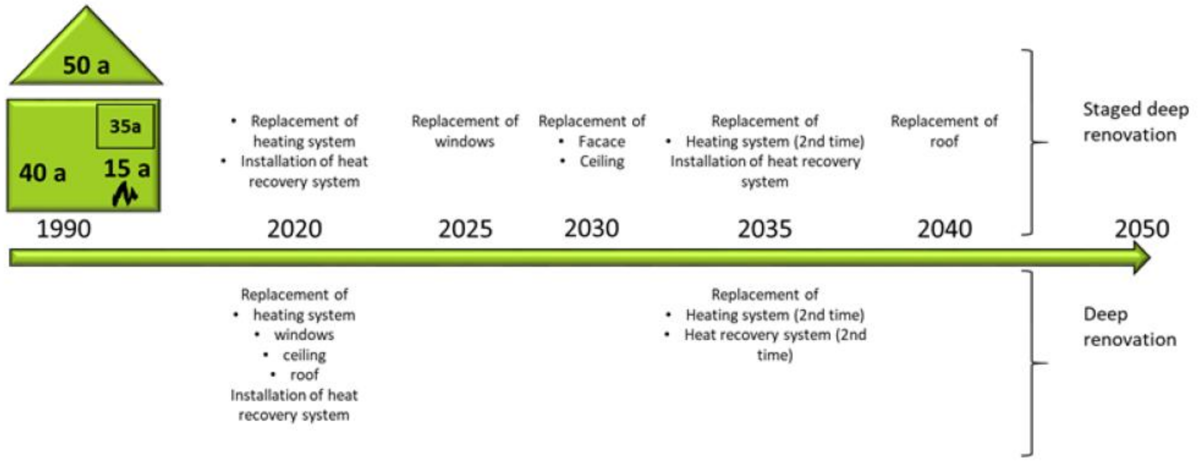


Figure 15: Comparison of one-step and staged renovation in a timeline. One-step renovations provide larger savings earlier; staged renovations use the components´ life spans completely and stretch investment costs. Source: [iBRoad 2020]

In the context of ePANACEA project, the first Regional Exploitation Board (REB) meetings, performed in the five geographical EU areas, highlighted that "tailored recommendations" from the EPC linked to a "roadmap to nZEB" is probably the most valuable information for end users [ePANACEA, D6.1 2020]. This statement was confirmed in the end-users workshops and interviews conducted in the target countries (Austria, Belgium, Finland, Greece, and Spain) plus Germany [ePANACEA, D3.2 2021].

In both cases (REB meetings and end-users workshops) the two EPC schemes developed under [ePANACEA, D2.1 2020] were presented: one user-related version, oriented to end users, with very visual graphics (including a "roadmap towards nZEB" chart, see Figure 35), and another, more technical version addressed authorities.

Although there is no common definition in the EU, according to [EPBD 2018/844/EU], the building renovation passport (BRP) is generally considered as an instrument that can stimulate cost-effective renovation in the form of a "long-term, step-by-step deep renovation roadmap for a specific building based on quality criteria, following an energy audit, and outlining relevant measures and renovations that could improve the energy performance".

iBRoad project provides an individual long-term strategy for building owners to reach optimum energy performance and thereby contribute to GHG reduction. The iBRoad Renovation Roadmap consists of a tailored renovation plan with a long-term horizon for deep step-by-step renovations [iBRoad 2020].

Figure 16: iBRoad Renovation Roadmap; example with three renovation steps. Source: [iBRoad 2020].

As introduced, financial constraints are the main reason for people not to renovate or why building owners choose less efficient solutions. The more successful building passports combines the renovation advice with financial support, legal requirements and/or communication campaigns [EU 2020]. The analysis of different actual schemes which share some characteristics and objectives with the building passport, show that aggregating and streamlining financial support (grants and loans) is required to make long-term solutions (i.e. deep renovations) viable [EU 2020].

The survey campaign launched within ePANACEA project reveals that the "estimate cost of investment per renovation measure/combination of renovation measures" is the third characteristic[7] which is considered important for a BRP from the respondents. The following one is "outlining the final energy saving after implementation of each renovation measure/combination of measures" [ePANACEA, D2.5 2021].

Hence, for the above-mentioned reasons, **EPCs are the basis for renovation roadmaps BRPs. They provide the concept, the calculation methods and the efficiency classes to assess the energy performance of buildings associated with the different individual or package of EEMs, and the inclusion of a financing assessment method, based on the cost-optimal methodology, is a necessary instrument for planning the staged deep renovations.**

[7] The first and second more successful characteristics are: "EPC should be issued by qualified expert" and "customised measures for the specific building".

Economic assessment should be integrated into staged deep renovation roadmaps and BRP, but the renovation plan should take into account the **occupant needs and specific situations** such as age, financial situation, composition of the household, etc. The renovation roadmap will therefore be specifically tailored to each homeowner (e.g. a young family or an elderly couple may have different needs and financial availability). **All this factors together with the relevant energy indicators (e.g. energy consumption, energy rating, etc.) included in the renovation roadmaps / BRPs will define the long-term duration of whole deep refurbishment plan, the number of the retrofitting steps and the sequence of the implementation of the EMMs packages or individual EEMs.**

ePANACEA provides an integrated energy efficiency building performance assessment based on actual energy consumptions which in combination with the optimization assessment from a financial perspective based on the cost-optimal methodology, enables the possibility of updating renovation roadmaps / BRPs in relation with the current occupant situation, it means, the possibility of providing dynamic roadmaps if necessary.

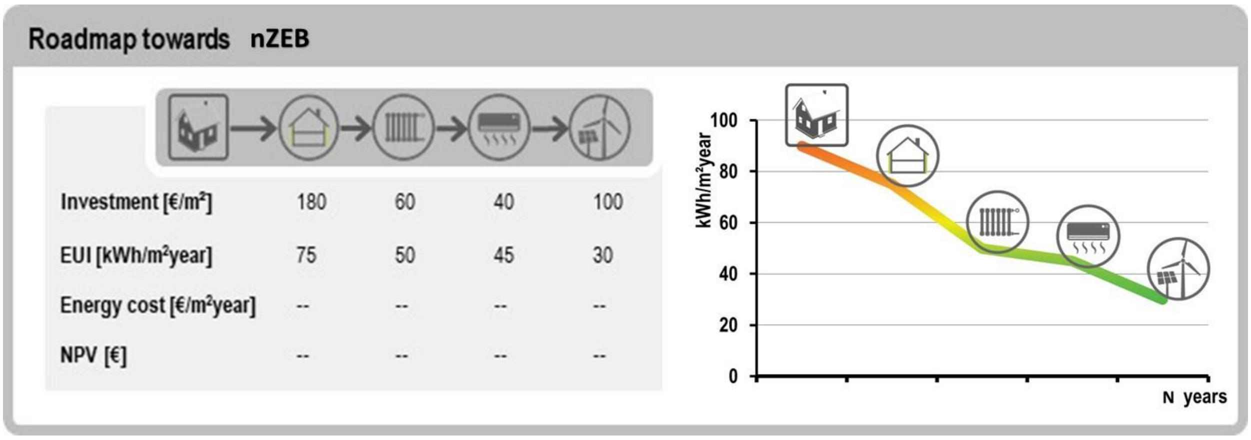


Figure 17: ePANACEA roadmap approach towards nZEB.

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