DECARBONISING THE BUILT ENVIRONMENT: RETROFIT STRATEGIES AND WHOLE LIFE CARBON ASSESSMENT IN EARLY 20TH-CENTURY MULTI-FAMILY HOUSES/

Federica Gallina - *Polytechnic University of Turin, Italy*
Jacopo Andreotti - *Polytechnic University of Turin, Italy*
Roberto Giordano - *Polytechnic University of Turin, Italy*
Marco Savino Piscitelli - *Polytechnic University of Turin, Italy*

federica.gallina@polito.it

Abstract. Considering the climate urgency and the European Union's (EU) decarbonisation goals, the construction sector is one of the main contributors to greenhouse gas emissions. According to the European Commission, buildings account for approximately 40 per cent of the EU's final energy consumption and over a third of its energy-related greenhouse gas emissions. Such impact affects the lifecycle of buildings, from material production and construction to use, maintenance, and decommissioning. The International Energy Agency's forecasts estimate that over 85 per cent of existing buildings will still be in use by 2050, while the annual renewal rate of the European building stock is only about 1 per cent. In this scenario, renovating the existing buildings is key to achieving climate neutrality and avoiding new CO2eq emissions. The main purpose of the study, carried out by the Department of Architecture and Design (DAD) and Department of Energy (DENERG) at Politecnico di Torino, was to develop a simplified Whole Life Carbon (WLC) assessment over 19 case studies of multi-family houses built in Turin (Climate zone E) between the 1940s and 1970s. The study was divided into an analysis of climate parameters, building orientation, energy requirements, and building typologies. Then, some energy efficiency solutions were developed, including renovations of the building envelope, the addition of solar shading, and replacement services (primarily mechanical and electrical). The WLC assessment considered both Embodied Carbon (EC) and Operational Carbon (OC) emissions over a 50-year period. Consistent with UNI EN 15978 and RICS guidelines, the adopted methodology is based on the framework proposed within the #BuildingLife project led by Green Building Council Italia. A comparative analysis of advanced retrofit strategies demonstrates the potential of innovative, low-carbon renovations to support the decarbonisation of the building stock.

Introduction. Unlike many European cities, which are characterised by relatively recent buildings, Italian cities have developed in layers, giving rise to a highly heterogeneous and recognisable architectural landscape (BPIE, 2011). It is home to compact historic districts, 19th-century neighbourhoods, and a vast post-World War II residential heritage, the latter often energy inefficient (ENEA, 2023) but now fully integrated into the urban identity. Today, it represents one of the most significant challenges for Italy's ecological transition. The redevelopment of these buildings is therefore not a simple technical intervention, but an action with profound repercussions on urban quality, the future of the built environment, and the ability to achieve national and European energy targets (Ruggieri et al., 2023).

EU policies emphasise this urgency: the European Green Deal (European Commission, 2019) and the subsequent revision of the Energy Performance of Buildings Directive - EPBD (European Commission, 2024) recognise the key role of existing buildings in the decarbonisation process, promoting the integration of Whole Life Carbon (WLC) into the design process to encourage the construction of zero-emission buildings and the spread of renovation passports (European Commission, 2024, Art. 12). In addition, the Renovation Wave strategy (European Commission, 2020) reiterates the need for profound and systematic interventions on existing buildings, supporting the process of building renovation, which in Europe currently stands at around 1% per year (IEA, 2021). In the national context, the PNIEC 2024 (MASE, 2024) identifies the energy upgrading of the building stock as an essential component of the climate strategy, while MASE emphasises that the transformation of the existing building stock requires advanced analysis tools and a progressive integration of energy performance, environmental impacts, and architectural quality. At the same time, evidence from the International Energy Agency indicates that over 85% of current buildings will still be in use in 2050 (IEA, 2021), underscoring the need to intervene in existing buildings rather than relying solely on new construction. International studies show that embodied emissions can account for 50-60% of the total in high-performance buildings (BPIE and KU Leuven, 2023; Röck et al., 2024), making a WLC assessment-oriented approach essential. In line with these considerations is the work carried out by the Department of Architecture and Design (DAD) of the Polytechnic University of Turin in collaboration with the Green Building Council (GBC) Italia (Giordano & Andreotti, 2024), which proposes a methodological framework for assessing and reducing emissions throughout the life cycle of buildings.

This paper expands upon the growing body of research on WLC assessment, analysing a sample of 19 multi-family buildings, both tower blocks and terraced houses, built in Turin (climate zone E) between the 1950s and 1970s to define a set of possible low-carbon retrofit scenarios. The research, conducted by the Department of Architecture and Design (DAD) and the Department of Energy (DENERG) of the Polytechnic University of Turin, aims to:

- assess the effects of redevelopment strategies on embodied and operational emissions;
- compare advanced technological scenarios, including photovoltaic systems and storage batteries;
- analyse the impact of different end-of-life strategies for materials;
- identify the factors that most influence the effectiveness of decarbonisation in existing buildings.

This study advances current WLC research in three main ways. First, it applies a consistent WLC framework to a statistically derived series of 19 real multi-family archetypes, enabling cross-case comparison and identification

of recurring drivers of emissions. Second, the research integrates architectural retrofit design, on-site renewables and end-of-life scenarios within the same carbon balance, linking design choices to long-term emission trade-offs. Third, the study explores the interaction between operational decarbonisation and the growing relevance of embodied emissions in deep retrofits of existing housing, providing quantitative evidence for Mediterranean/continental European post-war residential stock. The research contributes to the debate on advanced, low-emission retrofit solutions, highlighting the potential of retrofitting existing buildings as a lever to support the achievement of European climate targets and the transition to a regenerative and carbon-neutral built environment.

Methodology. The methodological approach adopted in the study is divided into a sequential process consisting of two main macro-phases: the definition and characterisation of the building archetype and the assessment of environmental impact using the WLC indicator. The first phase involves identifying the archetype through statistical analysis, studying climatic conditions, defining the retrofit design proposal and the resulting system sizing. The second phase is focused on determining the system boundaries, cut-off rules and assessment scenarios for calculating embodied carbon and operational carbon emissions. To achieve the "Net Zero Emission" standard, the study included a final offsetting phase for residual WLC emissions, utilising a mechanism that allows greenhouse gas emissions to be balanced by financing projects that reduce, avoid, or absorb an equivalent amount of CO2 from the atmosphere. Two complementary approaches to carbon debt neutralisation were analysed:

- Monetisation of emissions: application of carbon pricing based on Emission Trading System (ETS) quotations (Directive 2003/87/EC), estimating a compensation cost of €100 per tonne of CO2eq emitted;
- Offsetting: evaluation of urban or off-site forestry projects. The carbon sequestration potential of specific tree species (including red oak, maple, lime and plane trees) was calculated over a 50-year time horizon, determining the number of trees and green space needed to neutralise the building's emissions balance.

To better understand the WLC analysis, here are some key definitions taken from the Italian methodological reference (Giordano and Andreotti, 2024): first of all, the WLC approach derives from the Life Cycle Assessment (LCA) approach and is to be understood as a carbon balance that considers both the emissions associated with the use of a building (Operational Carbon), determined based on energy requirements for air conditioning, lighting and domestic hot water, and the embodied emissions (Embodied Carbon), determined by considering the phases and modules of a building's life cycle, as defined by the UNI EN 15978:2011 standard (see FIGURE 1).

Embodied Carbon (EC) is the indicator that accounts for CO2eq 1) released, 2) stored, 3) removed, and 4) offset during one or more stages of the life cycle of a given asset, whether it is a product or a building. Operational Carbon (OC), on the other hand, is the indicator that accounts for carbon dioxide equivalent emissions released or avoided during the Use phase (module B6 and module B7) and the Beyond Life Cycle phase (module D2). As with an LCA analysis, the first step in calculating WLC is to define the boundaries of the system, i.e. the life cycle stages to be considered. Another element to be defined in a WLC calculation is the Reference Study Period (RSP), i.e. the total timeframe over which an analysis is conducted.

Archetype identification. The research analysed a sample of 19 multi-family buildings representative of Turin's early 20th-century building stock. The selection was made through statistical analysis based on two groups of variables: categorical and thermophysical/numerical.

In the first phase, four key attributes were considered, which made it possible to narrow down the field of analysis significantly:

- year of construction;
- building type;
- type of system and fuel;
- energy class.

The analysis shows that buildings constructed between 1940 and 1979, of the tower and terraced type, represent the majority. Most of them use natural gas for heating and domestic hot water (DHW) production, falling into energy class F, followed by E and G, which confirms their generally low energy performance.

The thermophysical variables considered include:

- transmittance of opaque (U_op) and transparent (U_tr) surfaces;
- thermal energy requirement for heating (Qh,nd);
- shape ratio S/V;
- window-to-wall ratio;
- average seasonal overall efficiency of the heating system (η_h).

The intersection of these variables made it possible to identify the archetypes representative of the Turin context. TABLE 1 summarises their main characteristics, while FIGURE 2 shows the geographical location of the buildings.

After selection, site inspections and diagnostic surveys were carried out to verify the construction technologies and materials used, in relation to typical post-war building methods. The identified archetypes exhibit homogeneous characteristics, representative of early 20th-century residential construction. The load-bearing structures are composed of reinforced concrete frames or a mixed system with load-bearing masonry. The opaque vertical envelope is typically characterised by uninsulated brick infill, often constructed using the "cassa vuota" technique (double planking with an uninsulated air gap) or semi-solid bricks, which result in high thermal transmittance values (Uop > 1.0 W/m²K). A recurring element is the presence of incorrect thermal bridges, particularly at balconies and structural nodes (beams and pillars on the façade). Regarding transparent closures, the current situation often reveals the presence of original wooden or metal single-glazed windows or partial replacements with double glazing, which are insufficient to guarantee adequate thermal insulation standards. FIGURE 3 shows an example of a construction detail before and after the intervention.

Project proposal. The retrofit proposals were put forward based on a series of site climate analyses through the evaluation of values such as dry bulb temperature, relative humidity, global radiation and degree days (Heating Degree Day - HDD and Cooling Degree Day - CDD), which provided an understanding of the current climate context: these analyses show that the heating season covers the months from October to April; the cooling season covers the months from June to September; May is not subject to either cooling or heating. At the same time, using solar charts and shading masks, it was possible to quantify the free solar gains, enabling the design of fixed or mobile shading systems for the most exposed façades (south, west, and east). Following these analyses, deep renovation retrofit strategies were developed, divided into:

- Envelope (Passive): Application of thermal insulation (external or internal cladding depending on constraints) to achieve transmittance in line with the NZEB standard; replacement of windows and doors with low-emissivity triple-glazed elements; integration of solar shading to control the summer heat load.
- Systems (Active): Decommissioning of gas boilers and installation of high-efficiency air-to-water heat pumps to provide heating and cooling services.
- Renewables: Installation of photovoltaic (PV) systems on the roof and, where possible, on the façade, sized using PVGIS [1] software to maximise on-site electricity production. Verification of the feasibility of installing battery energy storage systems (BESS).

Whole Life Carbon (WLC) calculation. The WLC assessment was conducted over a reference period of 50 years, in accordance with the UNI EN 15978:2011 standard. The system boundaries and scenarios considered for the assessment are as follows:

- Embodied Carbon (A1-A5, B4, C1-C4): Calculated by computing the materials needed for the retrofit (insulation, fixtures, systems). The phases included are Production (A1-A3), Transport (A4) calculated by selecting distances scenarios for three predefined types of transport: local 50 km, national 300 km, and international 1,500 km (Giordano, Andreotti, 2024), Construction (A5), periodic replacement of components with a useful life of less than 50 years (B4), and End of Life (C).
- Operational Carbon (B6): Calculated based on post-intervention energy requirements, converting electricity consumption into CO2eq emissions using the emission factors of the national electricity grid. The emission factor considered is static, a fixed value representing the average carbon intensity of national electricity for the reference year, which remains constant for the entire analysis time horizon and does not account for expected developments in the energy system, such as the increase in renewable sources. In addition, three technological scenarios were compared: in the first case (B6 – GRID), it was assumed that all electricity would be drawn from the grid; in the second case (B6 – GRID + PV), grid energy was supplemented with energy supplied by appropriately sized photovoltaic panels; in the third case, energy provided by the photovoltaic system was considered with the addition of Battery Energy Storage Systems (BESS), i.e. batteries used to store the electricity produced by the generation plants and make it available when needed (GRID + PV + BESS).
- End-of-Life Scenarios (C3-C4): two disposal scenarios were analysed (Giordano, Andreotti, 2024): a Baseline scenario, in which 100% of waste generated is sent to landfill, and a Circular scenario, which assumes that 70% of the waste produced is recycled and 30% is landfilled.

For the WLC assessment of the case studies, generic data were primarily used, obtained from databases such as the British ICE[2] and the GHG Conversion factor[3], or the Australian EPIC[4].

Results. The WLC assessment, in accordance with the methodological guidelines of Tools for Decarbonisation (Giordano, Andreotti, 2024), yielded mixed results, summarised in TABLES 2 and 3, showing the minimum, average and maximum values considering scenario B6 Grid+PV as fixed and the two end-of-life scenarios (100 vs. 70-30).

The analysis of the 19 case studies revealed a heterogeneous but consistent picture regarding the effectiveness of retrofit strategies. In terms of energy performance, the intervention on the building envelope resulted in a reduction in heating demand (QH, nd) of between 70% and 85% on average (see TABLE 4), from pre-intervention values that often exceeded 130-150 kWh/m²/a to post-intervention values below 30 kWh/m²/a. However, bioclimatic analysis and dynamic calculations have highlighted the emergence of a significant cooling requirement (QC, nd), especially in the 2050 scenario, which requires careful management to avoid compromising winter savings.

Regarding OC, electrification via heat pumps, combined with photovoltaic systems (Scenario 2), has enabled a reduction in operational emissions of up to 80-90% compared to the current situation based on natural gas (see TABLE 5). The integration of storage systems (BESS - Scenario 3) has been shown to increase energy self-sufficiency by up to 50-65%, drastically reducing grid consumption. However, the marginal benefit tends to decrease beyond a specific storage capacity, suggesting that oversizing batteries is neither economically nor ecologically advantageous.

Regarding EC, emissions peaked in the upfront phase (Phases A1-A5), mainly due to insulation materials (EPS/XPS or rock wool), new windows and doors and, to a significant extent, photovoltaic systems and batteries. In scenarios with BESS (Battery Energy Storage System), the embedded impact of batteries and their frequent replacement (every 10-15 years) has a significant effect on the overall balance. The WLC analysis shows that, despite the increase in embedded emissions, the overall 50-year balance is clearly favourable to retrofitting, with an overall reduction in emissions of between 40% and 60% compared to the business-as-usual scenario.

Discussion. The multi-case structure of the research allows the identification of robust trends beyond the specificity of individual buildings, strengthening the transferability of the results to similar post-war residential contexts. The results confirm a paradigm shift: in high-efficiency refurbished buildings, EC is no longer a negligible fraction but accounts for over 40-50% of total emissions over the life cycle. In particular, the integration of renewable energy production and storage systems (Scenario 3) improves operational performance but leads to an immediate increase in embodied emissions. The “carbon payback time” for these technologies is generally between 5 and 8 years, making them a viable option only if they have an adequate useful life and efficient recycling chains.

A crucial point that emerged is the influence of the end-of-life scenario (Phase C). The transition from a "100% landfill" scenario to a "70% recycling" scenario reduces the WLC impact, which is particularly true for projects that extensively use aluminium, glass, and steel. The choice of the waste decommissioning scenarios highlights the importance of designing interventions with a view to Design for Disassembly, facilitating the future recovery of installed materials.

Looking at climate projections for 2050 and the growing need to adapt buildings to increasingly critical summer conditions, there is a strong need to prioritise strategies that reduce the demand for active cooling. In this scenario, both increasing the thermal inertia of the building envelope, which helps to mitigate internal temperature fluctuations, and adopting effective solar shading systems, which can limit thermal loads during the hottest months, play a central role. The resilience of buildings to climate change thus becomes a priority design parameter, on a par with energy efficiency, guiding choices towards solutions that improve thermal comfort and the ability to respond to future climate stresses.

Conclusions. The study shows that even in architecturally and historically consolidated residential fabrics, where envelope transformations are constrained, significant life-cycle emission reductions are achievable without demolition, supporting decarbonisation pathways compatible with heritage conservation. Some design strategies should be prioritised, aimed not only at reducing operational emissions but also at minimising impacts throughout the entire life cycle of the building. Design choices must integrate energy performance, material durability, recycling potential, and adaptability over time to maximise the effectiveness of the retrofit with a view to overall decarbonisation. The first strategy involves reducing energy requirements (in both winter and summer) through a high-performance building envelope. Secondly, the choice of insulation and finishing materials must favour low-carbon solutions that are natural (such as hemp, cork, and wood) or recycled. The electrification of consumption and self-production from renewable sources is the most effective strategy for reducing CO2.

Additionally, a circular approach to end-of-life management is essential for minimising the overall environmental impact. Finally, it should be noted that, despite retrofitting, none of the case studies achieves the "zero emissions" target. A residual carbon footprint remains that requires offsetting strategies. The study highlighted that the direct monetisation of these emissions (at £100/t CO2eq) would entail high costs, making alternative strategies such as urban or off-site forestry not only more economical but also beneficial to the environment. However, although offsetting residual emissions is necessary to achieve "Net Zero", it should be a last resort, with priority given to reducing emissions at source.

In conclusion, considering these findings, future research prospects will necessarily focus on integrating advanced predictive models. Considering the uncertainties associated with climate change and the evolution of construction technologies, this integration will enable the refinement of intervention strategies to ensure the adaptability of existing buildings.

References.

1. BPIE & KU Leuven (2023). *Whole-Life Carbon Requirements for Buildings: A Framework for European Harmonisation*. Buildings Performance Institute Europe.
2. BPIE (2011). *Europe's Buildings Under the Microscope*. Brussels: Buildings Performance Institute Europe.
3. CEN (2011). *EN 15978:2011 Sustainability of Construction Works – Assessment of Environmental Performance of Buildings – Calculation Method*. Brussels: European Committee for Standardization.
4. D'Alonzo, V., & Petranzan, D. (2021). *Retrofit strategies for post-war housing: Environmental and architectural balance. Energy and Buildings*, 253, 111531.
5. ENEA, CTI (2023): Rapporto Annuale sulla Certificazione Energetica degli Edifici.
6. European Commission (2024). Direttiva EPBD 2024/1275 del 24 aprile 2024. *Recast of the Energy Performance of Buildings Directive (EPBD)*. Official Journal of the European Union.
7. European Commission (2020). *A Renovation Wave for Europe – Greening our buildings, creating jobs, improving lives*. COM (2020) 662 final. Brussels: European Commission.
8. European Commission (2019). *The European Green Deal*. COM(2019) 640 final. Brussels: European Commission.
9. Giordano, R., & Andreotti, J. (2024). *Strumenti per la decarbonizzazione del patrimonio edilizio esistente*. GBC Italia.
10. IEA – International Energy Agency (2021). *Net Zero by 2050: A Roadmap for the Global Energy Sector*. Paris: IEA.
11. Ministero dell'Ambiente e della Sicurezza Energetica, MASE (2024). Piano Nazionale Integrato per l'Energia e il Clima. https://www.mase.gov.it/portale/documents/d/guest/pniec_2024_revfin_01072024-errata-corrige-pulito-pdf
12. Parlamento europeo e Consiglio dell'Unione europea. (2003). Direttiva 2003/87/CE del Parlamento europeo e del Consiglio, del 13 ottobre 2003, che istituisce un sistema di scambio di quote di emissioni dei gas a effetto serra nell'Unione europea, e che modifica la direttiva 96/61/CE.
13. Pomponi, F., & Moncaster, A. (2016). *Embodied carbon mitigation and reduction in the built environment – What does the evidence say? Journal of Environmental Management*, 181, 687–700.
14. RICS (2017). *Whole Life Carbon Assessment for the Built Environment*. London: Royal Institution of Chartered Surveyors.
15. Röck, M., Pristerá, G., Ramon, D., Van de moortel, E., Mouton, L., Kockat, J., Toth, Z., Allacker, K. (2024). *Science for Policy: Insights from Supporting an EU Roadmap for the Reduction of Whole Life Carbon of Buildings*. IOP Conf. Series: Earth and Environmental Science 1363, 012008. DOI: 10.1088/1755-1315/1363/1/012008
16. Ruggieri, G., Andreolli, F., & Zangheri, P. (2023). A Policy Roadmap for the Energy Renovation of the Residential and Educational Building Stock in Italy. *Energies*. https://doi.org/10.3390/en16031319.

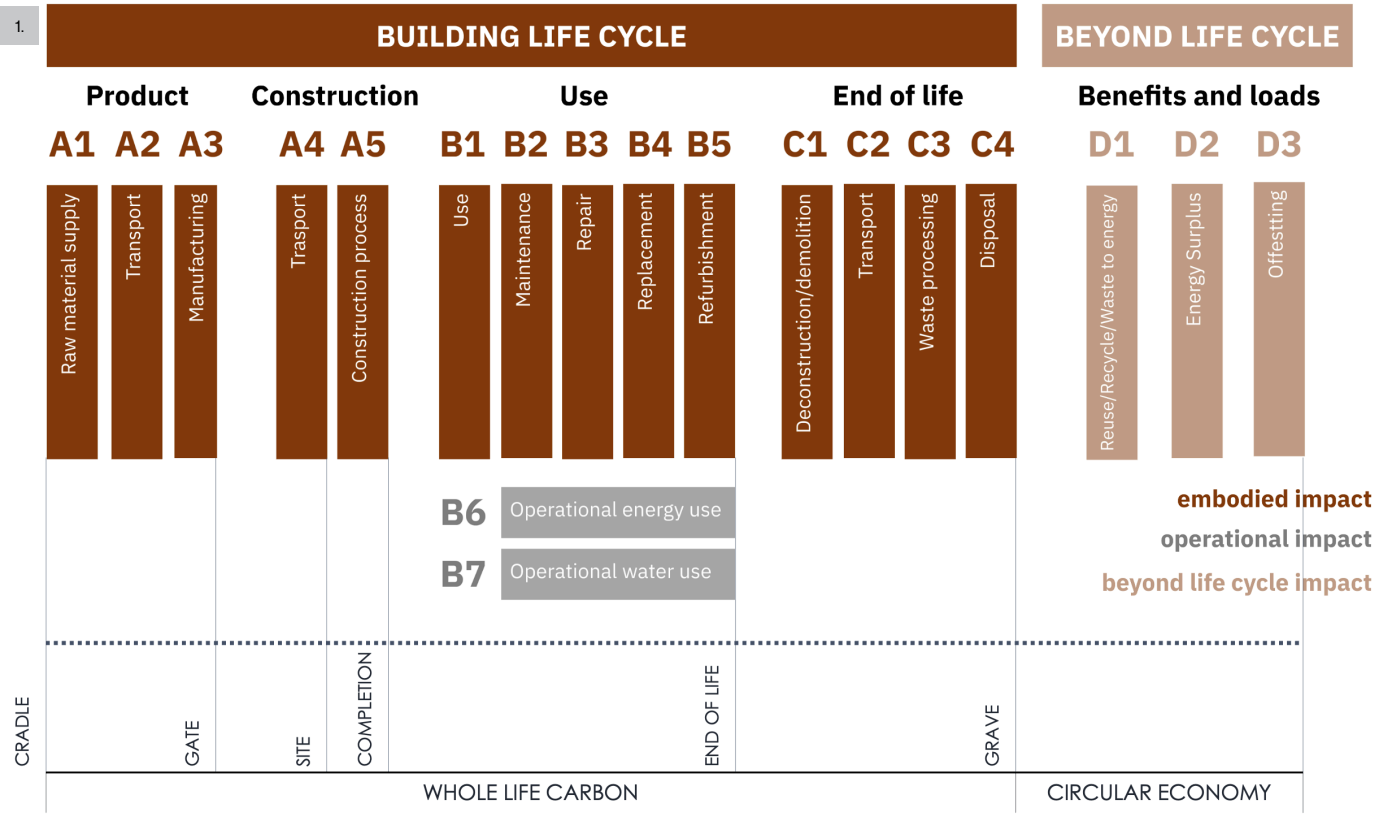
Figures.

FIGURE 1 - Life cycle stages and modules for a building, according to UNI EN 15978:2011 (Authors' elaboration).
FIGURE 2 - Geographical location of the archetypes under study in the Turin area. Latitude: 45.07°N Longitude: 7.68° E. Climate zone E.
FIGURE 3 - Example of construction detail before and after the intervention (Authors' elaboration).

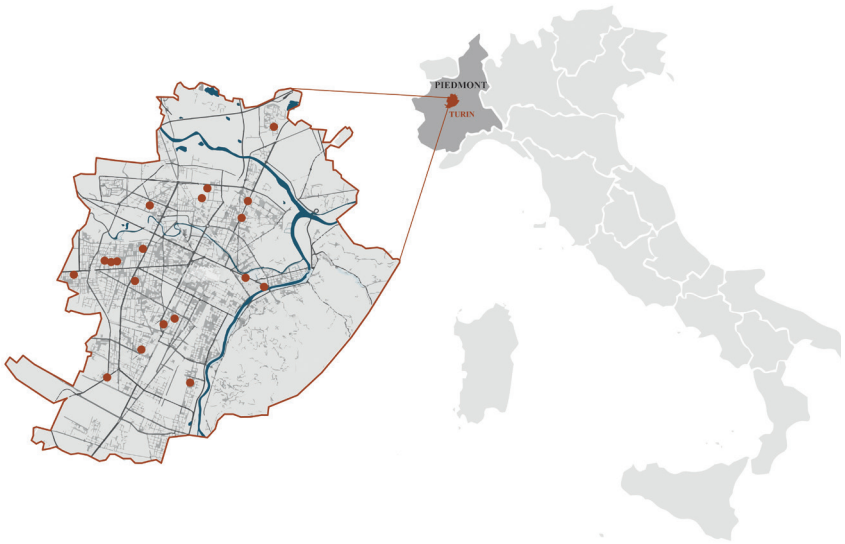
Notes.

1. https://pvgis.com/it
2. https://circularecology.com/embodied-carbon-footprint-database.html
3. https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2022
4. https://msd.unimelb.edu.au/research/projects/current/environmental-performance-in-construction

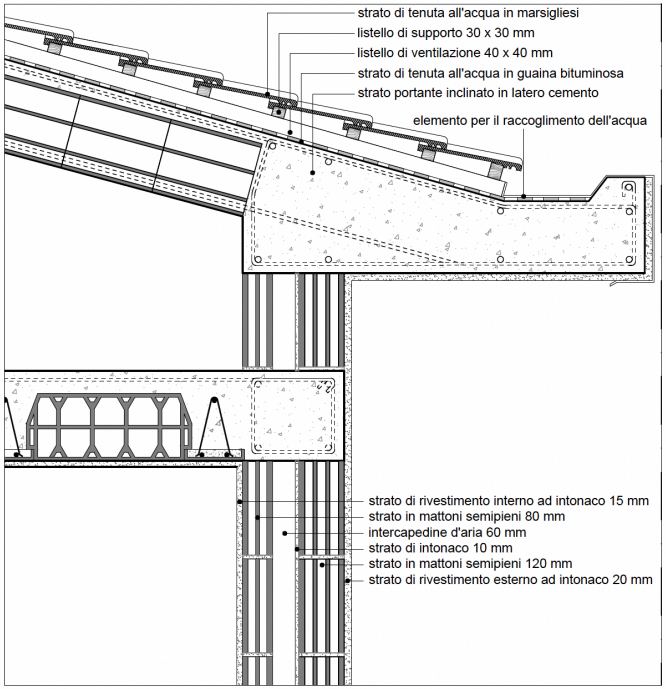
1.


BUILDING LIFE CYCLE
BEYOND LIFE CYCLE
Product
Construction
Use
End of life
Benefits and loads
A1 A2 A3
A4 A5
B1 B2 B3 B4 B5
C1 C2 C3 C4
D1 D2 D3
Raw material supply
Transport
Manufacturing
Trasport
Construction process
Use
Maintenance
Repair
Replacement
Refurbishment
Deconstruction/demolition
Transport
Waste processing
Disposal
Reuse/Recycle/Waste to energy
Energy Surplus
Offsetting
B6 Operational energy use
B7 Operational water use
embodied impact
operational impact
beyond life cycle impact
CRADLE
GATE
SITE
COMPLETION
END OF LIFE
GRAVE
WHOLE LIFE CARBON
CIRCULAR ECONOMY

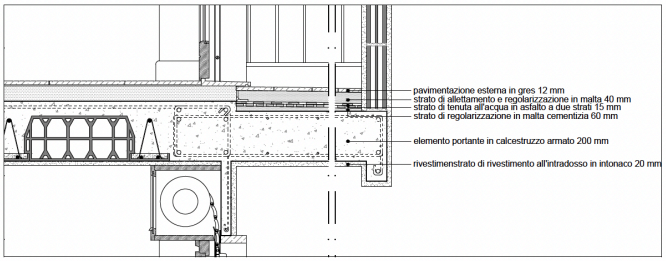
2.

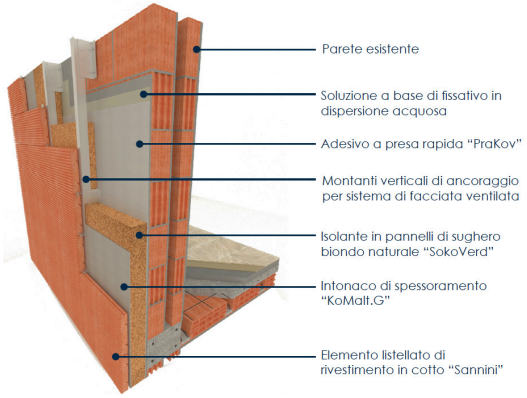

PIEDMONT
TURIN

NODO COPERTURA-PARETE ESTERNA



NODO PARETE ESTRENA-SOLAIO-BALCONE





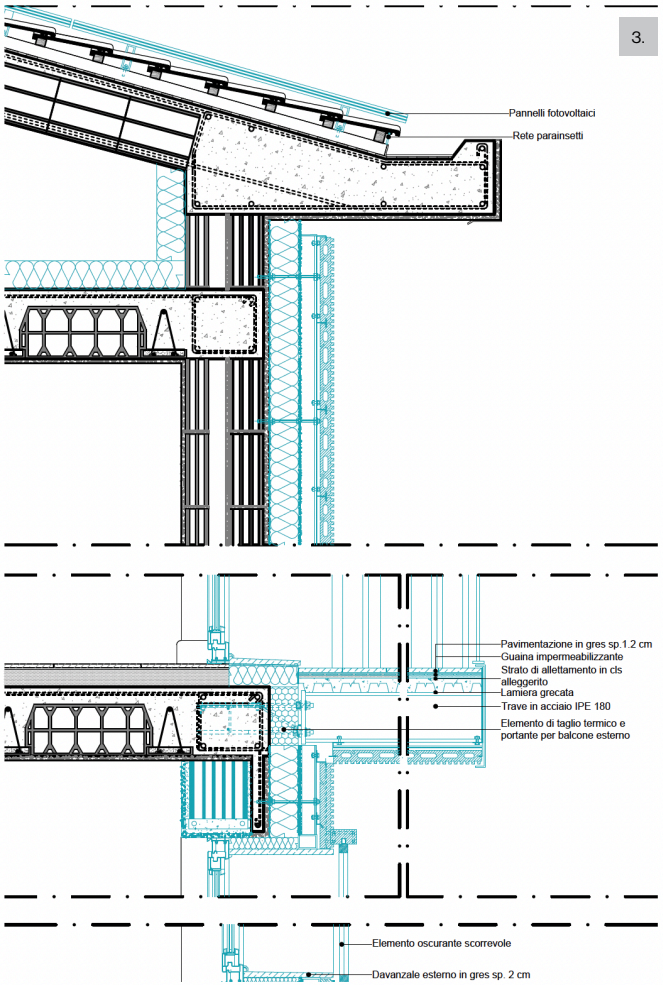




Table 1. Summary table of the characteristics of the selected archetypes.

ID case study	Intended use	Construction year	Floors	Building type	Reference area [m²]
1	MFH	1955	6	linear	800,00
2	MFH	1960	10	linear	1.440,00
3	MFH	1960	6	linear	879,72
4	MFH	1963	10	linear	4.366,32
5	MFH	1943	5	linear	340,00
6	MFH	1963	8	linear	975,00
7	MFH	1952	6	linear	1.750,00
8	MFH	1971	7	linear	3.205,70
9	MFH	1953	3	linear	503,10
10	MFH	1959	7	tower	1.503,00
11	MFH	1956	7	linear	744,00
12	MFH	1954	6	tower	600,00
13	MFH	1954	5	linear	512,00
14	MFH	1900	7	linear	1.633,70
15	MFH	1971	7	linear	2.780,00
16	MFH	1956	10	linear	4.320,00
17	MFH	1960	11	linear	3.520,00
18	MFH	1959	7	linear	2.780,00
19	MFH	1957	8	linear	2.400,00

Table 2. WLC assessment results: WLC GRID+PV - 100% landfill scenario.

	min	medium	max
[$kgCO_2e$]	179.307	1.050.824	3.931.135
[$kgCO_2e/m^2$]	125	635	1.260

Table 3. WLC assessment results: WLC GRID+PV – 70-30 scenario (70% landfill – 30% recycle).

	min	medium	max
[$kgCO_2e$]	178.021	1.030.640	3.931.337
[$kgCO_2e/m^2$]	112	623	1.231

Table 4. Summary table of results for heating demand (QH, nd): in the Ante phase, it was estimated starting from the pre-intervention Qh,nd values (considering an average efficiency of an old gas boiler equal to 0.7) multiplied by the average emission factor.

ID case study	Qh,nd ANTE [kWh/m²anno]	Qh,nd POST [kWh/m²anno]	REDUCTION [%]
1	58,68	17,77	70%
2	76,40	11,86	84%
3	65,68	24,08	63%
4	85,38	33,86	60%
5	70,84	9,97	86%

6	185,48	57,50	69%
7	103,18	15,92	85%
8	74,48	27,68	63%
9	78,40	29,98	62%
10	56,50	26,82	53%
11	60,53	13,96	77%
12	-	14,89	0
13	68,30	6,91	90%
14	85,53	13,68	84%
15	97,46	23,10	76%
16	-	20,33	0
17	57,61	18,22	68%
18	169,35	15,19	91%
19	60,64	20,75	66%
		Medium value	74%

Table 5. Summary table of Operational Carbon Ante and Post-intervention values: in the Ante phase, it was estimated starting from the pre-intervention Qh,nd values (considering an average efficiency of an old gas boiler equal to 0.7) multiplied by the average IPCC/ISPRA emission factor consistent with the Covenant of Mayors database. For the OC post, the B6 value Grid+PV was considered.

ID case study	OC ANTE [$kgCO_2e/m^2anno$]	OC POST [$kgCO_2e$]	OC POST [$kgCO_2e/m^2anno$]	REDUCTION [%]
1	58,68	401.095,50	10,03	41%
2	76,40	490.057,00	6,81	69%
3	65,68	388.935,50	8,84	53%
4	85,38	3.025.000,00	13,86	44%
5	70,84	207.645,48	12,21	40%
6	185,48	1.136.514,94	23,31	56%
7	103,18	1.098.359,80	12,55	58%
8	74,48	1.418.654,65	8,85	59%
9	78,40	159.677,94	6,35	72%
10	56,50	579.900,26	7,72	53%
11	60,53	494.256,37	13,29	24%
12	-	2.014,00	0,07	0
13	68,30	30.352,06	1,19	94%
14	85,53	4.416,45	0,05	100%
15	97,46	1.725.820,50	12,42	56%
16	-	8.805,00	0,04	0
17	57,61	729.595,00	4,15	75%
18	169,35	64.685,00	0,47	99%
19	60,64	192.080,00	1,60	91%
			Medium value	66%

LCA-BASED APPROACH TO DRIVE THE DEVELOPMENT OF A LOW-EMISSION PREFABRICATED WALL: A COMBINED EXPERIENCE BETWEEN UNIVERSITY AND ENTERPRISES/

Jacopo Andreotti - *Polytechnic University of Turin, Italy*
Benedetta Quaglio - *Polytechnic University of Turin, Italy*
Mauro Sarotto - *Sarotto Group, Italy*

jacopo.andreotti@polito.it

Abstract. The decarbonisation of the European construction sector requires a systematic transition towards low-emission building products and components. In this context, the updated Energy Performance of Buildings Directive (EPBD) introduces the mandatory assessment of Whole Life Carbon (WLC), thereby extending the regulatory focus beyond Operational Energy to include Embodied Carbon (EC) emissions associated with material production, construction processes, maintenance, and end-of-life stages. This paper contributes to the growing body of research on WLC implementation by presenting a combined academic–industrial study aimed at reducing EC in prefabricated components. The collaboration involves the Department of Architecture and Design at the Politecnico di Torino, the Sarotto Group, and Ricehouse s.r.l.

The research compares two technical solutions for prefabricated walls applied to a Sarotto Group's case study: the Klimasismico system, based on concrete and synthetic insulation, and an innovative RiceCycling Wall (RCW) prototype composed of rice husks, natural cement and geopolymeric foam. A WLC analysis was carried out according to the Life Cycle Assessment standards and the EU Level(s) framework, using generic datasets from OneClickLCA©. System boundaries encompass all the primary stages of the building life cycle: Production (A1-A3), Transport (A4), Construction (A5), Maintenance (B2), Repair (B3), Replacement (B4), Energy Use (B6), and End-of-Life (C1-C4).

Results highlight a reduction of approximately 11,500 kg CO_2e when substituting Klimasismico with the RCW, driven primarily by lower emissions in the Production and Replacement stages. However, the bio-based prototype increases Transportation and End-of-Life impacts due to its higher mass. In the near future, additional activities should be undertaken to enhance the final version of the RCW.

The study demonstrates that integrating bio-based materials and short supply-chain solutions can support the decarbonisation targets set by EPBD IV. It also highlights the importance of WLC studies in research as a guiding tool for innovation in construction systems.

Introduction. The construction sector is a significant contributor to the climate crisis, accounting for an estimated 34% of global energy demand and 37% of total greenhouse gas emissions (UNEP, 2024). In response, the European Union (EU) has implemented a suite of plans and strategies, including the Green Deal (European Commission, 2019), to achieve continental climate neutrality by 2050 through the decarbonisation of the construction sector (EU, 2021).

A crucial instrument in this process is the recent update of the Energy Performance of Buildings Directive - EPBD IV (EU 1275, 2024), which establishes a framework for enhancing the efficiency of the EU building stock by reducing energy demand and GreenHouse Gas (GHG) emissions. EPBD IV introduces the Whole Life Carbon (WLC) assessment as a core feature. WLC is an assessment that considers carbon equivalent emissions (CO2e) and removals (when they occur) throughout the building's life cycle, quantified by two mean indicators: the Operational Carbon (OC), which encompasses emissions from energy consumption during building operation (e.g., heating, cooling, and lighting), and the Embodied Carbon (EC), which accounts for CO2e emissions associated with construction materials, transport, site operations, maintenance, demolition, and waste management.

While EU policies (EU 1791, 2023) already support measures to reduce OC, addressing EC requires a harmonised effort across the construction sector's stakeholders – e.g., material manufacturers, designers, universities, and contractors.

Furthermore, effective decarbonisation strategies require the integration of circular economy principles, bio-based and low-carbon materials, design-for-disassembly approaches, and cost-effective solutions. The paper deals with the challenge of EC reduction by a cooperation program among the Department of Architecture and Design (DAD) of the Politecnico di Torino and two enterprises: 1) Sarotto Group, experienced in the prefabrication of Nearly Zero Energy Buildings (NZEB) in Narzole (CN, Italy); 2) Ricehouse s.r.l.specialiseded in the enhancement of rice waste for building material production, in Andorno Micca (BI, Italy).

The research was started by a WLC study of the current building, based on Life Cycle Assessment (LCA) standards UNI EN ISO 14040/44:2021, its building specs UNI EN 15978:2011 and UNI EN 15643:2021, and following the sustainable framework of Level(s) (Dodd et al., 2017). Additionally, the WLC was utilised to aid in the development of a new low-carbon prefabricated wall, which would replace the current one made of concrete and synthetic insulation, by combining rice husk and natural cement.

Although the wall element is currently being industrialised, within the paper, it was analysed by considering the production stage and other processes (such as construction) and by setting up scenarios (replacements, disposal, and recycling) that affect its life cycle using CO2e data. Overall, two WLCs were carried out. The former refers to the current building, and the latter refers to the hypothetical building, respectively: Biocasa (2007) and Ricecycling House (2025). The comparison shows how the EC is distributed on both buildings' life cycles and the potential benefits expected by the Ricecycling House. The contribution describes a research experience that combines the relationship between manufacturing innovation and the Circular Economy, as well as how innovation aligns with EPBD IV requirements and decarbonisation goals in the construction sector.