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Analisi LCA di edifici NZEB

Life Cycle Assessment on Nearly Zero Energy Buildings

UNIONE EUROPEA
Fondo Sociale Europeo
Fondo Europeo di Sviluppo Regionale

Agenzia per la Coesione Territoriale

MINISTERO DELL'AMBIENTE E DELLA TUTELA DEL TERRITORIO E DEL MARE

PON GOVERNANCE E CAPACITÀ ISTITUZIONALE 2014-2020

SOGESID SPA INGEGNERIA TERRITORIO AMBIENTE

Introduction

- The University of Roma Tre is part of the Project of National Interest (PRIN) titled ”Renovation of existing buildings in a NZEB vision”

- Network of researchers from 12 Italian universities divided in 6 operational units

- Work of Unit 5 will be centered on the Cost Optimality in energy audit of existing buildings.

Screenshot of the PRIN web site: www.nzebplatform.it

A NZEB is defined in Article 2(2) of the Directive 2010/31/EU (EPBD) as ”a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced onsite or nearby”.

Every member state has developed its own parameters for the characterization of national NZEB creating a non standardized technical definition at international level.

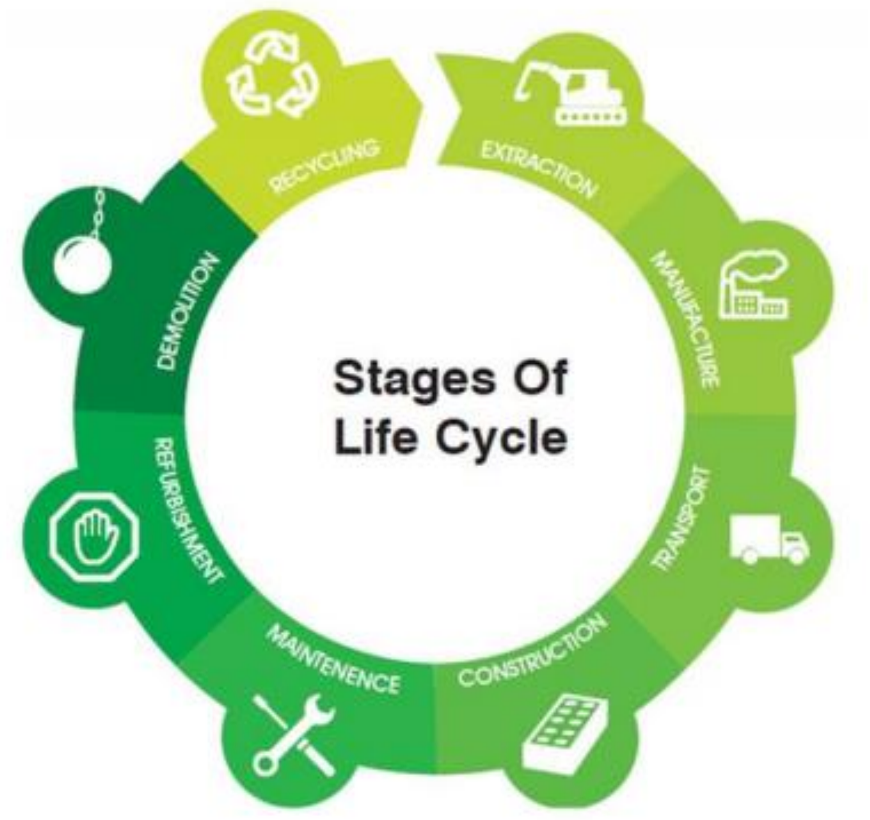
- Very high thermal insulation of the transparent and opaque envelope (about the half of the current law limits).
- Very high efficiency of the systems (heat pumps with high COP)
- Integration of renewable energy systems nearby the building (the building is considered the physical boundary)
- The building works in synergy with an energy grid (no energy storing systems have been considered in the study)

The improvement of the energy efficiency during the use phase of the buildings implies the introduction of extra-materials and renewable energy systems in the building that increase its Embodied Energy and Embodied Carbon.

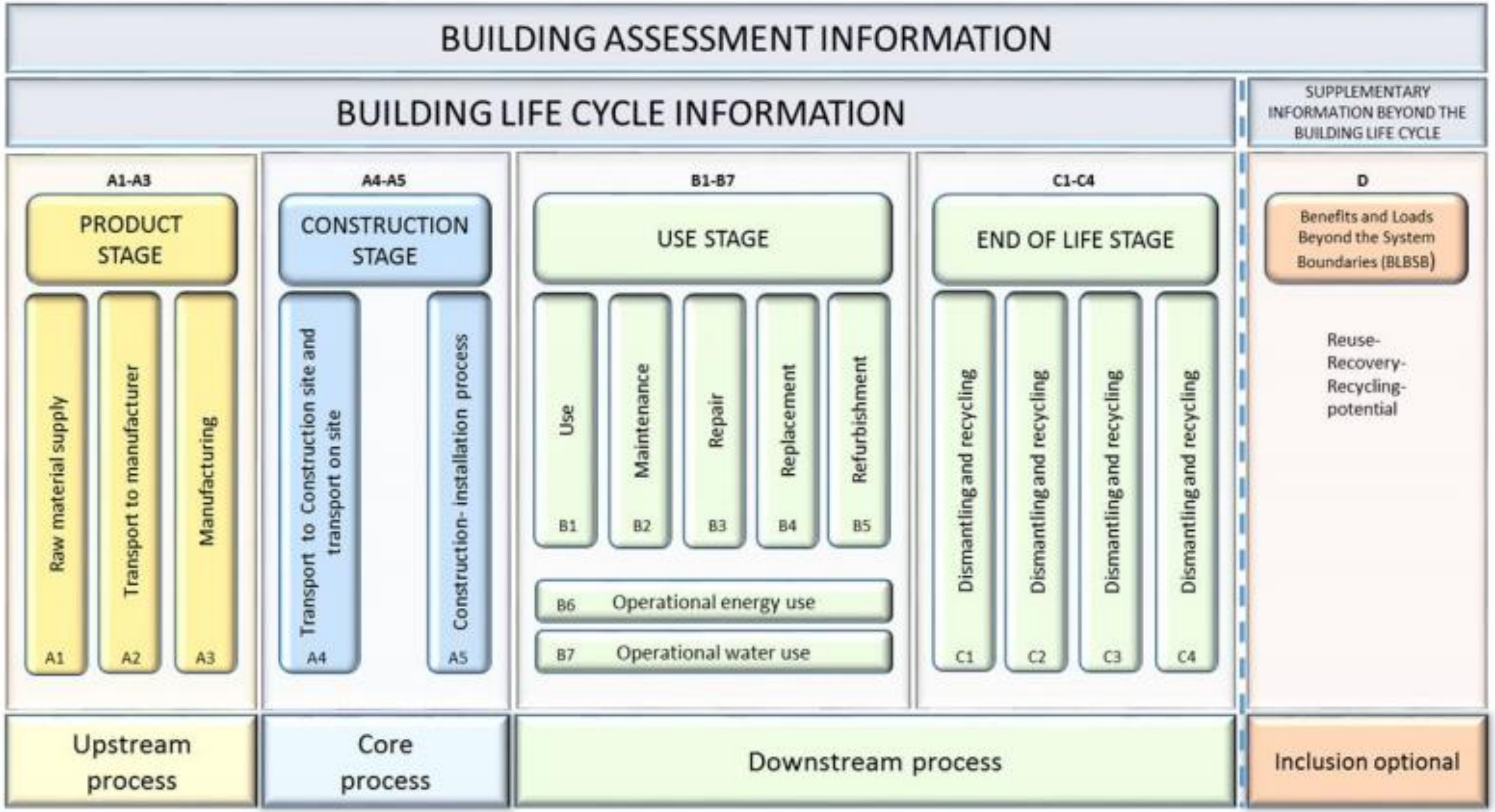
Potential Burden Shifting

The shift of burdens is the transfer of the environmental impacts caused by the use of operational energy to the materials and energy systems embodied in the building

In particular there is a transfer of the environmental burdens from the use stage to the construction, production and end-of life ones.



In order to consider the burden shifting an LCA approach is mandatory.



The Product Category Rules (PCR) indicate the previous LCA stages to be included in the analysis.

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Embodied Energy: definition

- The initial Embodied Energy includes all phases from the extraction of the raw material until it is ready to be delivered from the manufacturer.

- The recurring Embodied Energy is the energy used in maintaining and repairing the building over its effective life (stages B2-B5).

- The total Embodied Energy considered in this study includes the energy uses in producing, transporting, installing and finishing the building materials and components during initial erection as well as renovation of the building.

Embodied Carbon: definition

• The initial Embodied Carbon includes the emissions produced during all phases from the extraction of the raw material until it is ready to be delivered from the manufacturer.

• The recurring Embodied Carbon is the CO_2 emissions spread in maintaining and repairing of the building over its effective life (stages B2-B5).

• The total Embodied Carbon considered in this study includes the sum of the emissions spread in producing, transporting, installing and finishing the building materials and components during initial erection as well as renovation of the building.

In order to evaluate the environmental effectiveness of the NZEB retrofit of existing buildings two indicators are considered of interest:

The energy payback time (EPBT) is the ratio between the difference of initial Embodied Energy after and before the retrofit and the annual saved energy due to the retrofitting.

$$EPBT = \frac{E_i}{E_0}$$

The carbon payback time (CPBT) is the ratio between the difference of initial Embodied Carbon after and before the retrofit and the annual carbon reduction due to the retrofitting.

$$CPBT = \frac{M_i}{M_0}$$

Some payback times found in literature works.

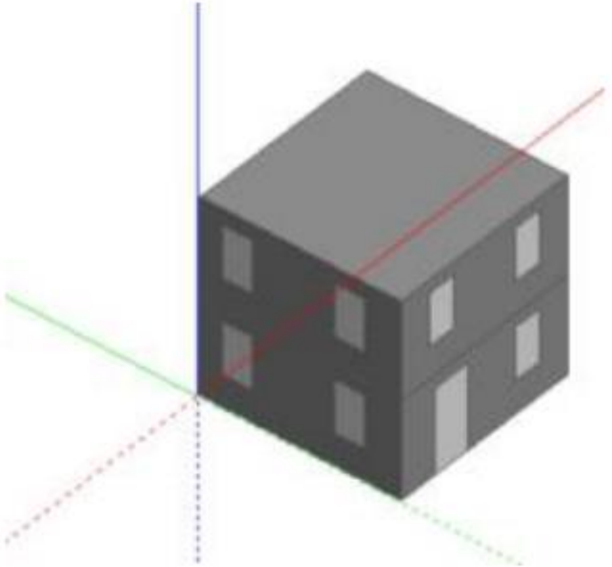
	EPBT	CPBT	Reference
Solar thermal panel glazed	-	12-30 months	Comodi et al. (2016)
Solar thermal panel unglazed	-	1-2 months	Comodi et al. (2016)
External overhangs	-	60 y	Huang et al. (2012)
22 kW photovoltaic system	7.5 y	5.2 y	Lu and Yang (2010)

The works are centred on building parts and very low literature about entire building retrofit has been found.

LCA of an ideal NZEB building

The case study

- Building of 6x6x6 meters dimensions
- Minimum living space and construction materials
- Minimum transparent surface (12,5% useful surface)
- Three Italian locations (Fiumicino, Turin, Palermo)
- Flat roof with photovoltaic systems integration
- Electricity the only energy vector (heating, cooling and DHW are guaranteed by an electric heat pump)



Two configurations have been considered:

- Reference building (D.M. 162 15th of July 2015)
- NZEB building

Fiumicino (Rome)	*Standard Building*	*NZEB Building*
U-value walls	0.38 W/m²K	0.18 W/m²K
U-value roof	0.36 W/m²K	0.18 W/m²K
U-value ground floor	0.40 W/m²K	0.40 W/m²K
U-value windows	2.40 W/m²K	0.80 W/m²K
Photovoltaic surface	0 m²	12 m²
Turin	*Standard Building*	*NZEB Building*
U-value walls	0.30 W/m²K	0.18 W/m²K
U-value roof	0.26 W/m²K	0.18 W/m²K
U-value ground floor	0.31 W/m²K	0.31 W/m²K
U-value windows	1.90 W/m²K	0.80 W/m²K
Photovoltaic surface	0 m²	16 m²
Palermo	*Standard Building*	*NZEB Building*
U-value walls	0.45 W/m²K	0.18 W/m²K
U-value roof	0.34 W/m²K	0.18 W/m²K
U-value ground floor	0.48 W/m²K	0.40 W/m²K
U-value windows	3.20 W/m²K	0.80 W/m²K
Photovoltaic surface	0 m²	12 m²

Every Location	*Standard Building*	*NZEB Building*
COP heating pump air-air (heating)	3.5	3.5
COP heating pump air-air (cooling)	3	3
COP heating pump air-air (DHW)	3	3
Lighting (200 lm per square meter in all rooms)	Traditional Fluorescent lamps	LED lamps

Differences between the two solutions:

• Increase of the envelope insulation.

• Substitution of traditional fluorescent lamp with LED ones.

• Introduction of the PV systems on the roof.

NZEB balance

- The energy consumptions have been determined using the dynamic code Energy Plus within the interface of Design Builder
- The photovoltaic production has been simulated with a hourly step using a literature formula and considering an average efficiency of 12%, 30° south inclination and employing the values of horizontal solar radiation of the weather data of Design Builder.

Fiumicino (Rome)	*Standard Building*	*NZEB Building*
Primary energy consumption	3008 kWh	1991 kWh
Photovoltaic production	-	2036 kWh
Turin	*Standard Building*	*NZEB Building*
Primary energy consumption	3379 kWh	2271 kWh
Photovoltaic production	-	2290 kWh
Palermo	*Standard Building*	*NZEB Building*
Primary energy consumption	3270 kWh	2170 kWh
Photovoltaic production	-	2220 kWh

After that we modelled the building with the life cycle analysis method, in accordance with the standard UNI EN ISO 14040 and 14044, and we calculated the Embodied Energy and Carbon of the case study.

SimaPro software and the database Ecoinvent 3.4 were employed in the Life Cycle Analysis.

The single issue indicator Cumulative Energy Demand (CED version 1.09) was used for the Embodied Energy determination. It includes the direct uses as well as the indirect or grey consumption of energy due to the use of, e.g. construction materials or raw materials.

The Global Warming Potential (IPCC 2013 GWP 100a version 1.03) was used for the determination of the Embodied Carbon. It expresses the greenhouse gases emissions of anthropogenic origin for different time horizons, usually for 20 to 500 years. In this study, data were used for a period of 100 years. Characterization values for greenhouse gas emissions are normally based on global warming potentials published by the IPCC (Intergovernmental Panel on Climate Change).

LCA Hypothesis

- Building life cycle is supposed to be equal to 60 years
- Transportations distances are all considered equal to 60 km
- Different disposal scenarios were considered:

Concrete elements are landfilled
Polystyrene is incinerated
Metals are recycled
Glass is recycled

- Different maintenance frequencies were supposed:

Load bearing structures - 100 years
Windows - 35 years
Wall lining - 25 years
Wall coverings - 10 years
Services - 20 years

Results of Life Cycle Analysis

• A cradle to grave analysis has been run for both buildings configurations

• Comparing the two building configurations, the NZEB solution causes an increase in the total Embodied Energy:
Turin +31%
Rome +25%
Palermo +22%

Fiumicino (Rome)	*Standard Building*	*NZEB Building*
Embodied Energy	12530 MJ/m^2	15623 MJ/m^2
CED (use phase)	23684 MJ/m^2	~ 0 MJ/m^2
CED (end of life)	802 MJ/m^2	1000 MJ/m^2
Turin	*Standard Building*	*NZEB Building*
Embodied Energy	13017 MJ/m^2	17076 MJ/m^2
CED (use phase)	27864 MJ/m^2	~ 0 MJ/m^2
CED (end of life)	804 MJ/m^2	1004 MJ/m^2
Palermo	*Standard Building*	*NZEB Building*
Embodied Energy	12361 MJ/m^2	15069 MJ/m^2
CED (use phase)	26006 MJ/m^2	~ 0 MJ/m^2
CED (end of life)	801 MJ/m^2	997 MJ/m^2

Results of Life Cycle Analysis

• The shift of burdens happens also for the carbon potential of the building with higher impacts connected to the total Embodied Carbon of the NZEB building in comparison with the reference one:
Turin + 21%
Rome +18%
Palermo +16%

Fiumicino (Rome)	***Standard Building***	***NZEB Building***
Embodied Carbon	826.7 kg CO_2-eq	1004.7 kg CO_2-eq
CED (use phase)	1276 kg CO_2-eq	0 kg CO_2-eq
CED (end of life)	110.7 kg CO2-eq	130.5 kg CO_2-eq
Turin	***Standard Building***	***NZEB Building***
Embodied Carbon	847.8 kg CO_2-eq	1079.1 kg CO_2-eq
CED (use phase)	1501.2 kg CO_2-eq	0 kg CO_2-eq
CED (end of life)	118.6 kg CO_2-eq	136.4 kg CO_2-eq
Palermo	***Standard Building***	***NZEB Building***
Embodied Carbon	818.2 kg CO_2-eq	979.7 kg CO_2-eq
CED (use phase)	1401.1 kg CO_2-eq	0 kg CO_2-eq
CED (end of life)	110.3 kg CO_2-eq	124.3 kg CO_2-eq

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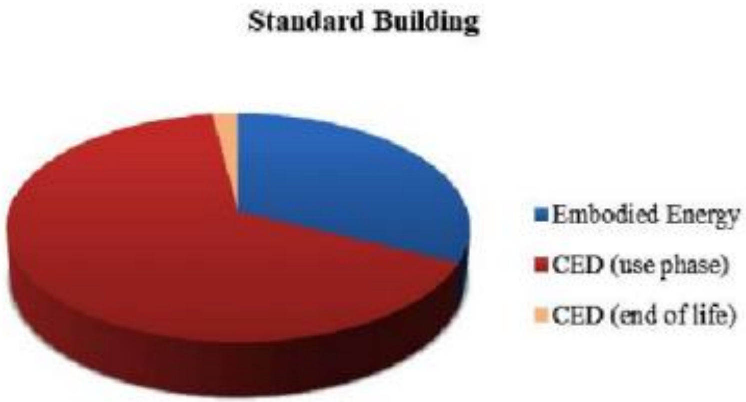
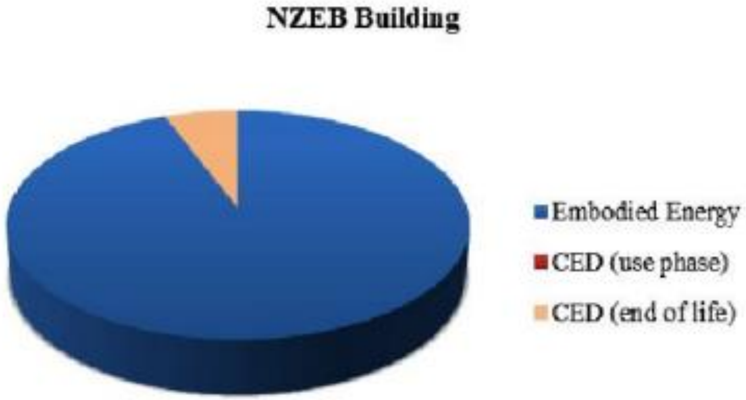
Results of Life Cycle Analysis

- There is an increase of the incidence of the total Embodied impacts
- The incidence of the total Embodied Energy and Carbon is respectively of 32% and 36% in the reference building located in Fiumicino
- In the Fiumicino NZEB solution the incidence of the EE and EC becomes equal to 94% and 89%.
- The NZEB solution brings to the almost total cancellation of the impacts linked to operational energy and so to the use stage.

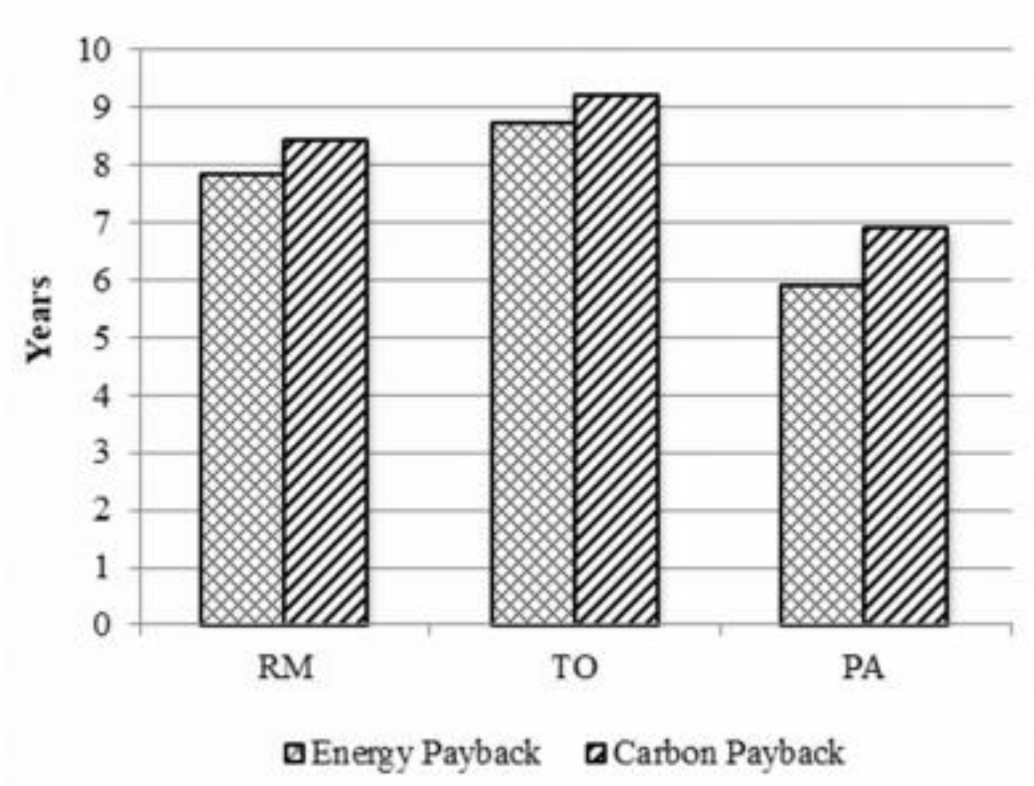




Results of Life Cycle Analysis

The energy and carbon payback time for every solution.

	EPBT	CPBT
Turin	8,7	9,2
Fiumicino	7,8	8,4
Palermo	5,9	6,9



In the north of Italy the payback periods are slightly higher because of the higher envelope requirements and lower annual solar radiation on horizontal surface.

A real case study

Moving beyond the initial ideal case study, we decided to consider a real construction subjected to different retrofit interventions, each one of increasing level. The building – which is a school - was selected by the group of professor Corrado of the Politecnico di Torino.

In particular the paper tries to integrate the economic analysis of cost-optimality with the evaluation environmental effective interventions.

The literature on cost effectiveness of energy retrofit of buildings is wide and developed even before the EPBD, that encourages the best practices as regards the cost-effective transformation of existing buildings into nearly zero-energy buildings.
The Guidelines contained in the Commission Delegated Regulation No.244-2012 establish a methodology for the identification of cost-optimal levels in different energy efficiency measures.

The case study

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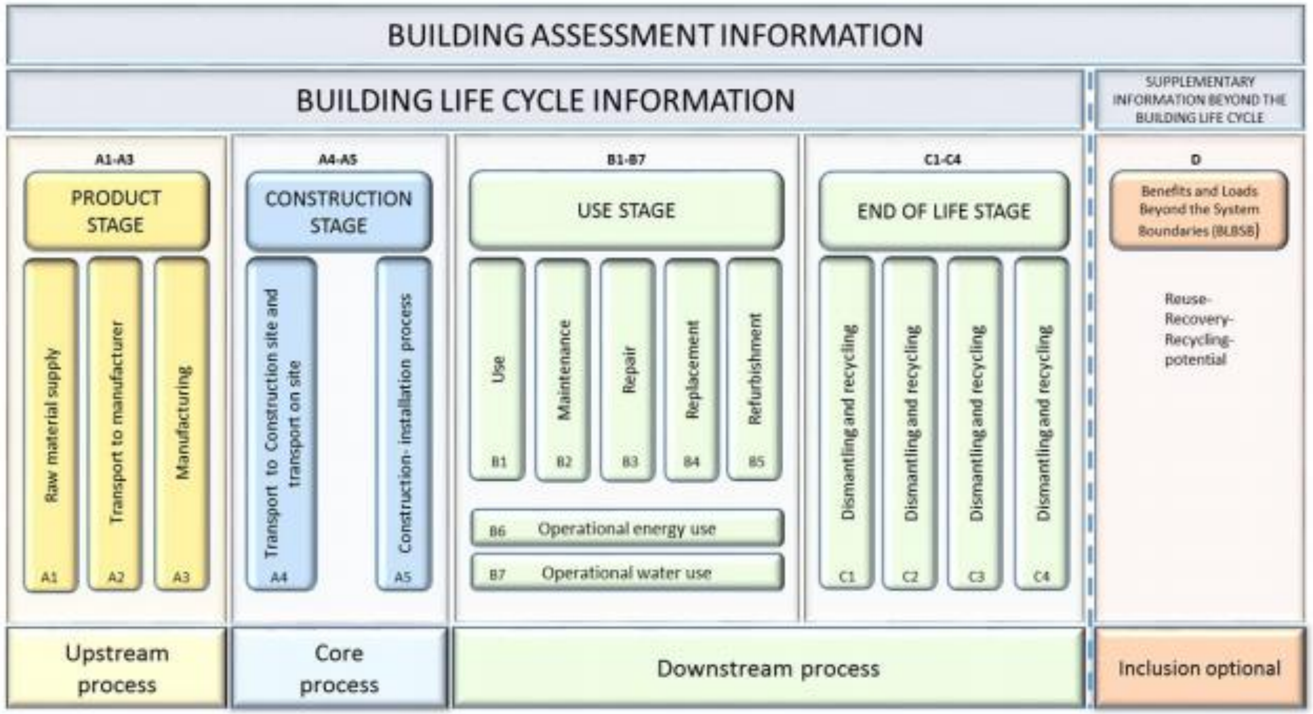
Methodology: LCA modelling

- The analysis follows the standards UNI EN ISO 14040 and UNI EN ISO 14044
- Ecoinvent database, included in SimaPro software, is employed
- Retrofit interventions lifespan is supposed to be equal to 50 years (as suggested by PCR)
- Transportations distances are all considered equal to 60 km
- End-of-life stage is not included
- Different maintenance frequencies were supposed:
    - Load bearing structures - 100 years
    - Windows - 35 years
    - Wall lining - 25 years
    - Wall coverings - 10 years
    - Services - 20 years

Methodology: LCA modelling

• Since the construction process is not energy intensive due to the absence of excavation processes and energy consuming machines, the impacts related to stage A5 were deemed irrelevant.

• Impacts connected to the operational water use were not considered in the study because of the very low water consumption in schools



Methodology: Energy modelling

• The energy modelling was performed by the group of prof. Corrado

• The building is modelled with an energy simulation software following the technical specification of the Italian Standard UNI/TS 11300

• The model was calibrated starting from real occupation profiles and using standard climatic conditions. • A standard climate was established to perform the retrofit scenarios so that the energy saving potential was not affected by specific weather data.

The retrofit solutions

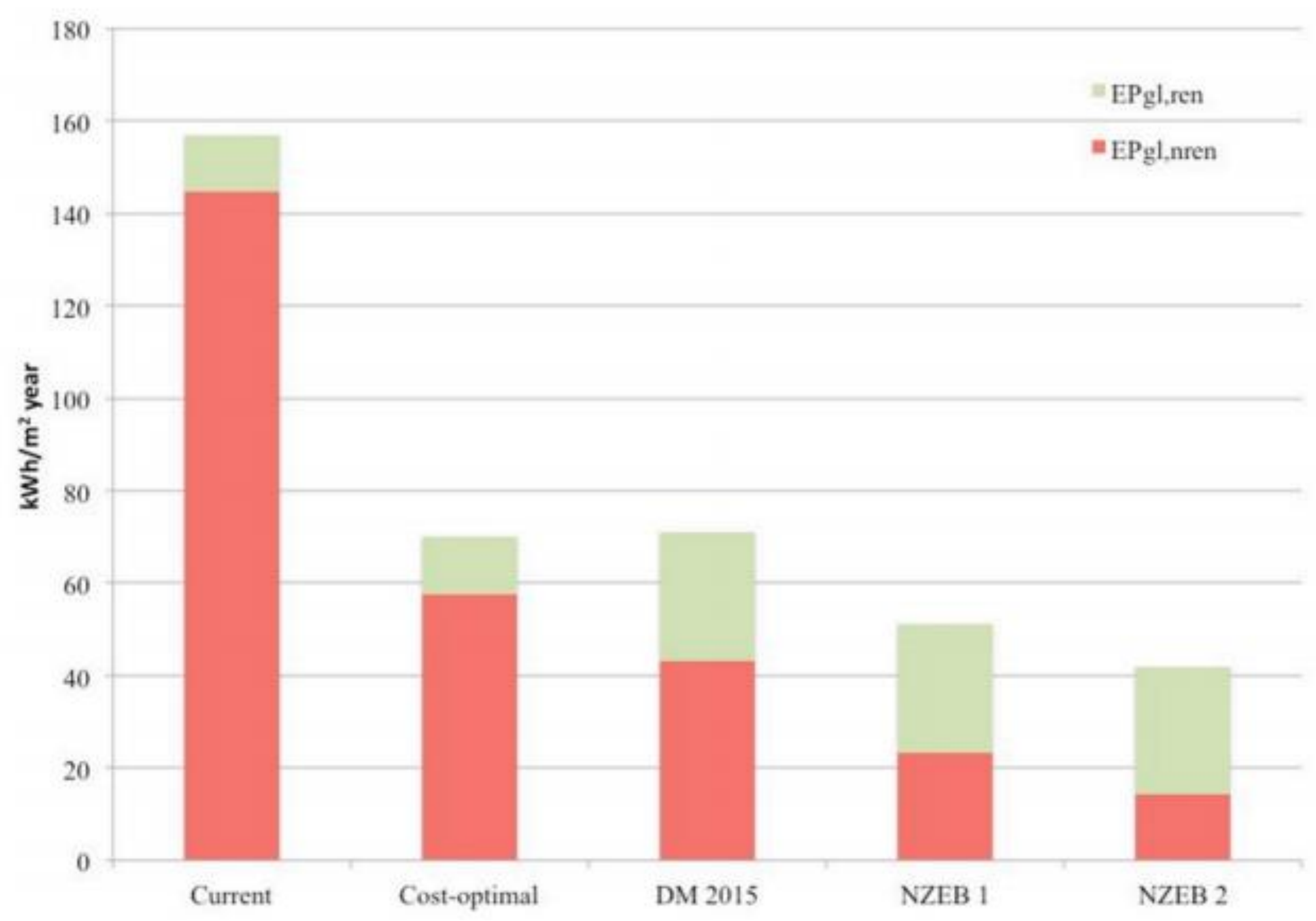
Four retrofit scenarios were envisioned for the building used as a case study:

- a cost-optimal solution;
- a retrofit intervention that allows the building to respect the current Italian legislation on energy efficiency (now called compliant with the DM 2015);
- two retrofits to achieve the NZEB standard, as defined by the Italian legislation (called NZEB1 and NZEB2).

The Life Cycle Inventory

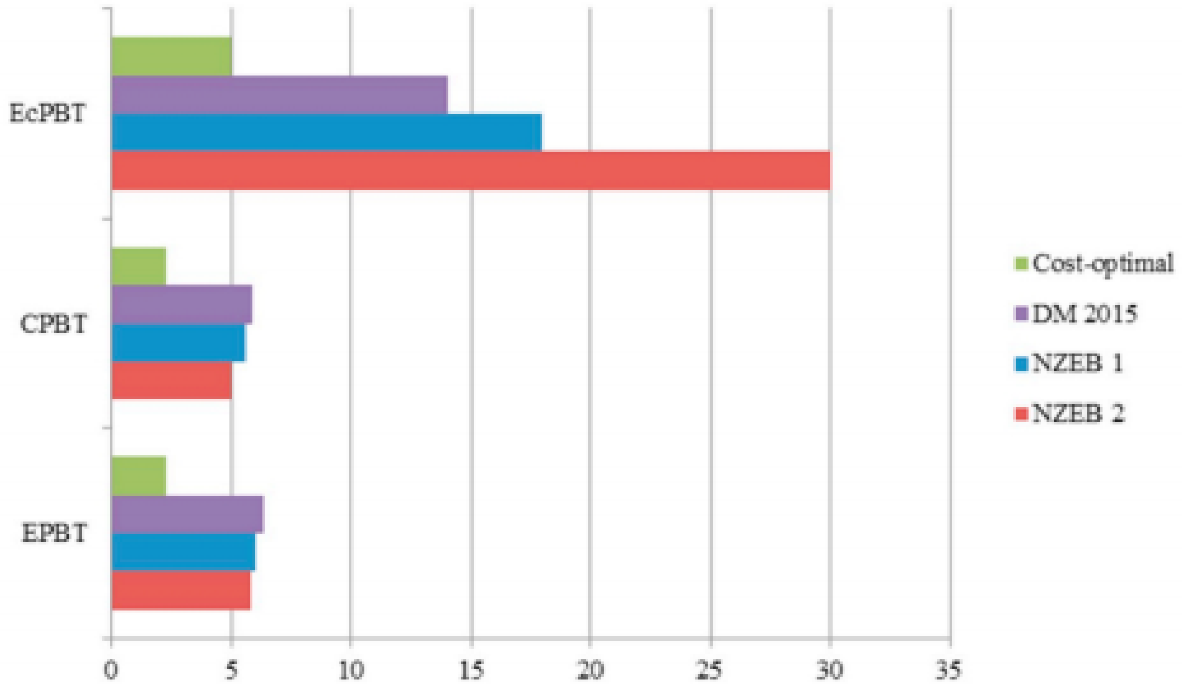
Component	Materials	Cost-optimal	DM 2015	NZEB 1	NZEB 2
Envelope					
Vertical walls	Rockwool	26442 kg	31630 kg	43300 kg	43300 kg
	Plaster	479675 kg	480000 kg	480000 kg	480000 kg
	Mortar glue	109017 kg	152253 kg	152253 kg	152253 kg
Transparent surfaces	PVC window frame	–	1399 m^2	1399 m^2	1399 m^2
	Flat Glass, coated	–	25741 kg	38612 kg	38612 kg
	Argon	–	19 m^3	19 m^3	19 m^3
Solar shadings	Viscose	–	730 kg	730 kg	730 kg
	Glass fibre	–	528 kg	528 kg	528 kg
	Aluminium frame	–	350 m^2	350 m^2	350 m^2
Systems					
Generator	Heat Pump	–	857 kW	857 kW	–
	Biomass Boiler	–	–	–	231 kW
	Heat Storage	–	–	–	5780 l
	Wood Collection, Production	–	–	–	53125 kg
Solar Collectors	Evacuated tube collectors	–	6 m^2	6 m^2	6 m^2
	Heat storage	–	600 l	600 l	600 l
	Pump	–	40 W	40 W	40 W
	Copper pipes	–	40 kg	40 kg	40 kg
	Polyurethane Insulation	–	25 kg	25 kg	25 kg
	Solar station	–	1	1	1
	Frame (stainless steel)	–	120 kg	120 kg	120 kg
PV	Mono-crystalline panels	267 m^2	400 m^2	533 m^2	533 m^2
	Inverter	40 kW	60 kW	80 kW	80 kW
	Electric wires	200 m	200 m	200 m	200 m
	Aluminium frame	6768 kg	10140 kg	13689 kg	13689 kg
Ventilation system	18 ventilation units with heat recovery and steel ducts	120 m^3/h	120 m^3/h	120 m^3/h	120 m^3/h
Lighting	LED lamps (30 W)	–	–	1151	1151
	Fluorescent lamps (36 W)	1151	1151	–	–

The results



Overall specific energy consumptions for the different retrofit solutions.

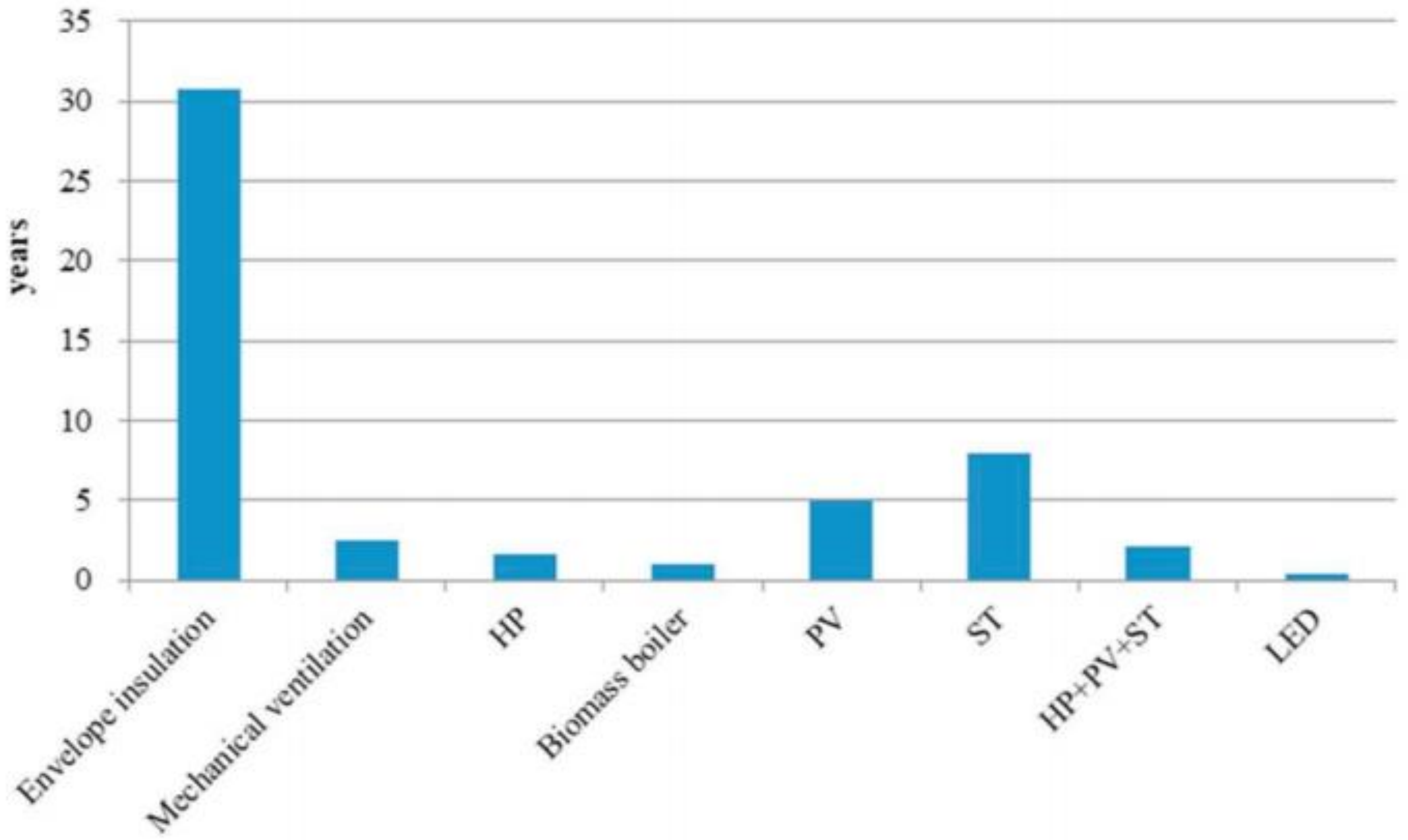
The results



LCA results and comparison between the economic and environmental payback times. The economic payback times are always higher than the environmental ones.

	EE (MJ)	EC (kg CO2-eq)	Energy saving (MJ/year)	Carbon saving (kg CO_2/year)	EPBT	CPBT
NZEB 1	23 118 043.80	1 654 762.40	3 373 147.51	253 000.00	6.9	6.5
NZEB 3	22 826 407.94	1 534 762.40	3 460 936.46	259 000.00	6.6	5.9
DM	21 873 500.74	1 491 532.20	3 114 509.25	233 000.00	7.0	6.4
Cost-optimal	6 854 550.19	580 532.20	2 401 055.64	180 000.00	2.9	3.2

The results



Energy payback times for some retrofit interventions (HP: heat pump, ST: solar thermal, envelope insulation includes both opaque and transparent surfaces).

Some interventions have lower payback periods.

The values are comparable to other literature results.

Dynamic LCA modelling

Definition of DLCA

The DLCA is ”as an approach to LCA which explicitly incorporates dynamic process modelling in the context of temporal and spatial variations in the surrounding industrial and environmental systems” [Collinge]

In particular, we would like to analyze the effect of future emission factors in the incidence of the use house of a NZEB building.

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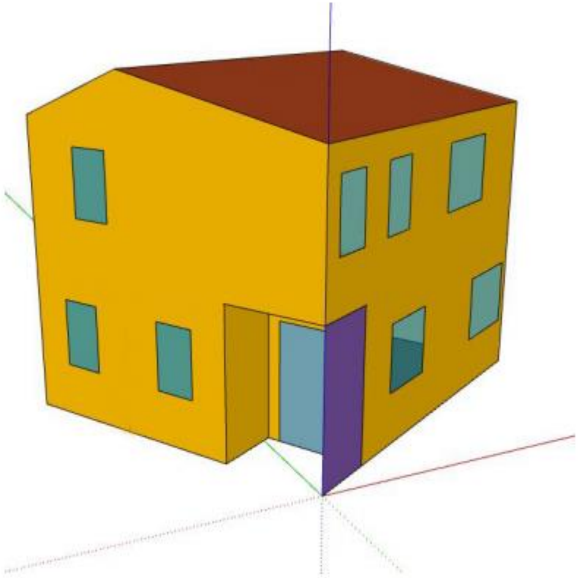
Dynamic properties

Literature review on the topic.

	Dynamic LCA area	Dynamic field
Collinge et al. (2013)	Dynamic LCI	Technological progress
	Dynamic LCIA	Weighting factors
	Dynamic LCIA	Characteristic factors
Su et al. (2017)	Dynamic LCI	Technological progress
		Occupancy behaviour
	Dynamic LCIA	Weighting factors
	Dynamic LCIA	Characteristic factors
Negishi et al. (2018)	Dynamic LCI	Emissions, resource consumption
	Dynamic LCIA	Climate change, toxicity

The case study

- NZEB ”all electric” building
- Heated surface equal to 100 m^2
- Location: Trento (climatic zone F)
- Structure: Glulam beam and columns
- Walls: High insulated, light wooden frame
- Roof: Wooden frame, aerated and high insulated
- Shape factor (1/m): 1.24
- Windows to wall ratio (%): 8.1%



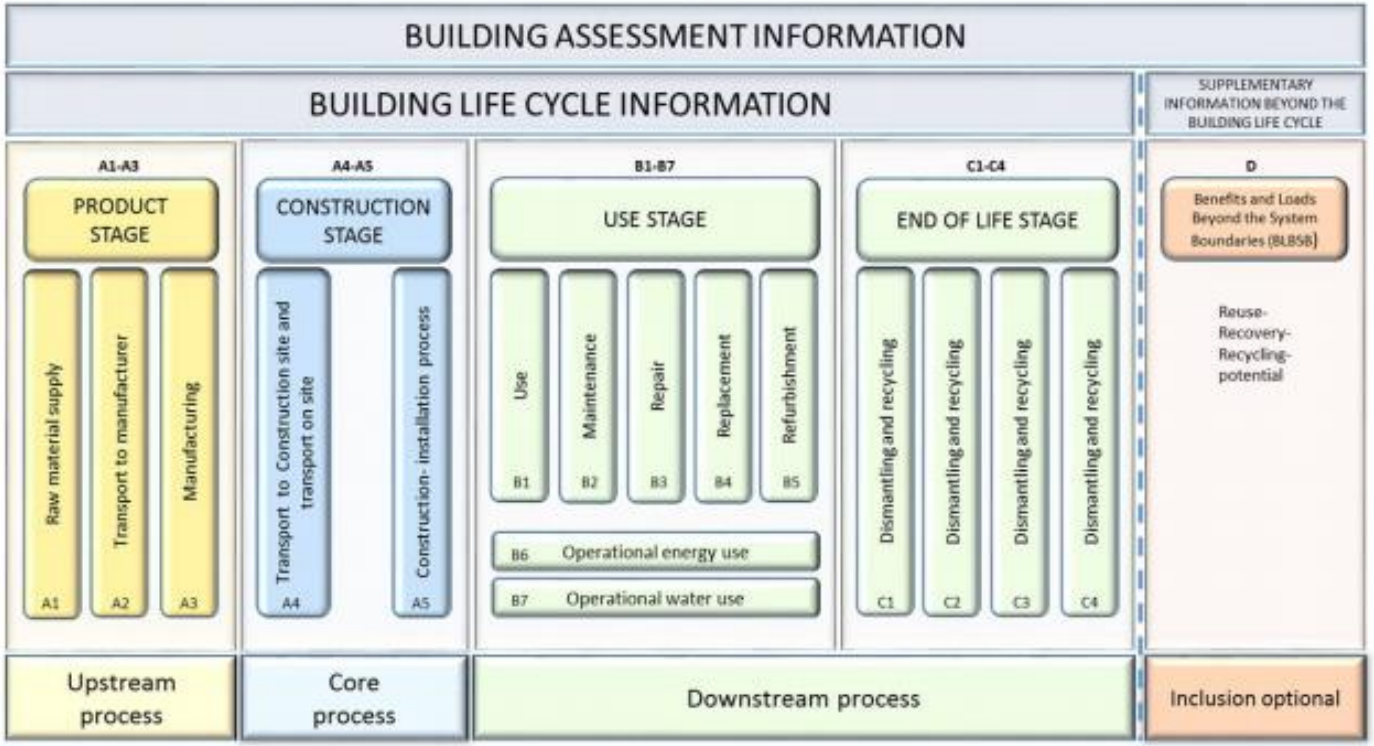
Methodology: LCA modelling

- The analysis follows the standards UNI EN ISO 14040 and UNI EN ISO 14044
- The functional unit is 1 m^2 of heated surface
- Retrofit interventions lifespan is supposed to be equal to 50 years (as suggested by the PCR)
- Transportations distances are all considered equal to 60 km
- End-of-life stage is included: aluminum, glass, steel and copper elements are recycled, reinforced concrete is partially recycled (0.582 kg/kg of reinforced concrete) after the separation from steel and moreover wood components are incinerated.
- Different maintenance frequencies were supposed:
    - Load bearing structures - 100 years
    - Windows - 35 years Wall lining - 25 years
    - Wall coverings - 10 years
    - Services - 20 years

Methodology: LCA modelling

• Since the construction process is not energy intensive due to the absence of excavation processes and energy consuming machines, the impacts related to stage A5 were deemed irrelevant.

• Impacts connected to the operational water use were not considered in the study because the building is not equipped with water distribution systems.



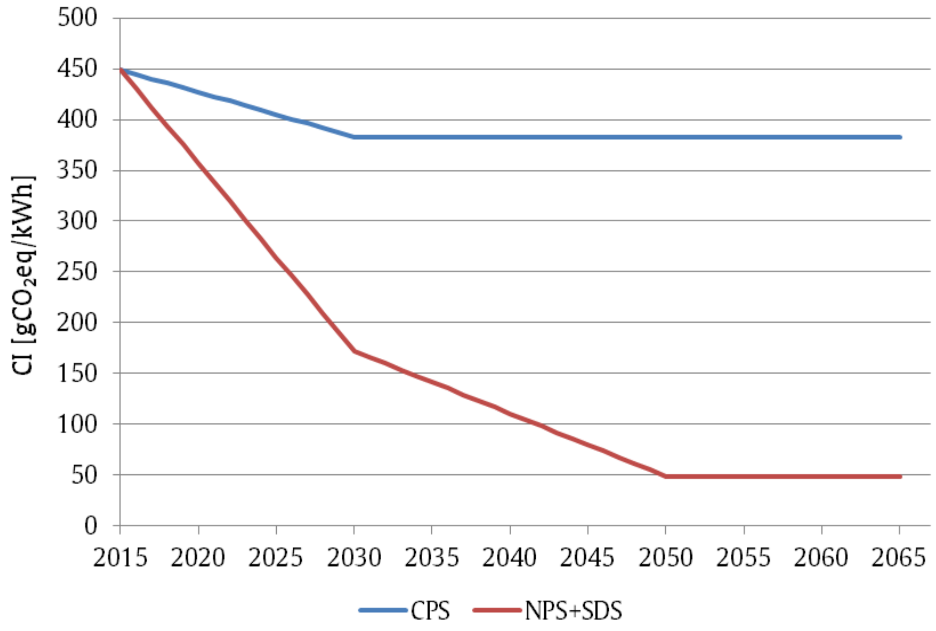
Methodology: Energy modelling

- The building is modelled with an energy simulation software following the technical specifications of the Italian Standard UNI/TS 11300
- The model was calibrated starting from real consumptions data.
- A whole year monitoring of the consumptions was available with a time frequency of ten minutes.

Methodology for the carbon intensity (CI) calculation

Linear modelling

It is based on data about future energy mixes for electricity production foreseen in the National Energy Strategy (CPS-2030, NPS-2030 and SPS-2050).



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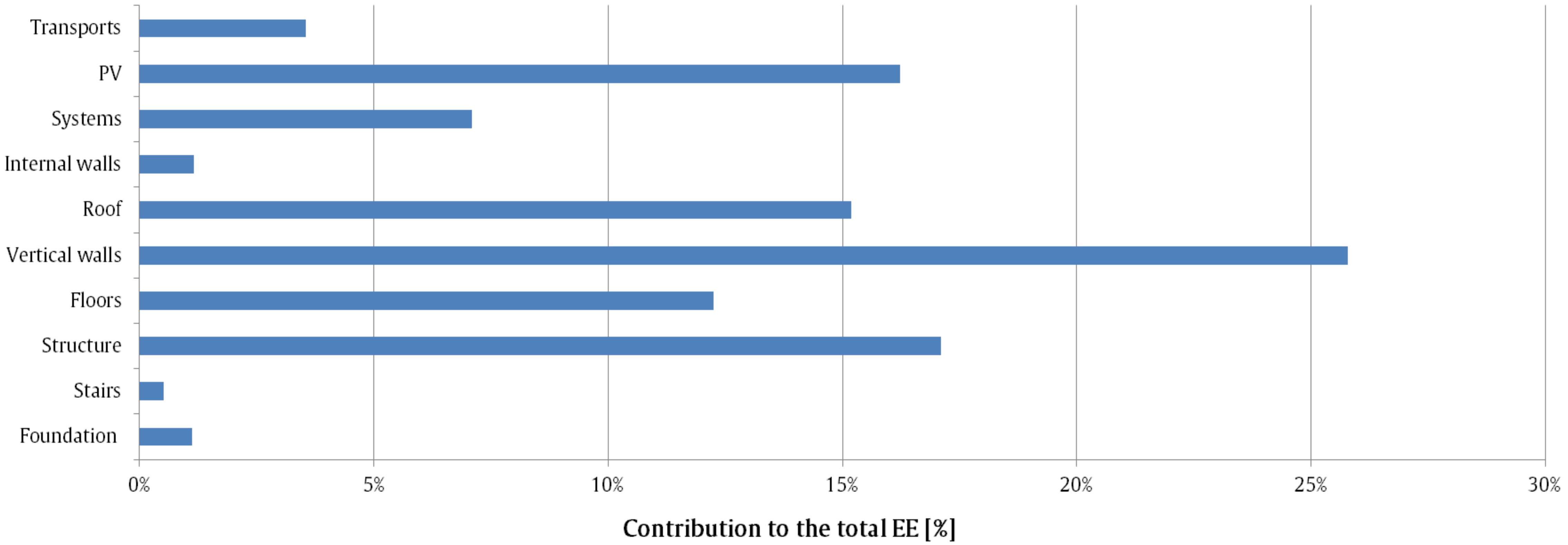
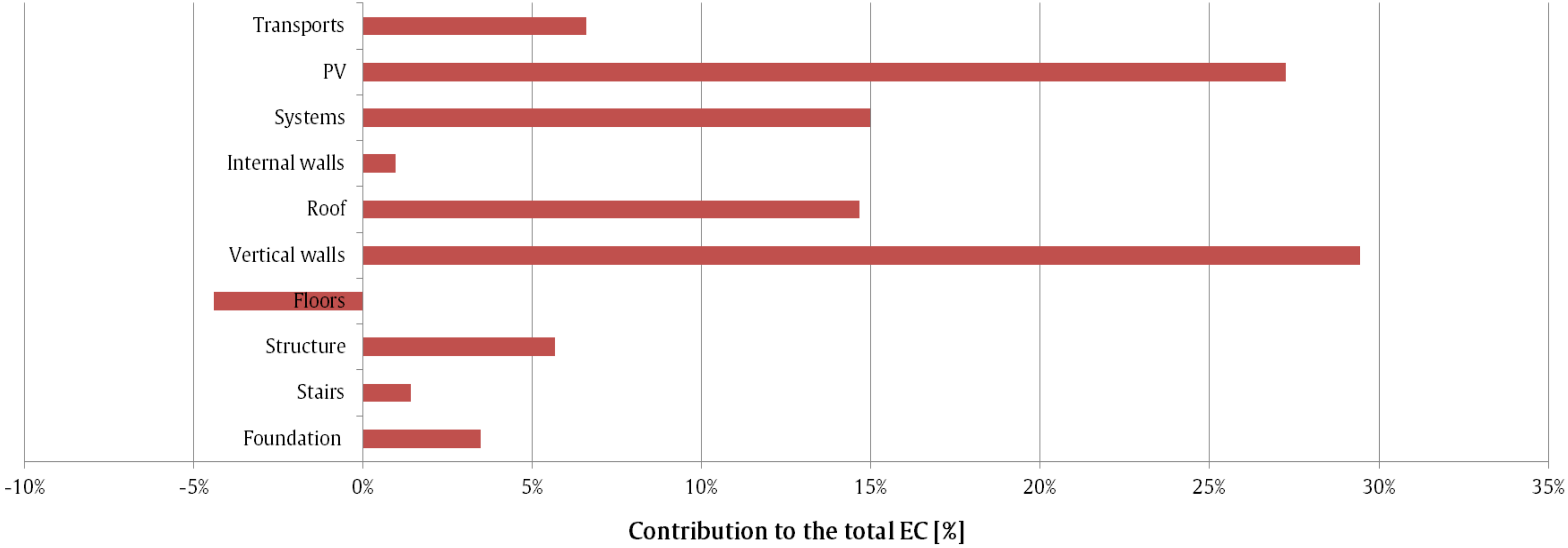
Life Cycle Energy results



Contribution to the total embodied energy of every building component.

Life Cycle Emissions results



Contribution to the total embodied carbon of every building component.

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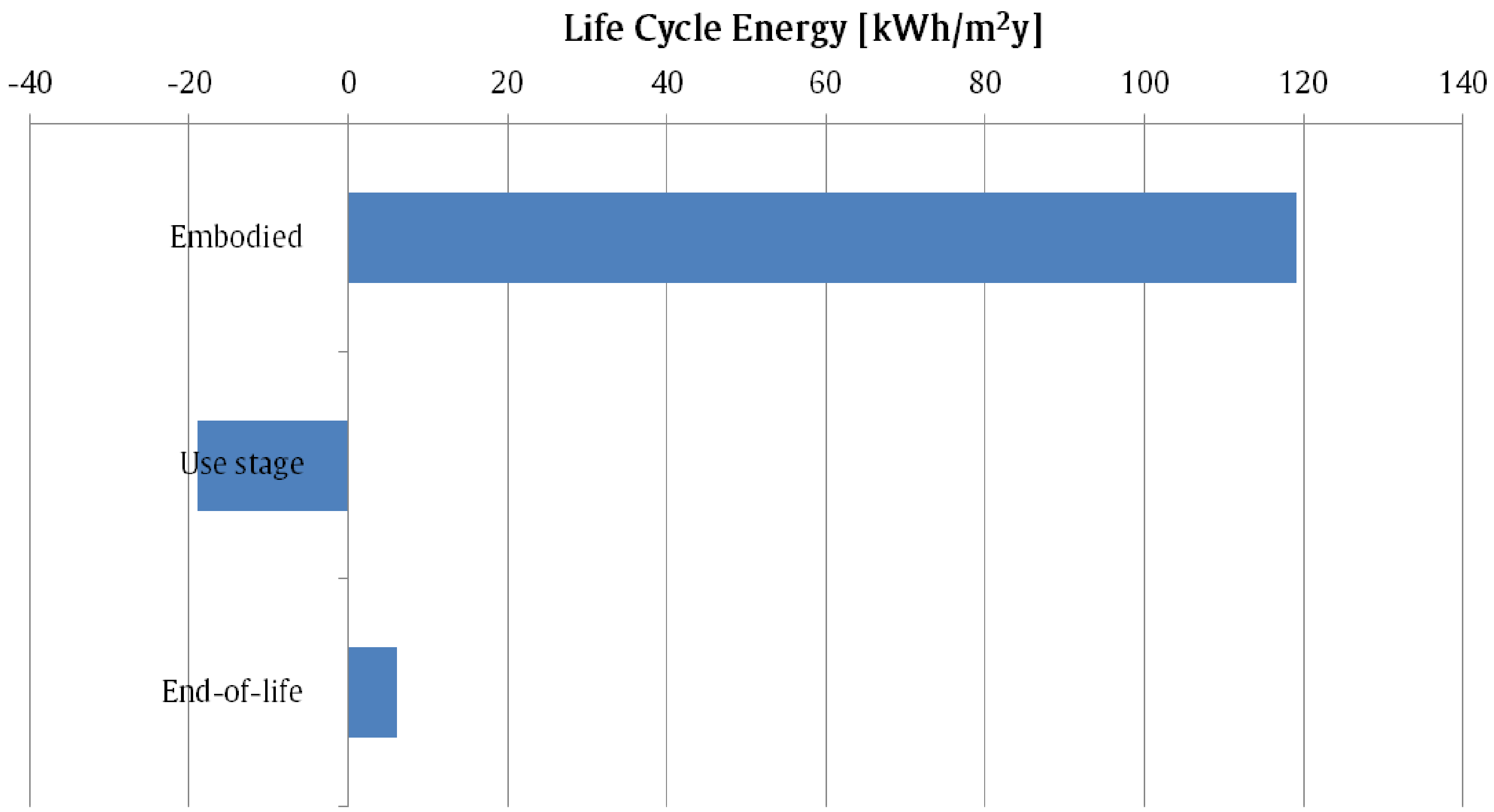
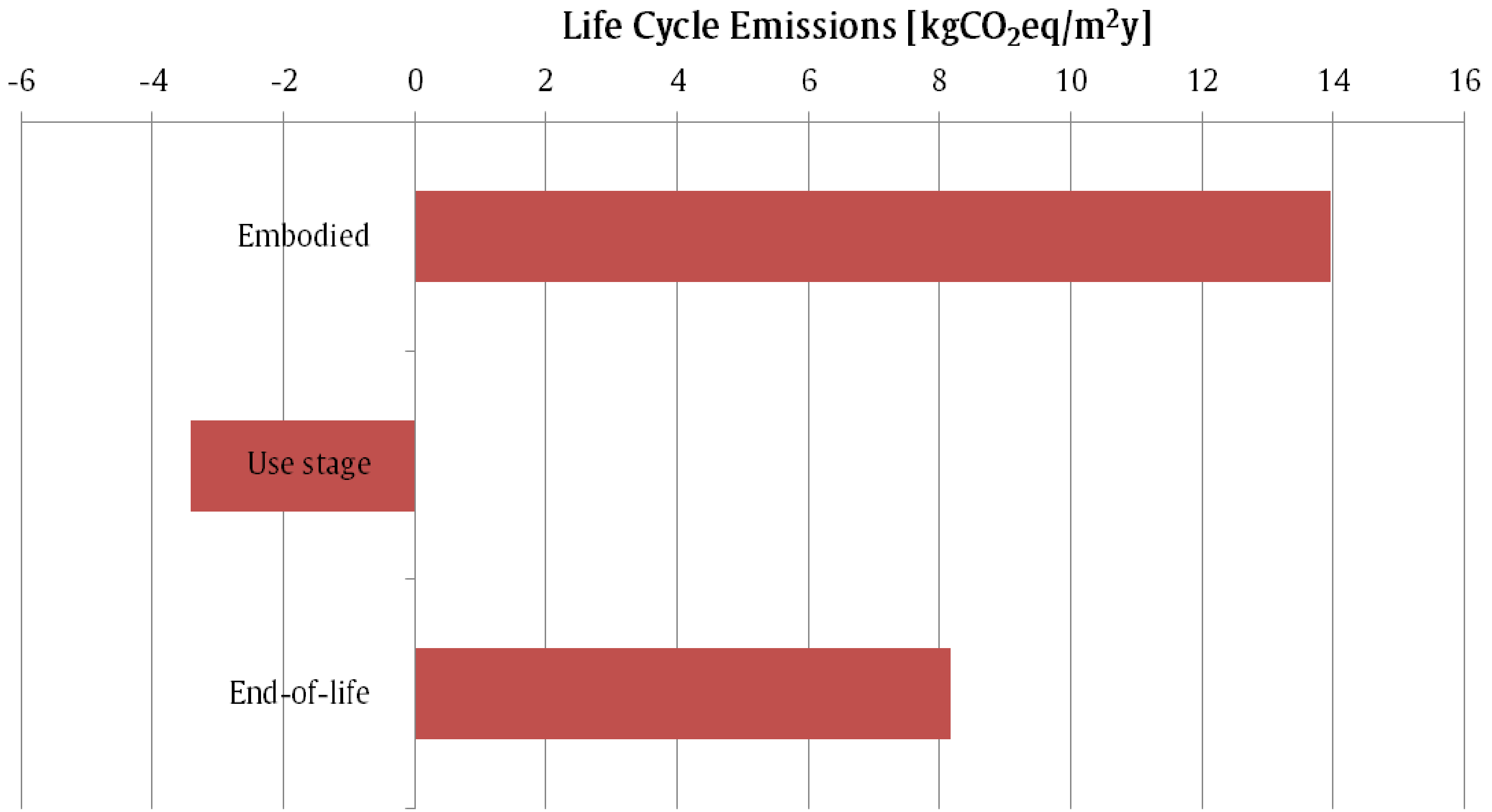
Life Cycle Energy balance



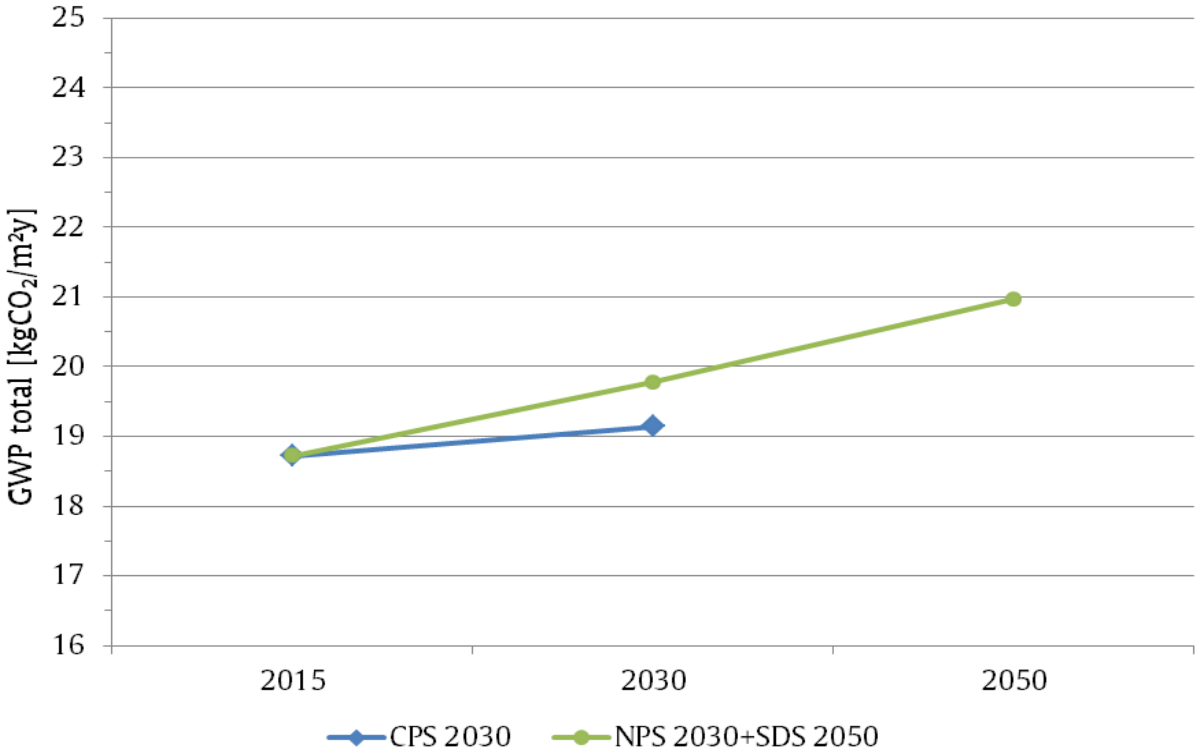
Symmetrical weighting factors.

Life Cycle Carbon balance



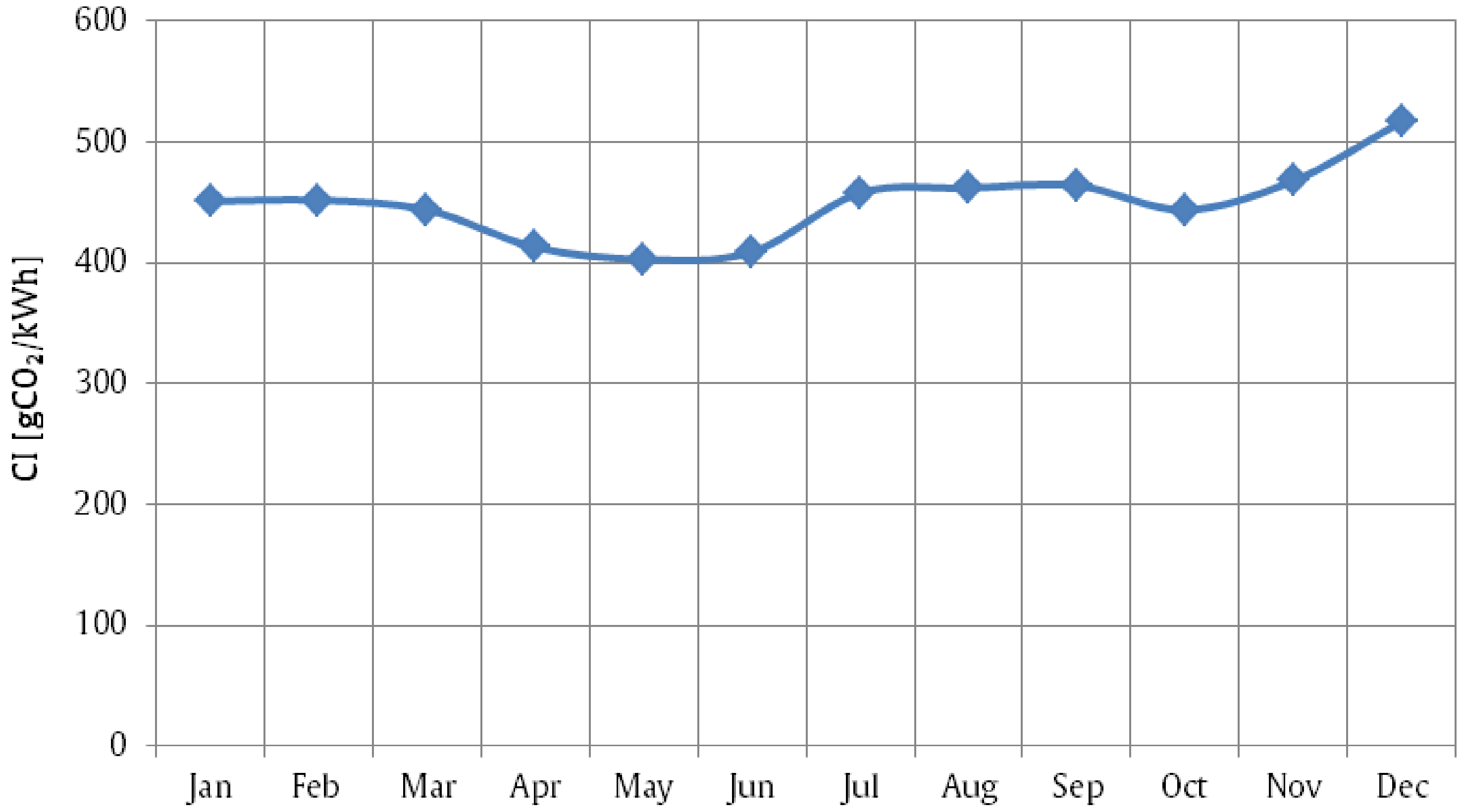
Symmetrical weighting factors.

Dynamic Life Cycle Emissions results: decarbonisation



Total GWP of the building in different decarbonisation scenarios.

Dynamic Life Cycle Emissions results: dynamic Carbon Intensity



Monthly carbon intensity for low voltage electricity in Italy (2015).

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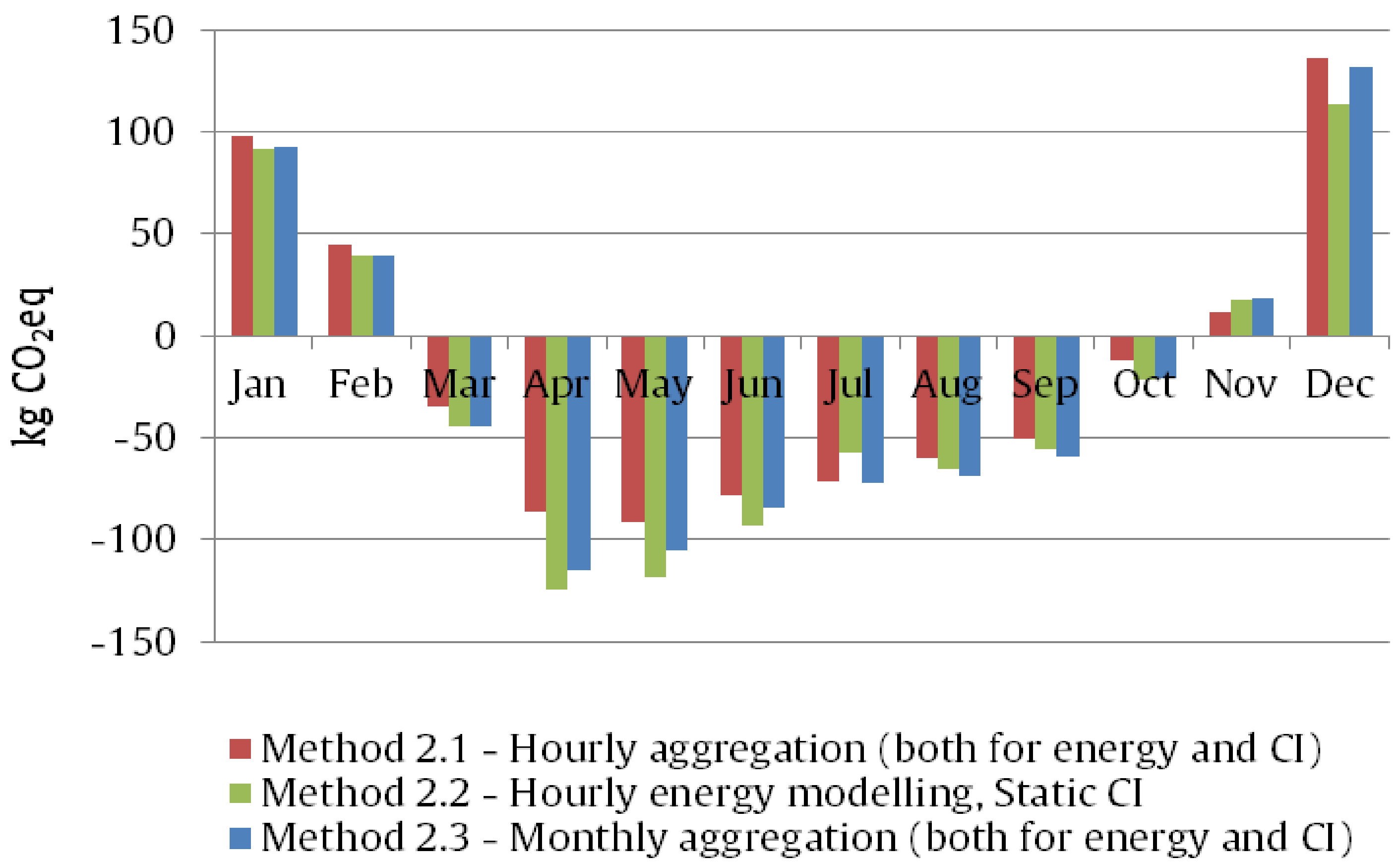
Dynamic Life Cycle Emissions results: dynamic CI



Carbon emissions every month with different combinations of modelling methods for energy and CI.

Conclusions

Conclusions (1/2)

- The NZEB spread will increase the impact linked to the construction phase of the buildings causing a shift of burdens

- In the case study analyzed the average increase has been determined to be equal to 26% for Embodied Energy and 19% for the Embodied Carbon

- The initial shift of burdens from the use phase to the construction one occurs only in the short term

- Some interventions have lower payback times

- Some interventions have a higher energy saving potential within the time frame considered in the analysis

Conclusions (2/2)

- The payback periods calculated are much lower than the useful life of the building confirming the important role on NZEB in addressing climate change and energy supply issues.

- It is essential to introduce the dynamic approach in LCA studies

References

- F. Asdrubali, C. Guattari, L. Evangelisti, G. Grazieschi, *Evaluation of the energy and environmental payback time for a nZEB building. An Italian case study*, 18th International Conference on Environment and Electrical Engineering, IEEE, Palermo 12-15 June 2018

- Asdrubali, F., Ballarini, I., Corrado, V., Evangelisti, L., Grazieschi, G., Guattari, C., *Energy and environmental payback times for an NZEB retrofit*, Building and Environment, 147, (2019), pp. 461-472.

- F.Asdrubali, P.Baggio, A.Prada, G.Grazieschi, C.Guattari, *Dynamic life cycle assessment modelling of a NZEB building*, Energy, in press (2019), https://doi.org/10.1016/j.energy.2019.116489

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GRAZIE PER L’ATTENZIONE

UNIONE EUROPEA
Fondo Sociale Europeo
Fondo Europeo di Sviluppo Regionale

Agenzia per la Coesione Territoriale

MINISTERO DELL'AMBIENTE
E DELLA TUTELA DEL TERRITORIO E DEL MARE

PON GOVERNANCE E CAPACITÀ ISTITUZIONALE 2014-2020

SOGESID SPA
INGEGNERIA TERRITORIO AMBIENTE