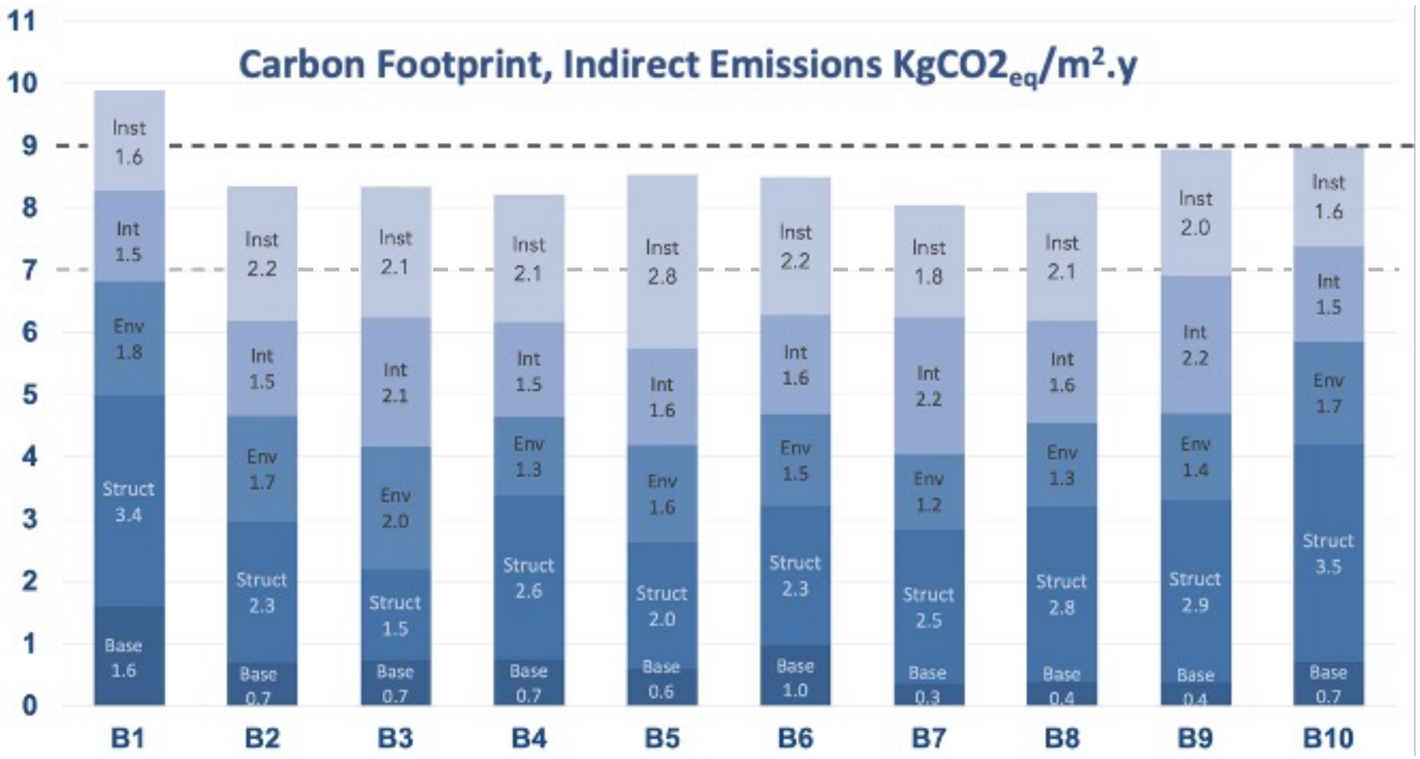
Estia

Design Benchmarks of Indirect CO2 Emissions for Construction and Renovation



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Objectives and method

- The Canton of Geneva recently approved Articles 117 and 118 of the Constructions and Installations Law (LCI) to promote low-carbon constructions and renovations. The enforcement regulations require a carbon footprint calculation, ensuring CO2 emissions remain below the limit set by SIA recommendations or norms. Additionally, the choices must be justified in a document called the design concept.
- The design concept must justify the construction and material choices of the 5 main construction element categories to ensure a coherent global low-carbon design of the building, reducing both direct and indirect emissions. This study aims to propose benchmark carbon footprint values for these five emission categories and provide recommendations to reduce their impact.
- To achieve this, we analysed the carbon footprint calculations for 10 new low-carbon buildings: 2 with the Minergie ECO label (Minergie targets) and 8 with the Sméo label (SIA 2040 targets) using LesoSai software. Additionally, we assessed the carbon footprint of 5 refurbished buildings and the renovation scenarios of 20 refurbishment projects using EPIQR+ CO2 software.

→ We conducted an analysis of the carbon footprint of 10 new low-carbon constructions and 25 refurbishment projects in order to propose CO2 benchmark values for 5 design categories.

New constructions

- Simplified method for carbon footprint analysis
- Analysing carbon footprints of ten buildings divided into five groups
- Establishing limits and indicative metrics across “responsibility groups“
- Detailed carbon footprint analysis of 4 buildings: Gaining insight into the challenges and decarbonation strategies
- Next steps

Carbon Footprint “responsibility groups“ for accountable design choices

Carbon footprint by materials.
lesosai, KBOB, …

Carbon footprint by “responsibility groups“

Group 1 : Basement and surroundings
Group 2 : Structure
Group 3 : Building envelope
Group 4 : Interior fittings
Group 5 : Technical installations

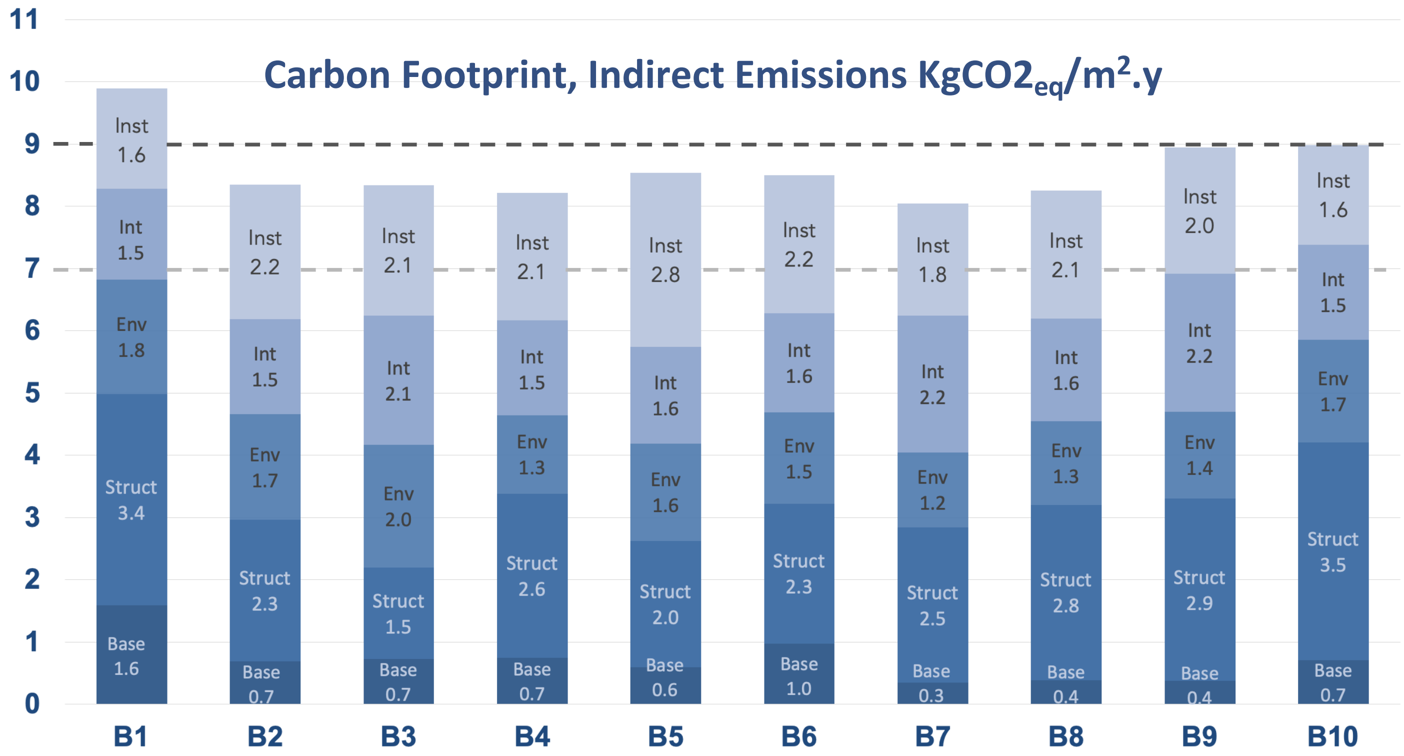
- Estia has conducted a previous study on the technical feasibility and limitations of carbon footprint software for the Geneva Law on low carbon constructions (LCI art 117, 118)
- Current footprint result exports, mostly based on materials or thermal model categories, are inconsistent and can be confusing. (Lesosai, KBOB)
- We propose an analysis method based on five categories rooted in a logical construction framework. These categories correspond to different main building specialties, holding the different design stakeholders accountable for the impacts.
- This classification, inspired by the ECCbat classification for construction costs, can also facilitate the evaluation of financial costs associated with carbon optimisation in construction and renovation.

→ Transitioning from an informative CO2 footprint presentation to a design-oriented presentation intending to make design choices accountable for their impact.

Group structure and accountable design stakeholders

Stakeholders	LCI Carbon Classification	eCCC-Bat cost Classification
Civil Engineer, Architect, Project Owner	**Group 1. Basement and Surroundings**	
	1.1 Basement excavation	B.6
	1.2 Foundation	B.7
	1.3 Raft	C.1
	1.4 Underground wall cladding	E.1, F.1
	1.5 Surroundings	I.2, I.4, I.5, I.7, D.1.3
Civil Engineer, Architect	**Group 2. Structure**	
	2.1 Structural walls	C.2
	2.2 Structural columns	C.3
	2.3 Slabs and beams	C.4
	2.4 Roof	C.4
Building Physics Engineer, Architect	**Group 3. Building Envelope**	
	3.1 External wall cladding	E.2
	3.2 Openings	E.3
	3.3 Roof covering	F.1, F.2
	3.4 Thermal insulation	
Architect	**Group 4 Interior Fittings**	
	4.1 Partition walls	G.1
	4.2 Flooring	G.2
	4.3 Wall coverings	G.3
	4.4 Ceiling coverings	G.4
	4.5 Fixtures	G.5
	4.6 Acoustic insulation	
HVAC Engineers, Electrical Engineer	**Group 5. Technical Installations**	
	5.1 Electrical systems	B.4, D.1, D.3, D.4, I.6
	5.2 Heating and cooling installations	B.4, D.5, D.6, D.8, I.6
	5.3 Ventilation and air conditioning	D.1, D.7
	5.4 Sanitary Installations	B.4, C.1, D.8, I.6
	5.5. Photovoltaic panels	
	5.6 Transport facilities	D.9

Carbon Footprint of 10 recent residential and school buildings



Function	School	Resid Mixt	Resid. School	Resid.	Resid Mixt	Resid.	Resid.	Resid.	Resid.	Resid School.
ERA m^2 FF	5500	9000 1.01	5500 0.94	3500 1.11	3300	6500	4000	4500	5000	14000
Materials	Concrete Wood	Prefab Concrete	Concrete Wood	Concrete	Concrete straw	Prefab Concrete	Concrete Bricks	Concrete Bricks	Concrete Bricks	Concrete

- All buildings are situated closer to the SIA 390 limit value of 9 $kgCO2/m^2y$ than to the target value of 7. This could be attributed to the "budget effect," as most of the buildings follow either the Sméo standard (B2-B9) with a limit value set to 9 $kgCO2_{eq}/m^2y$ either Minergie ECO (B1 and B10).
- All Sméo buildings are lower than 9 $kgCO2/m^2y$. It is a strict requirement, and it is possible to exceed this value only if there is a compensation in mobility or operational footprint.
- B1 and B10 exceed 9 $kgCO2/m^2y$. This could be attributed to higher Minergie ECO budget than Sméo label. But there are also structural and typological reasons making the target more difficult to attain. Underground elements with bigger surface, especially for B1 are present higher carbon-intensity. Higher span of bearing-load structure for school buildings can impact the group 2 - structure.
- The lack of carbon optimization in the bearing load structure of B1, B4, B8 and B10 is underscored and can be better understood through a detailed analysis of B1 (slide 17) .
- We observe similar impact for installations, interior fittings, and the envelope (~2 $kgCO2eq/m^2y$), while the structure of most of the buildings has a higher overall impact.
- Transversal analysis of the buildings leads us to the observation that choices of one group often impact the CO2 emissions of another group. Notably B2, with lower structural impact thanks to the biosourced structure, presents a higher envelope impact, while B1 and B10, with a higher structural impact, have lower envelope impact.
- A global vision among the actors impacts is important to avoid the transfer of impact between groups and get better global result.

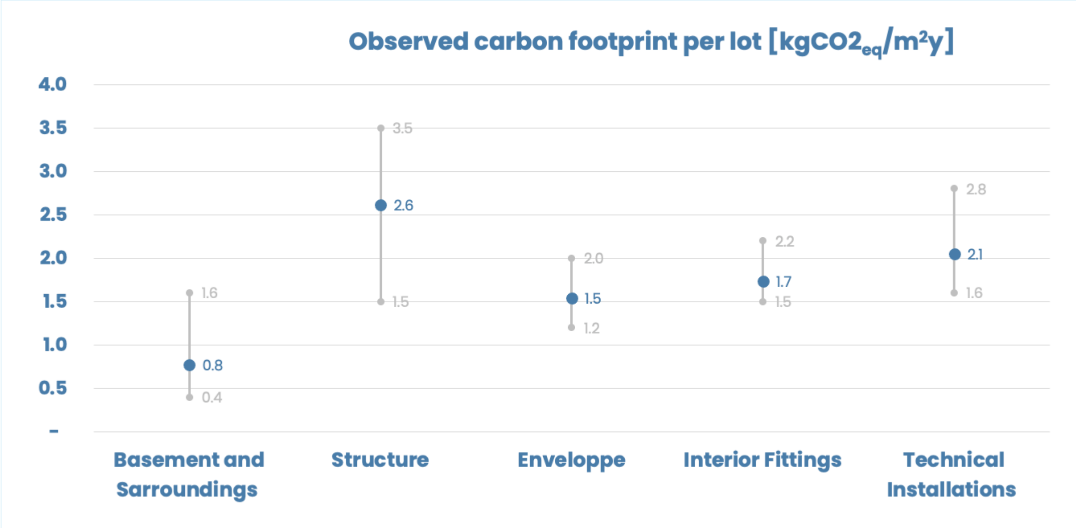
→ Whatever the construction technics, the carbon impact is around 8.5 ±0.5 kgCO2eq/m2y.

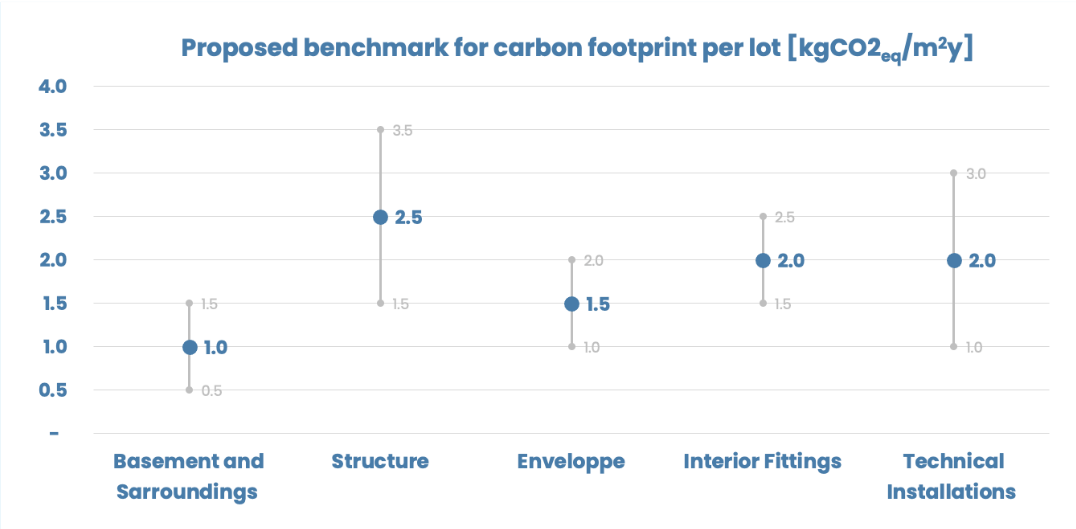
More questions than answers

- Why don't constructions using bio-based materials result in a lower overall impact ?
- Why doesn't concrete constructions exhibit a higher global carbon footprint?
- Why isn't there a single building made of bio-based materials at the top of the list? (We have buildings made of concrete and bricks, concrete, and prefabricated concrete).
- Why biodlings with higher structure impact, have lower envelope impact and inversely the ones with lower envelope impact, have higher structure impact
- Why isn't there a single building approaching the target value of 7 $kgCO_2eq/m^2y$ despite our call for projects from several developers of low-carbon buildings ?
- Why fully concrete buildings still perform well in terms of CO_2 ?
- Why is the footprint of installations varying so little, and why is it around 24% when international literature suggests a consensus of approximately 1/3 of the impacts ?
- Could these unexpected observations come from calculation biases, the norms, the KBOB database, the software, or the engineers who performed the calculations ?

→ Why does the choice of the primary materials has such minimal impact on the overall carbon footprint at a global level ?

Indicative observed values per lot and proposed benchmarks

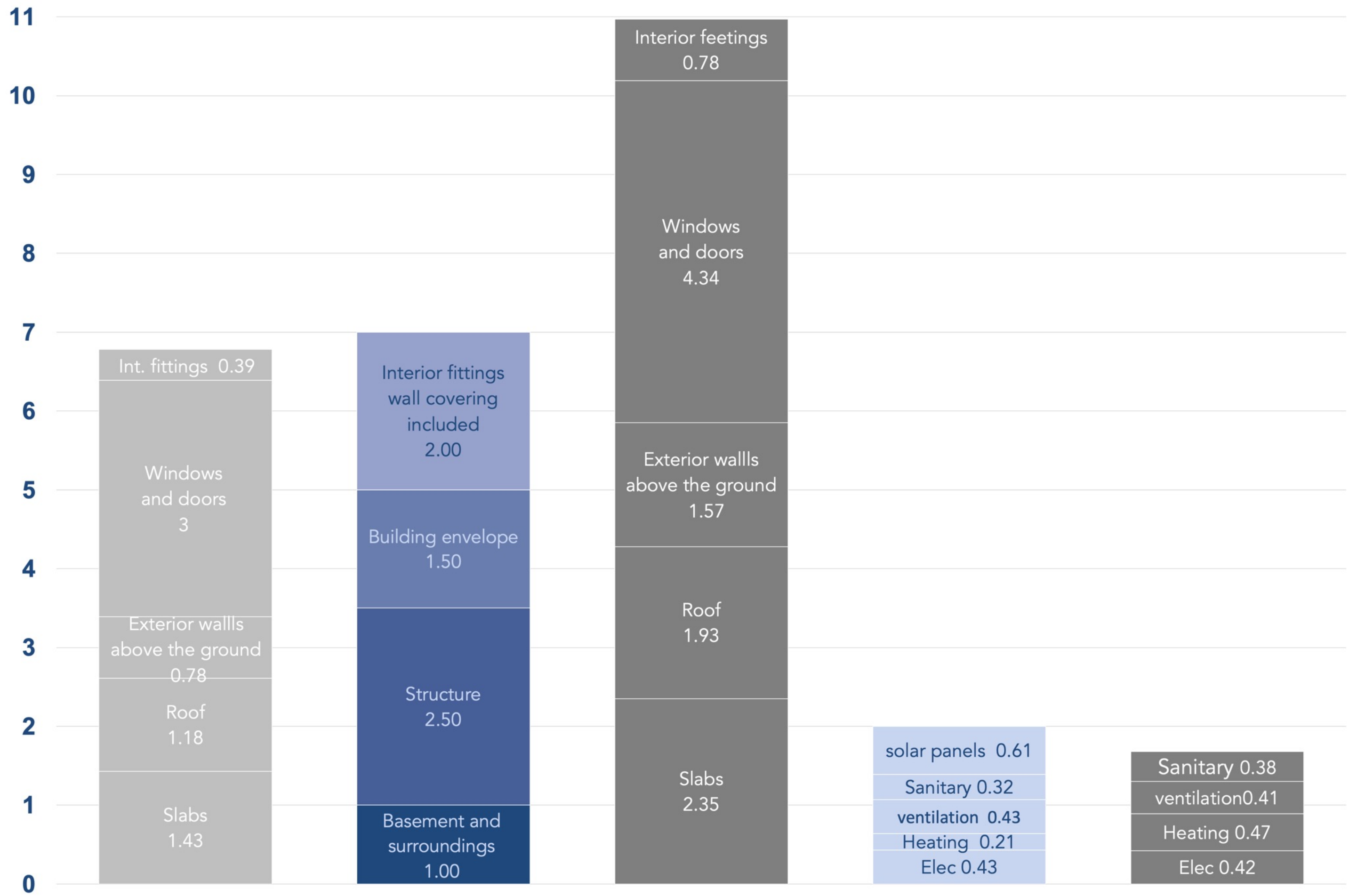




- Although the statistical sample is small (10 buildings mostly of divers programs) we observe a stable distribution between groups.
- We propose benchmarking values for each group as a discussion basis for the accountability of design stakeholders in an optimisation process.
- Although it is difficult to obtain the minimum values in every group it is possible to acquire a better value than the indicative middle value. If the impacts of a group are higher, design choices in other groups should compensate.
- The sum of the benchmark values equals the SIA 2040 limit value of 9 $kgCO2_{eq}/m^2.y$.
- **Basement and Surroundings, 1** $kgCO2_{eq}/m^2.y$: single underground level, reduced underground car park
- **Structure, 2.5** $kgCO2_{eq}/m^2.y$: optimised concrete structure, non-optimised mixed structure.
- **Envelope 1.5** $kgCO2_{eq}/m^2.y$: standard MOPEC, cladded exterior walls.
- **Interior fittings, 2** $kgCO2_{eq}/m^2.y$: standard residential interior fittings.
- **Installations, 2** $kgCO2_{eq}/m^2.y$: standard sober MOPEC for decarbonated heat.

→ We propose a set of benchmark values as a discussion bases for the accountability of the design stake holder choices (civil engineer, installation engineers, owner, architect).

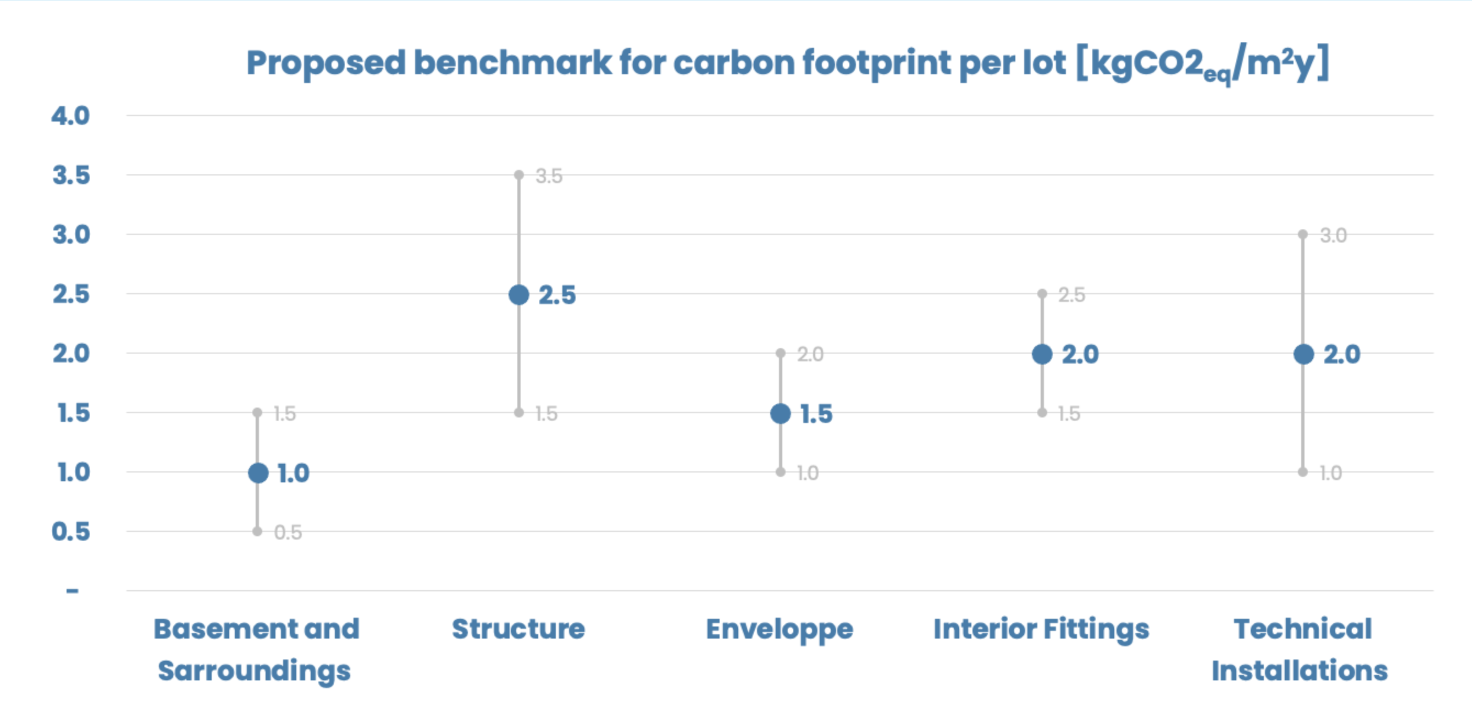
Comparison of the benchmark values with Minergie max and min values

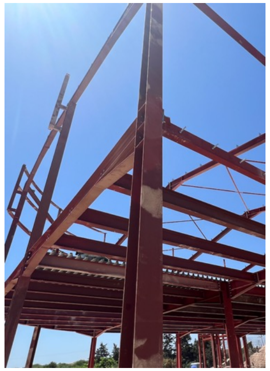


- Minergie classification is based on Lesosai export possibilities. The data is divided by thermal envelope elements (exterior walls, roof, slabs, windows). This thermal analyses classification can make it difficult to understand the impact distribution among different building stakeholders and detailed building elements.
- Minergie limit values vary depending on the program, the energy reference area, installation and technical choices. If we add construction elements and installation the upper limit can reach 12.5 $kgCO2_{eq}/m^2.y$ for residential buildings, which is well above SIA 390's 9 $kgCO2_{eq}/m^2.y$.
- The benchmark results addition (7+2) is close to to the Minergie lower limit of 8.46 $kgCO2_{eq}/m^2.y$ and the SIA 390 limit value of 9 $kgCO2_{eq}/m^2.y$
- In this study, we have observed a tendency among building actors to prioritise filling the CO2 budget rather than aiming for the lower target value.

→ The proposed middle benchmark values correspond to Minergie lower values.

Use of the benchmark guide for activating optimisation levers in early design

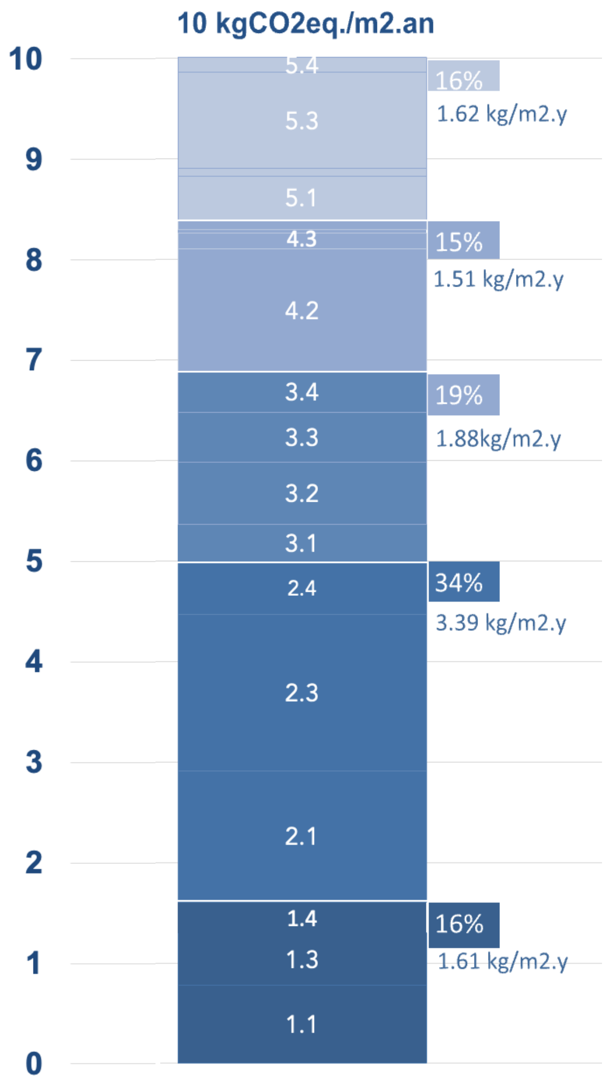



- The initial optimisations in the early stages of building design have significant impacts: the size of underground spaces, the form factor, the percentage of façade covered by windows, and the optimisation of Energy Surface Area. For example, the early decision to mutualize parking for the some of the buildings in the study, has significantly reduced the values in group 1.
- Group 2, 'Structure,' shows the largest variations among the five groups (from 1.5 to 3.5 kgCO2eq/m2.y). It is important to note that reducing the carbon footprint of the structure, for example, through the use of a point-supported vertical structure, can affect other aspects such as facade coverings, including filling elements. Conversely, a light façade may impact other elements of the structure.
- Lesosai calculations of installations lack exhaustiveness and transparency in their calculation. In this study, installations represent around 20% of emissions, whereas French studies establish their participation at around 1/3 of the total impact of the building.
- Modelling of technical installations, fittings, and underground constructions is poor in both reference impacts in KBOB and the existing Swiss software. The proposed thresholds are based on existing modelling. It is possible that their real impact is higher and will evolve according to the software and data base upgrades.

→ Knowing the impact of early design choices is a powerful lever for optimisation.

Detailed analysis methodology for the 5 lots



Group 5. Technical Installations
- 5.1 Electrical systems
- 5.2 Heating and cooling installations
- 5.3 Ventilation and air conditioning
- 5.4 Sanitary Installations
- 5.5. Photovoltaic panels
- 5.6 Transport facilities

Group 4 Interior Fittings
- 4.1 Partition walls
- 4.2 Flooring
- 4.3 Wall coverings
- 4.4 Ceiling coverings
- 4.5 Fixtures
- 4.6 Acoustic insulation

Group 3. Building Envelope
- 3.1 External wall cladding
- 3.2 Openings
- 3.3 Roof covering
- 3.4 Thermal insulation

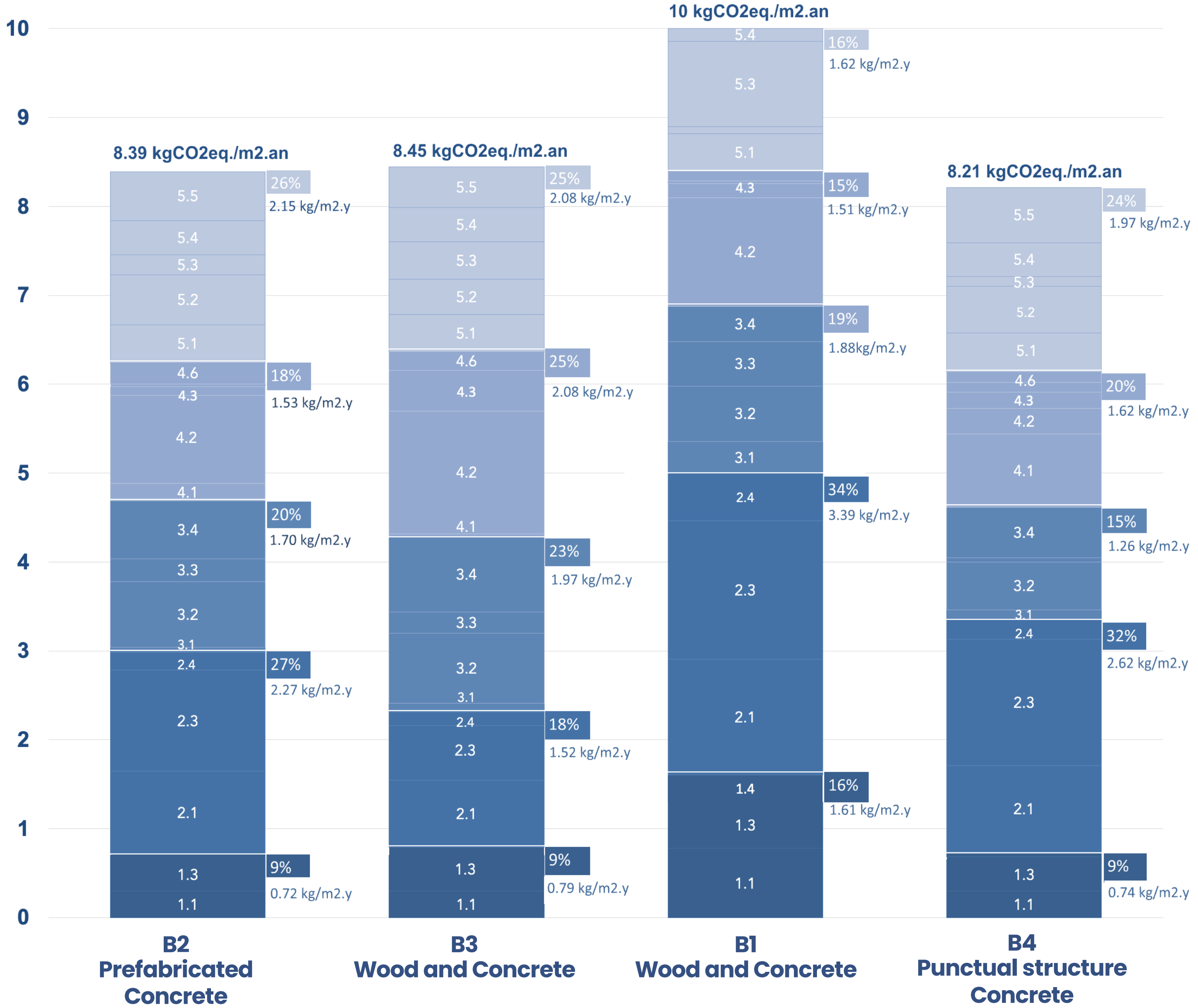
Group 2. Structure
- 2.1 Structural walls
- 2.2 Structural columns
- 2.3 Slabs and beams
- 2.4 Roof

Group 1. Basement and Surroundings
- 1.1 Basement excavation
- 1.2 Foundation
- 1.3 Raft
- 1.4 Underground wall cladding
- 1.5 Surroundings

- A detailed analysis of the content of the 5 lots gives better insight on the choices generating high CO2 emissions.
- For the 1.6 kgCO2eq/m²/year associated with the basement and surroundings (benchmark budget 1), excavation and the raft account for 1.3 kgCO2eq/m²/year. This raises concerns about the decision to build 15 meters deep. If this depth is necessary for any reason, the design team should be aware and seek compensations with other strategies.
- In this case, not only lot 1 has high carbon footprint, lot 2 also presents a value higher than the benchmark although there is use of wood in the structure. The hypothesis that this is due to large span of the load bearing structure (>8m) is not sufficient because not only 2.3, (slab and beams) is high, but also 2.1 and 2.2 (walls and columns).
- In group 4, the high impact of the 4.2 (flooring) questions the flooring composition.
- Ventilation and air conditioning in section 5.3 dominate the technical installation budget, raising concerns about this choice. This is especially pertinent if the project developer aims to adhere to the exemplary standards expected of public developers, with a total global budget of 7 kgCO2eq/m²/year.

→ Detailed analysis of the lots is a powerful tool for understanding the project choices.

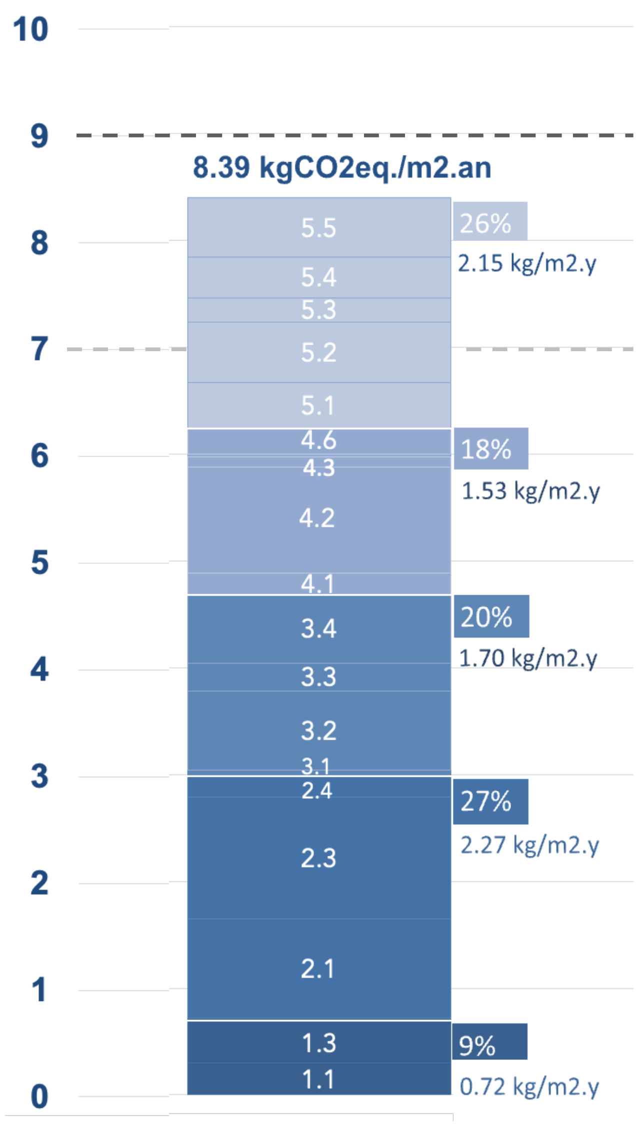
Detailed comparative analysis of 4 buildings



- We show how the five-group analysis enables to recognise the actors that could propose optimisation of their design choices or justify their higher impact in case the project developer would wish to attain the target of 7 $kgCO2_{eq}/m^2y$.
- The slab thickness (2.3) is a problem for B1 and B4 and in less extend for B2. Slab thickness could be the consequence of ventilation tubes in the slab, high span of load bearing, or acoustic problems. All these reasons could be treated with different strategies than thickening the slab.
- B2 uses a prefabricated self-bearing facade. In Group 2 (structure), this increases carbon emissions due to more load bearing elements but reduces the facade composition and covering structure (Group 2) resulting lower overall value.
- B3 demonstrates the opposite tendency, with a lighter structure made of wood and mixed slabs (Groups 2-3) and more emissions for insulation, fire protection, and covering materials.
- B1 has a higher structural impact with thick reinforced concrete walls (2%) in the basement and ground floor. The other groups are under the benchmark values. Further analysis will be provided in the following slide.
- B4 with a point-supported structure, has significantly reduced the weight of vertical structural elements. However, the structure still represents 30% of the impact due to the significant impact of the slabs.

→ Selecting low-carbon materials alone isn't an adequate strategy if it results in additional constraints for addressing other issues such as fire protection, building stability, and acoustics.

B2. Residential building with prefabricated concrete facade



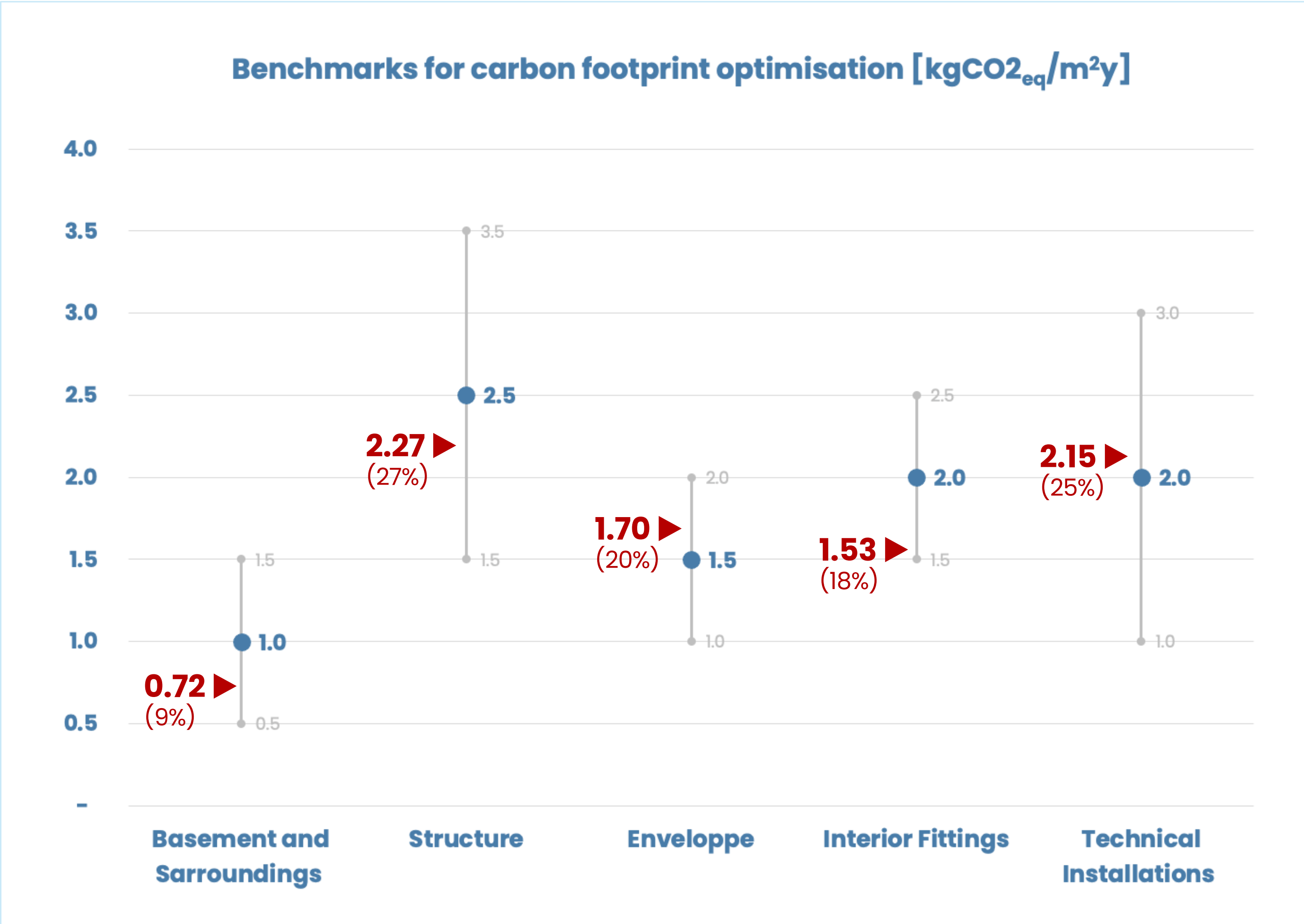
Activity: Residential
SRE: 9000 m2
Form factor: 1.01
Glass surface: 30 %
Structural material: Prefabricated concrete and concrete slabs
Number of stories: 5 +1 basement
Wall thickness: 30 - 45 cm
Slab thickness: 3 5-50-90 cm

*Additional, 0.3 $KgCO2_{eq}/m^2$.y has been accounted for external parking spaces in the neighbourhood.

- This Five-story residential building has a compact shape with a reduced glass surface. The facade consists of a thin precast concrete system with load-bearing walls in the interior. The slabs are made of 22 cm of reinforced concrete. There is one level of basement. The installations account for 26% of the CO2 impact, mostly due to the solar panels and other electrical installations but also due to the heat pump for heat recovery.
- **Group 5. Technical Installations >2**: The ground floor of this building is dedicated for school and commercial activities with higher needs for technical installations. Single flow ventilation (5.3) presents lower impact. The impact of 5.2 is due to the presence of heat recovery heat pump.
- **Group 4. Interior fittings <2**. Interior fittings are mostly wooden with some concrete surfaces left row. The high impact of 4.2 is due to high thickness screed up to 9 cm. This high impact could be also a calculation bias. The screed lifespan was considered 30 years. Floor surfaces are made of wood 0.6, tile 0.3, linoleum, and some surfaces left row.
- **Group 3. Envelope >1.5**. The 8 cm thickness facade concrete covering is responsible of the impact of 3.2. Prefabricated concrete uses large quantities of PUR (polyurethane) and EPS (expanded polystyrene) responsible for the high impacts of 3.4.
- **Group 2. Structure <2.5** . Reinforced concrete of reduced thickness 12 cm for vertical linear load bearing structure on the façade. Presence of some interior walls. Heavy and thick reinforced concrete slabs of 22 cm thickness.
- **Group 1. Basement and surroundings <1**. Single basement level. We consider 0.3 $kgCO2_{eq}/m^2y$ for the construction of a neighbouring car park.

→ This building's success lies in optimizing the 12 cm structural wall thickness, with further potential in slab composition, technical installations, and insulation type.

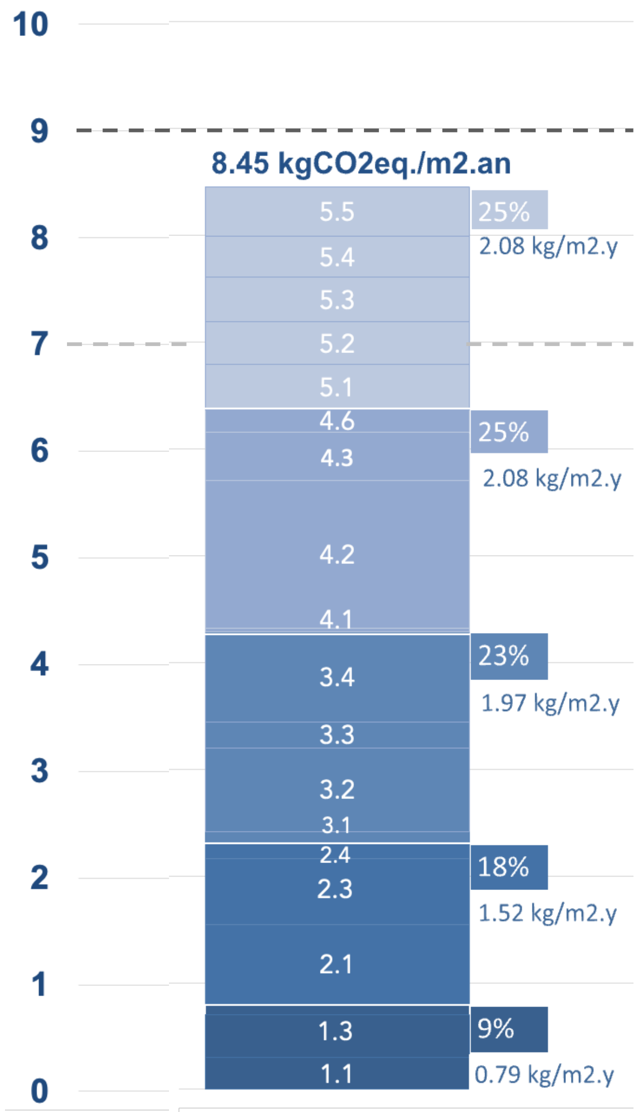
Benchmarking of B2 with prefabricated concrete façade



- All the groups are close to the indicative values. The building envelope's optimisation is projected in the impact of the structure group. The interior fittings is the most optimised group for this building.
- The installations group is above the indicative value. The direct emissions should be checked to verify that the high indirect emissions of the installations are justified by a significative reduction of the direct emissions.
- Reduction of the exterior wall thickness reduced the overall structure impact. There is additional potential by reducing the still content of the reenforced concrete (less still in higher storeys). Here we can see that 12 cm interior concrete solves also the problems of noise insulation and fire protection of the façade. No additional actions are required reducing the interior fittings and envelope impacts.
- Here we observe the inverse consequence chain in global carbon footprint. A material with high carbon footprint as a material choice (concrete) saves CO2 impacts for other utilities (acoustics, fire protection) giving a global lower impact.

→ Optimised prefabricated concrete (reduction of wall depth) leads to overall good performance.

B3. Residential building with mixed wood and concrete structure



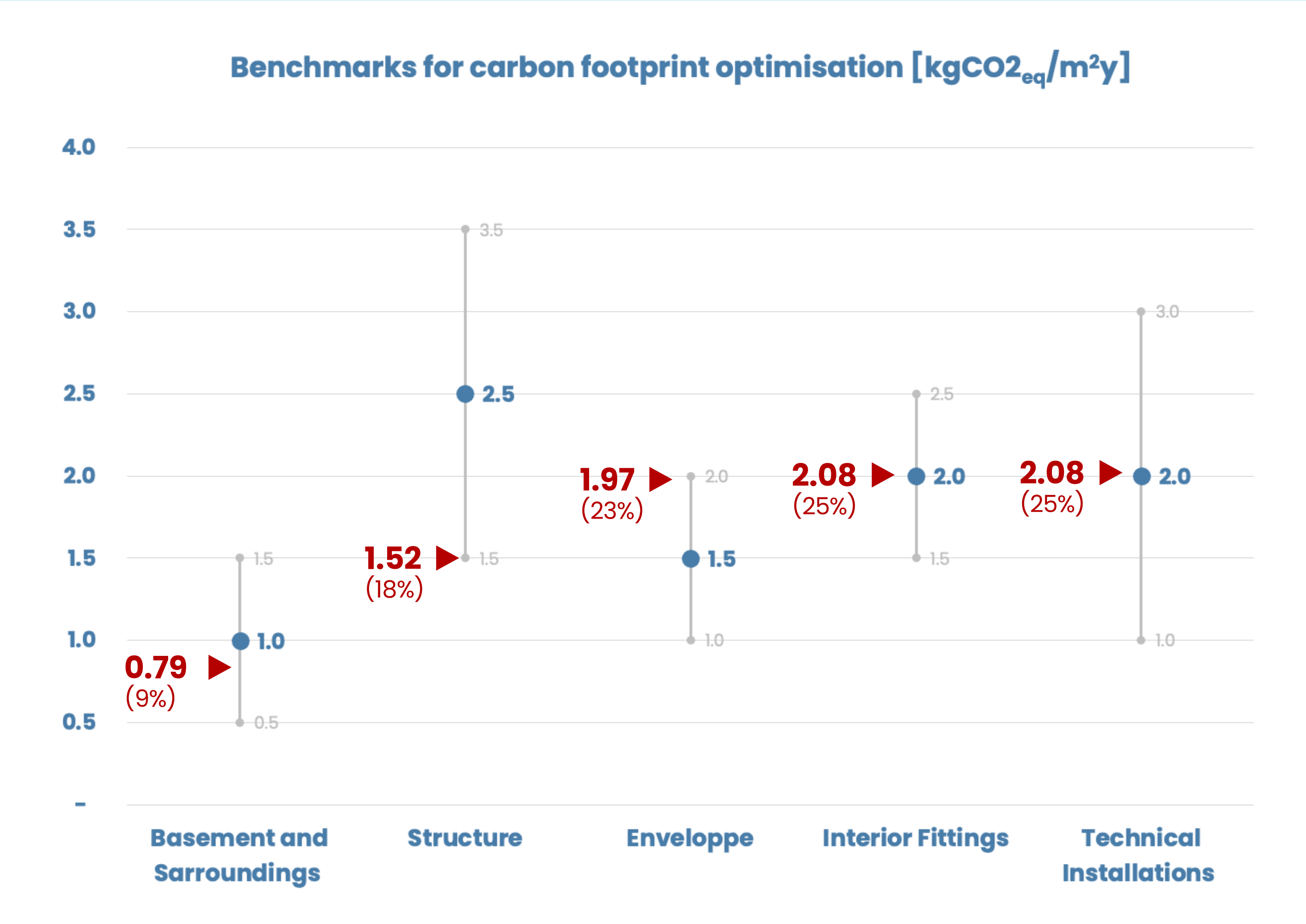
Activity:	Habitation, mixed
SRE:	5000 m2
Form factor:	0.94
Glass surface:	34 %
Structural material:	Cast in place concrete, wood
Number of stories:	5 to 6 (including 1 basement)
Wall thickness:	40 cm
Slab thickness:	50 cm

*Additional, 0.3 KgCO2/m2.y has been accounted for external parking spaces in the neighbourhood

- This residential building has a compact shape with a reduced glass surface. The structure has low impact made possible with a mix of wood pillars and slabs, with some concrete in the walls and ground floor. The wood structure of the facade is filled with compact insulation. The envelope and interior fittings have the largest impacts. The insulation layers and flooring elements are the thickest of the four buildings..
- **Group 5. Technical Installations >2**: The high impact of installations is due to the ventilation and electrical systems for residences, as well as high-complexity for office spaces. The point of 5.5 shows the impact of photovoltaic installations.
- **Group 4. Interior fittings <2:** Unoptimized coating thickness of 1.5cm for floor coverings. 4.2 shows the impact of cement screed of 7cm, vanished parquet/ceramic tile slab/ linoleum with a lifespan of 30 years.
- **Group 3. Envelope >1.5:** The concrete base and upper floors have a plaster finish on wooden frame. 3.1 depicts the triple glazed windows with a wood—metal frame. 3.4 the presence of EPS (Expanded Polystyrene) and PUR (Polyurethane) insulation in large quantities. The roof consists of 22cm of compact rock wool and plastered façade.
- **Group 2. Structure <2.5 :** The building consists of a mixed vertical structure of wood and concrete with a wooden slab. 2.1-2.2 show the reinforced concrete walls' impact as well as the impact of wooden columns. 2.3 shows the impact of wooden slabs.
- **Group 1. Basement and surroundings <1**. Single basement level. We consider 0.3 $kgCO2_{eq}/m^2y$ for the construction of a neighbouring car park.

→ Mixed wood-concrete structure reduces the footprint of this category. However, these savings are spend for insulation, installations, slab coverings with a global impact similar to concrete buildings.

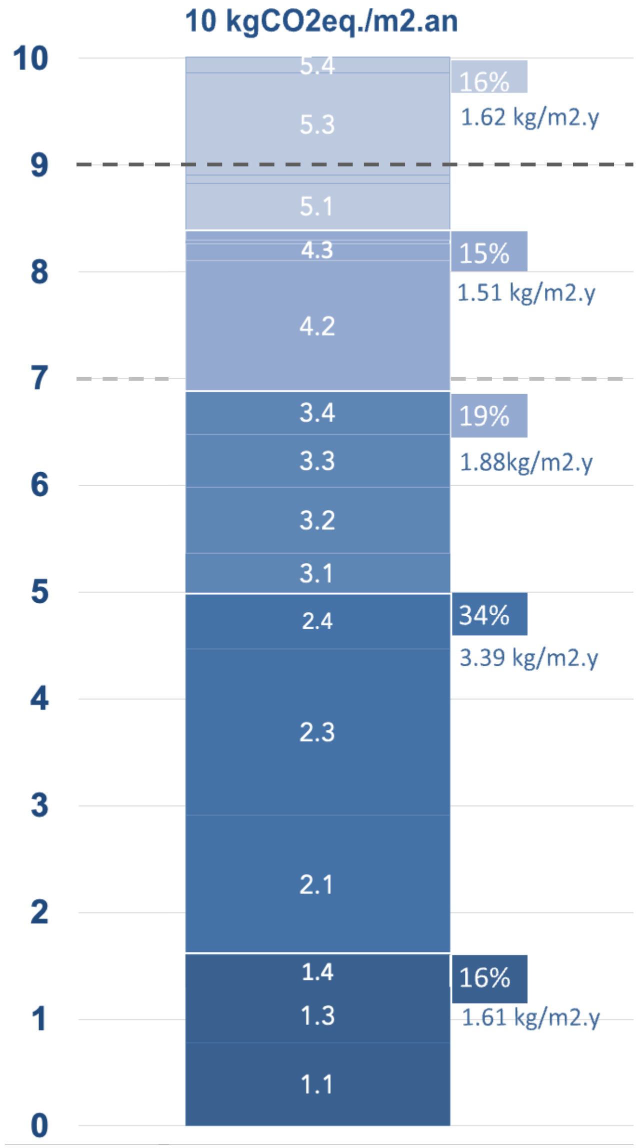
Benchmarking for B3, Residential – Mixed wood and concrete

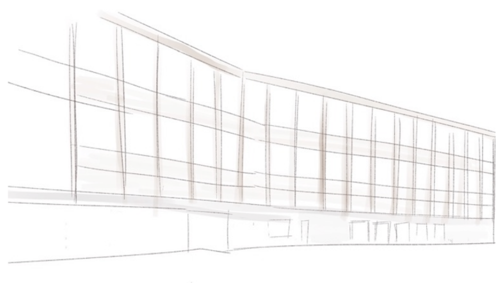


- The structure group has the lowest value, with a score of 1 kgCO2 less than the indicative value and 2 kgCO2 less than the maximum value. This is due to relatively small wall thicknesses, wooden slabs and some wooden pillars.
- The groups, interior fittings and installations are very close to the indicative values. The fact that the structure is light in nature means a lot of envelope and interior fittings have to take place. However, as the latter values aren't above the indicative values, the building's overall group balance seems successful.
- Envelope impacts are higher than the indicative benchmark due to insulation choices. This could be avoided with no architectural or cost impacts in an optimisation process towards the SIA target value.
- Screed and noise insulation rise the impact of Interior feedings.
- This building opens the discussion about the consequences of wood choice on fire protection and sound insulation impacts.

→ Optimised mixed wood-concrete structure leads to overall good performance.

B1. School made of a concrete and wood structure



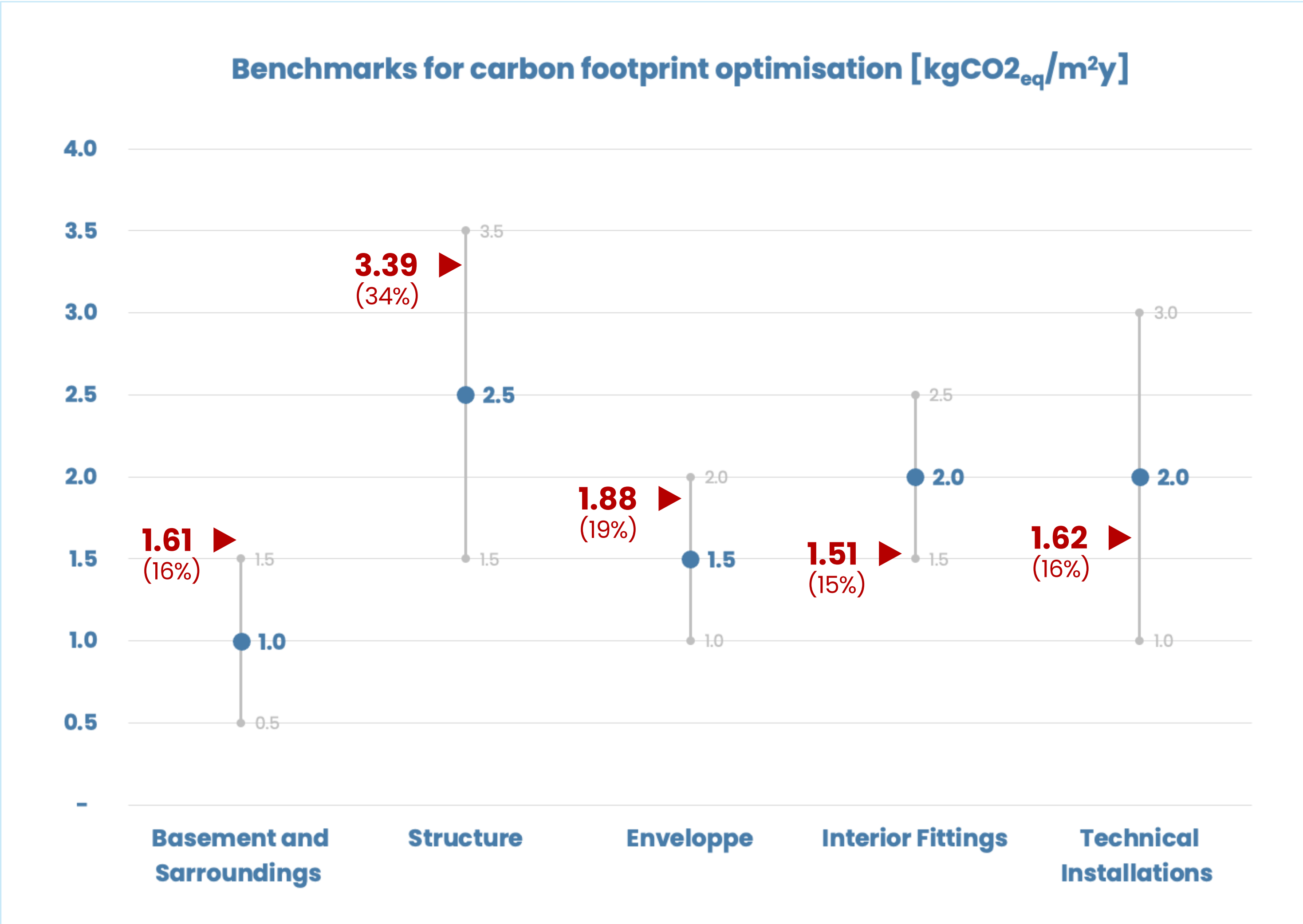


Activity:	School
SRE:	5000 m^2
Glass surface:	50%
Structural material:	cast in place concrete, wood
Number of stories:	4 (including 1 basement)
Wall / Pillars thickness:	30-50cm
Slab / Beams thickness:	23-50cm

- The school has a large footprint in relation to SIA limits. Excavations and underground construction occupy a large percentage of emissions. The structure mainly consists of cast in place reinforced concrete of large thicknesses. Wood is used punctually for some upper level structural elements and coverings. The main thermal insulation used is polystyrene highly intensive in emissions. Interior linings are generally of sober aesthetics. Technical installations emissions are high without photovoltaic panels, mostly due to the building's function demands.
- **Group 5. Technical Installations < 2**: Installations according to school function. Point 5.3 depicts the impact of ventilation systems needed for classes and offices.
- **Group 4. Interior fittings <2:** Interior lining are kept simple. Point 4.1 doesn't appear because the bricks of partitions walls are accounted for in the structure. Mainly linoleum floor coverings, no information on ceiling coverings.
- **Group 3. Envelope > 1.5:** Cast in place concrete and wood envelope with window openings. 3.1 shows exterior wall claddings in wood, plaster and aluminium.
- **Group 2. Structure > 2.5 :** Reinforced concrete linear load bearing exterior structure, some load-bearing interior walls, robust concrete slabs of substantial thickness. 2.1 and 2.2 show structural concrete and wooden columns 30-50cm. 2.3 reinforced concrete slabs of 23-50cm.
- **Group 1. Basement and surroundings > 1:** Large basement surface with thick retention walls. 1.1 large volume of basement excavations, 2200m2 of surface area of 5m depth. 1.3 thick concrete raft slabs and beams of 50cm.

→ Higher CO2 emissions could be explained by the higher budget allowed by the label but also by the program choices with deep and extended underground constructions and thick slabs.

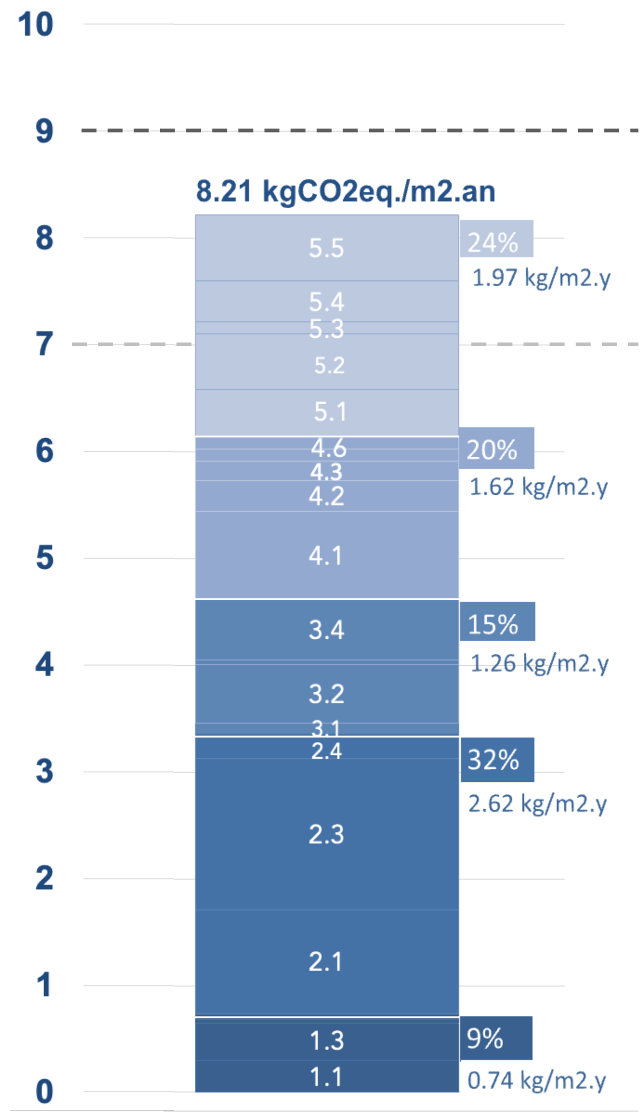
Benchmark of B1, School - Concrete and wood structure.



- The groups of interior fittings and installations are under the indicative values. The fact that installations have a low value may be due to the absence of photovoltaic panels. The direct emissions have to be checked in order to verify that the sobriety of the envelope and installations are not negatively impacting the operational emissions of the building.
- The structure above and below the ground level is a lot higher than the indicative values. This can be justified by the large span needed for school classes. This can be optimised by the architect and civil engineer.

→ As we can see on the category benchmark, structure and basement consumes 56% of the SIA budget.

B4. Residential building with concrete punctual structure



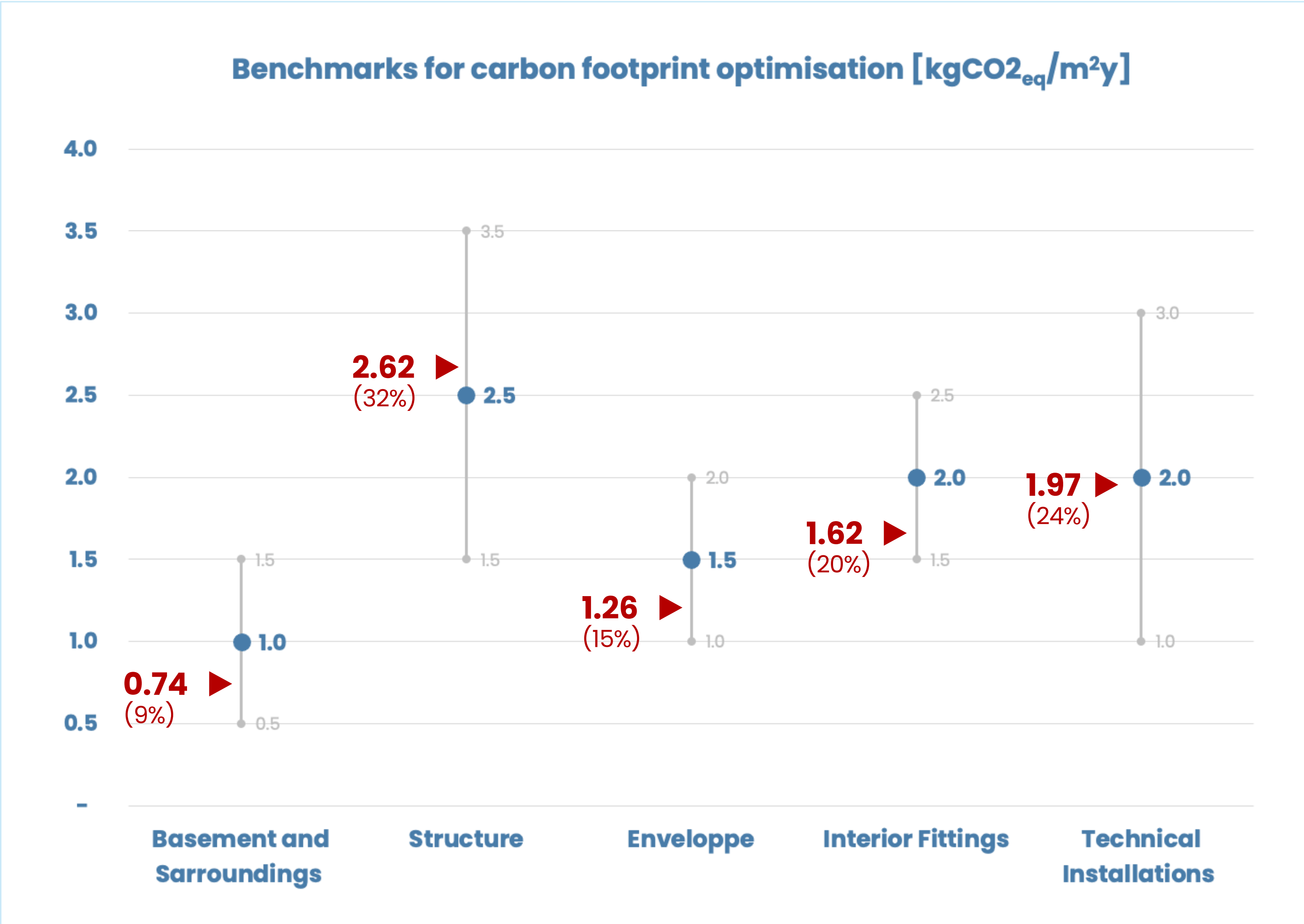
Activity: Residential
SRE: 4000 m2
Form factor: 1.11
Glass surface: 24 %
Structural material: Concrete beams and pillars
Number of stories: 6 + 1 basement
Wall thickness: 30-50cm
Slab thickness: 23-50cm

*Additional, 0.3 KgCO2/m2.y has been accounted for external parking spaces in the neighbourhood

- Six-story building, with the most compact shape of the four detailed analysis buildings and a smallest proportion of glass on the facade. Light concrete punctual vertical structure but thick concret slabs. Mixed covering in wood, aluminum, and concrete. Thin interior coverings. The slabs and the wall fillings have the heaviest impact on this buidling.
- **Group 5. Technical Installations ‹ 2**: Simple and efficient electrical and ventilation systems for residences. The point of 5.3 shows the low impact of natural ventilations, with simple air exhausts for kitchens and bathrooms. The 5.5 depicts the impact of photovoltaic installations.
- **Group 4. Interior fittings ‹2:** There is a sobriety in interior fittings. 4.2 shows the impact of the wood/tiles/linoleum/raw as flooring finishes combined to 7cm of screed. 4.1 shows the important impact of heavy partitions with reinforced concrete of 20cm or cement briques of 10cm taken into account within the structure. 4.6 shows the reduced carbon footprint of glass wool as acoustic insulation.
- **Group 3. Envelope ‹ 1.5:** Mixed covering of wood aluminium and concrete. Choice of insulation with good environmental performance. Reduced glass surface. Point 3.3 shows the impact of reduced glazing surface of around 25% with triple glazed wooden framed windows.
- **Group 2. Structure › 2.5 :** 2.1 and 2.2 show the point supported vertical concrete structure 2.3 depicts thick slabs of reinforced concrete of 20-24cm, wood of 18cm
- **Group 1. Basement and surroundings ‹1**. Single basement level. We consider 0.3 $kgCO2_{eq}/m^2y$ for the construction of a neighbouring car park.

→ This project benefits from its initial design choices (compacity, glazing ratio) rather than a specific material choice and presents the lowest impact compared to the 9 other buildings.

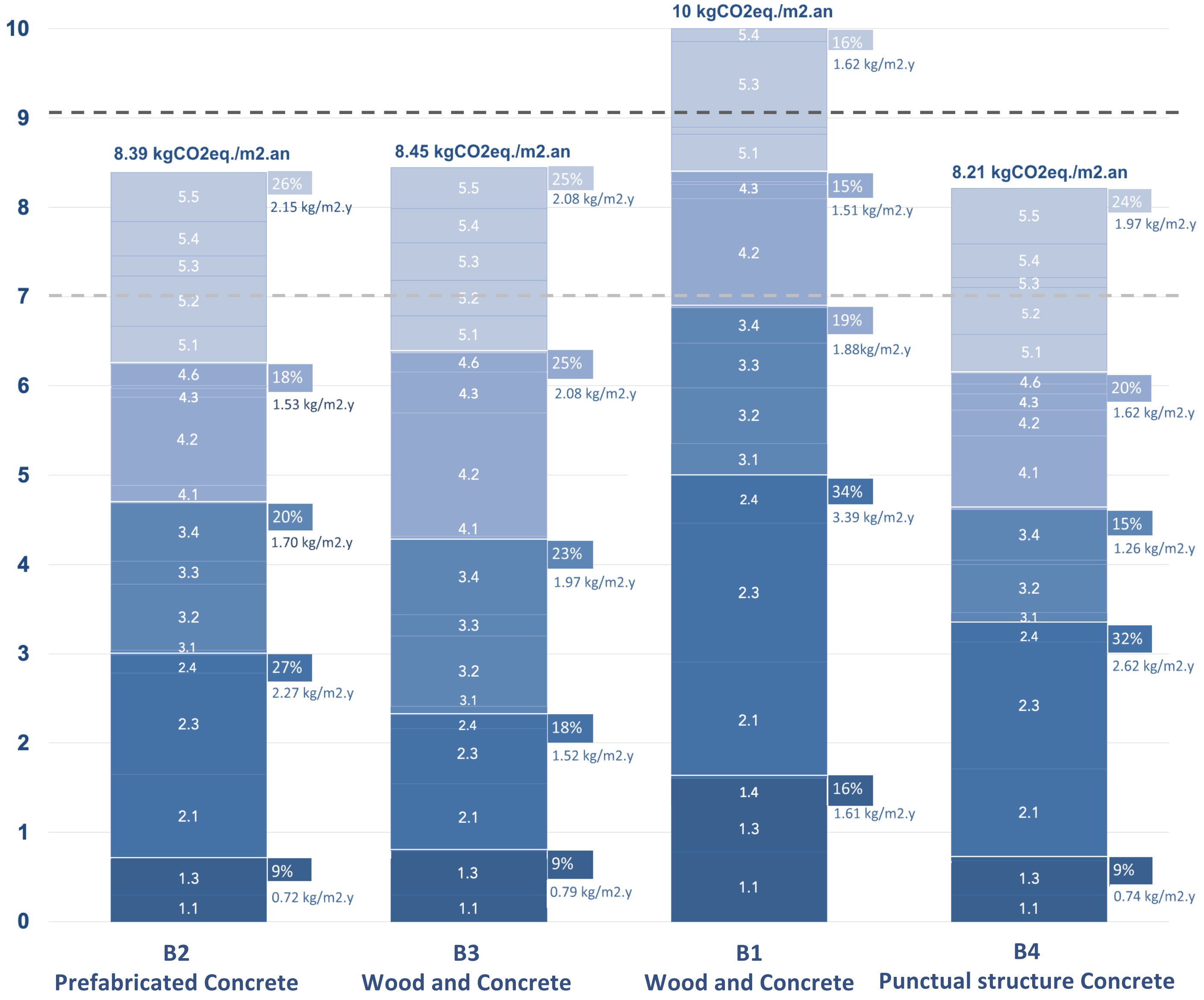
Benchmarking of B4, Residential - Concrete punctual structure



- The structure is above the indicative values. As seen previously, this is due to thick concrete slabs. Wooden slabs are present but still the minority.
- Value optimisation is observed for the interior fittings and envelope, occupying a small share of the overall building results. However, there is a lack of balance between the groups, given that the first two groups are above the indicative value while the other three groups are below it. A more holistic approach could be more effective.

→ The good performance of this project is evident across all design categories.

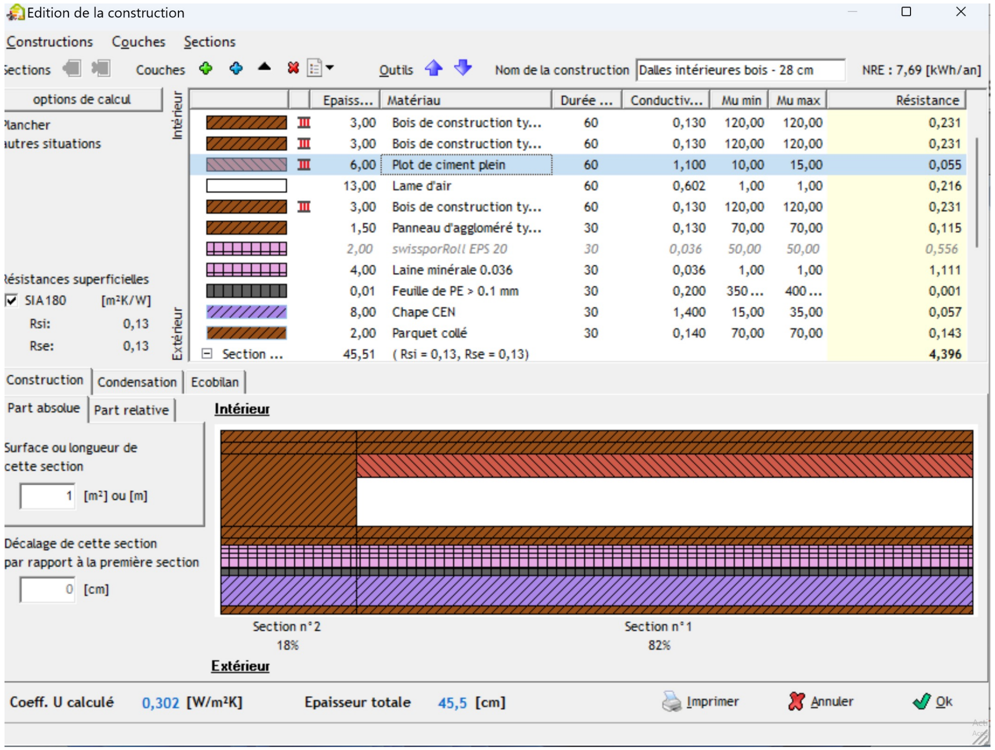
Study Feedback: Optimisation levers and limits for carbon



- Early design choices have an important impact : For instance, the impact of facades varies depending on design choices such as the form factor and glass proportion (Architect) and then the choice of insulating and covering materials (Building Physicist).
- A global approach and communication between actors is necessary to effectively reduce the complete carbon footprint of the building and avoid the shifting of impact from one group to another. Consequently, focusing on a single category or material is insufficient. This is because a group with low emissions may lead to an increase in emissions for another group.
- Also, in the detailed analysis, impact transfer between elements of the same category can be observed. For instance, there's a shift in the impacts from the optimisation of vertical structure to the horizontal structure.
- The choices and dimensions of floor elements represent the main impact of the interior design lot. Control and proper sizing of "invisible" parts such as screeds, frameworks, and acoustic insulation are as important as the choices of visible coverings. Often, the choice of wooden or mixed floor structure is not sufficient to reduce the global impact.
- A good design and dimensioning of elements, as well as understanding the specificities of materials implemented, such as the reinforcement percentage of concrete, are sources of simple optimisation.

→ Collaboration of all design teams is vital to achieving a collective reduction in CO_2 emissions.

Study Feedback: Modelling

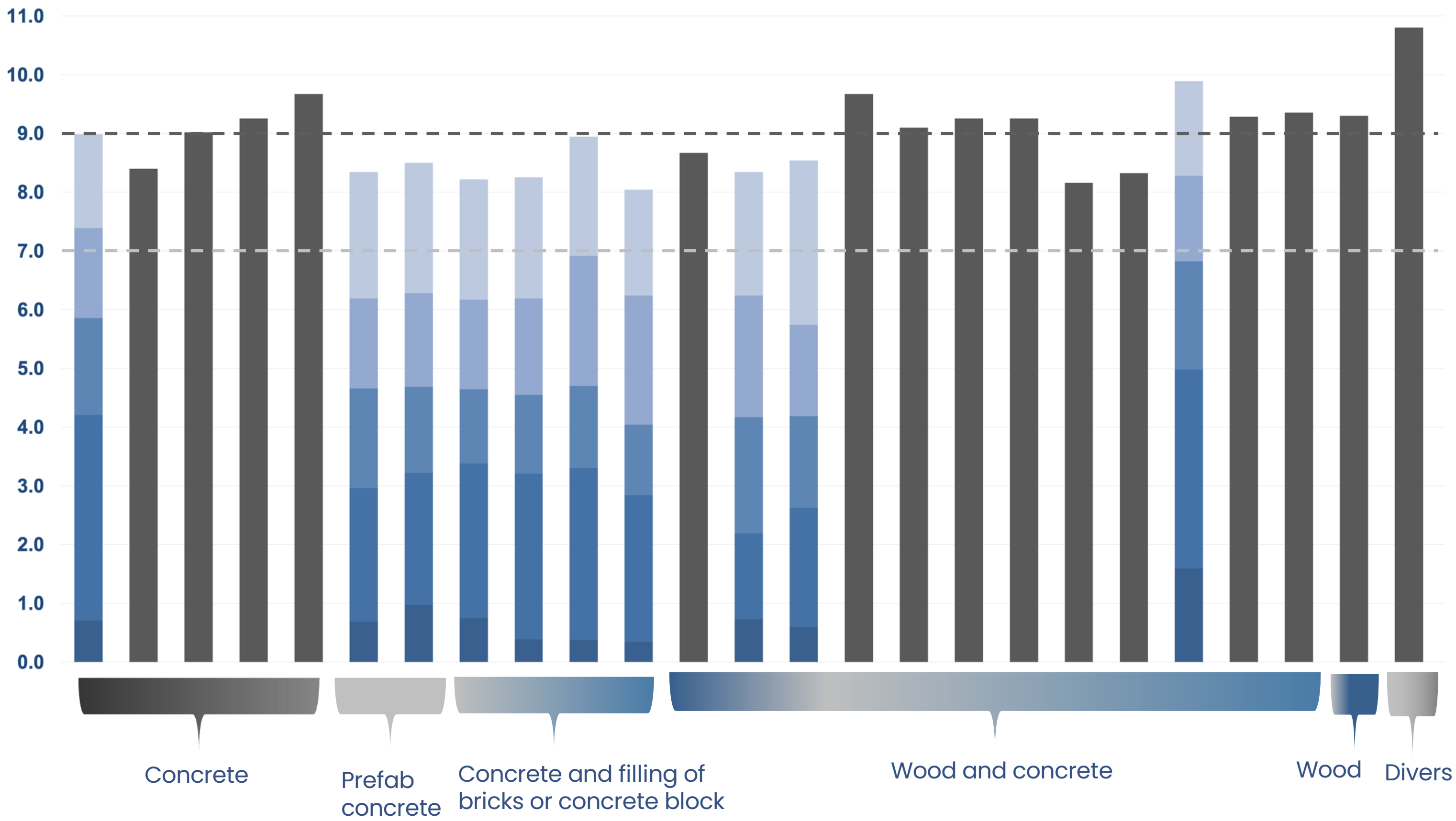


Life cycle assessment work requires the mobilisation of technical knowledge to avoid common errors observed during data analysis:

- Appropriate selection of data. For example, for concrete components, the choice of the reinforcement rate based on the specific use of concrete in the building (slab, wall, foundation, non-load-bearing wall, etc.).
- Selection of thicknesses based on materials. For example, Project 4 defined all coverings (wood, tile, linoleum, etc.) with equal thicknesses, distorting and increasing the impacts of the flooring lot (5.5).
- Uncertainties related to the number of uses of elements, i.e., how many times the element will be replaced during the building's lifespan. Lesosai defaults to 60 years for all elements (building lifespan defined by SIA 2032), which needs to be manually adjusted by element category according to SIA 2032.
- The exhaustivity of the materials is a serious problem. This starts even in the available materials and building elements in the databases. Lifts, fire protection, electronics are still absent from the database.
- High granularity of some technical installations (sanitary installations, heating, cooling, air distribution, electricity) seem to be a significant bias not differentiating buildings with high degree of technicity and sober buildings.

→ Achieving precision is challenging given the current state of databases and software.

Next steps



- We gathered the GWP Lesosai data for 25 new recent buildings, including schools and one residential building. It could be interesting to verify the benchmarking in a next study with a higher statistical sample of schools.
- Four full concrete buildings have the highest impact, above the sample average values, with half of them exceeding the SIA 390 limit. Within the sample, some interesting initiatives have been taken to reduce the concrete quantity. For instance, this is achieved by using thinner prefabricated elements or a concrete system with beams and pillars filled with other materials.
- The combination of wood and concrete in the sample exhibits significant heterogeneity in their utilisation across 12 buildings. While in certain instances it may result in the lowest building impacts within the sample, it consistently remains above the SIA lower limit. Further research with this sample would be valuable in determining the most efficient methods of incorporating wood in construction to reduce the global building footprint's carbon emissions.
- Schools exhibit a greater environmental impact due to program requirements such as large classes, extensive installations, electrical systems, and underground facilities. However, they are required to adhere to the same limits and target values as housing according to SIA 390 regulations. Conducting a comparative analysis on the footprints of six schools in both Roman and German Switzerland would be insightful. Generally, schools in Roman Switzerland demonstrate lower installation intensity, with features such as natural or hybrid ventilation and absence of cooling systems.

→ Further comprehension is required, on the significant effects of wooden constructions, the technical installations, the repercussions of certain choices on fire and noise protection.

Refurbishment

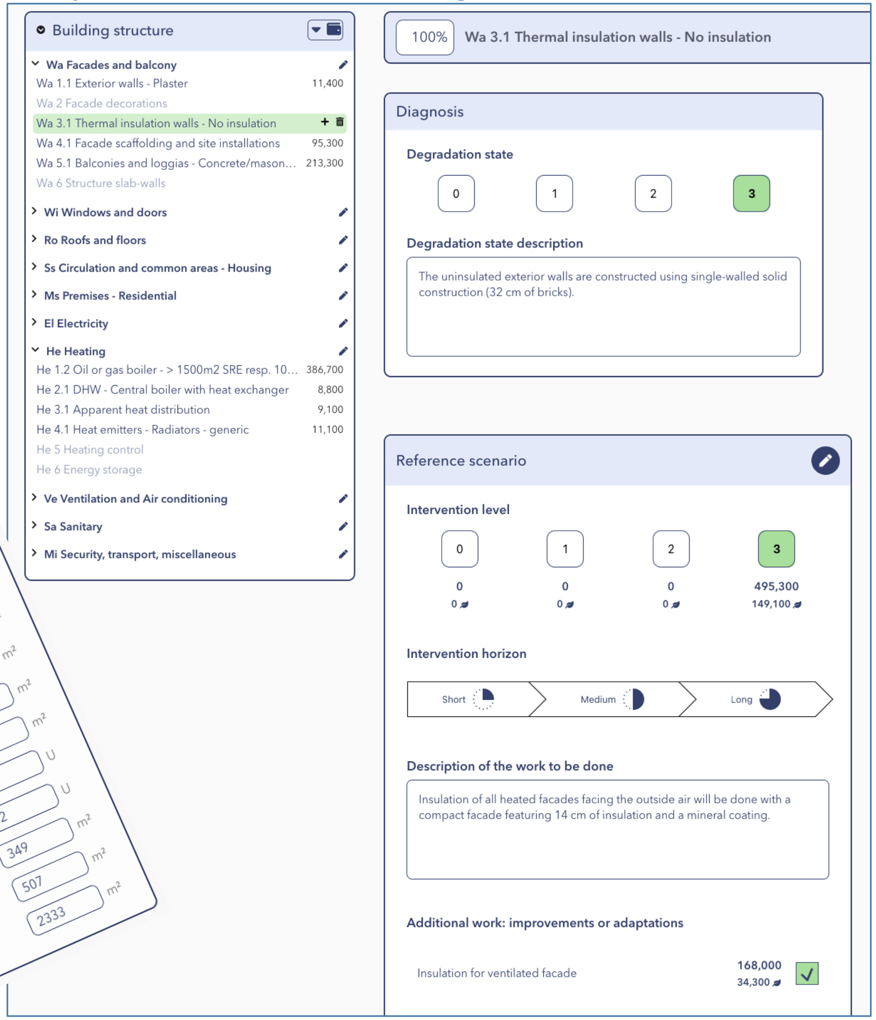
- EPIQR method for cost and carbon footprint calculations
- EDYCE: Renovation sample based on energy class
- Comparison of 3 real refurbishment results with E-DYCE projects
- Definition of indicative values per group

EPIQR+ to quickly calculate renovation costs and CO2 emissions of works

EPIQR

Groups and elements

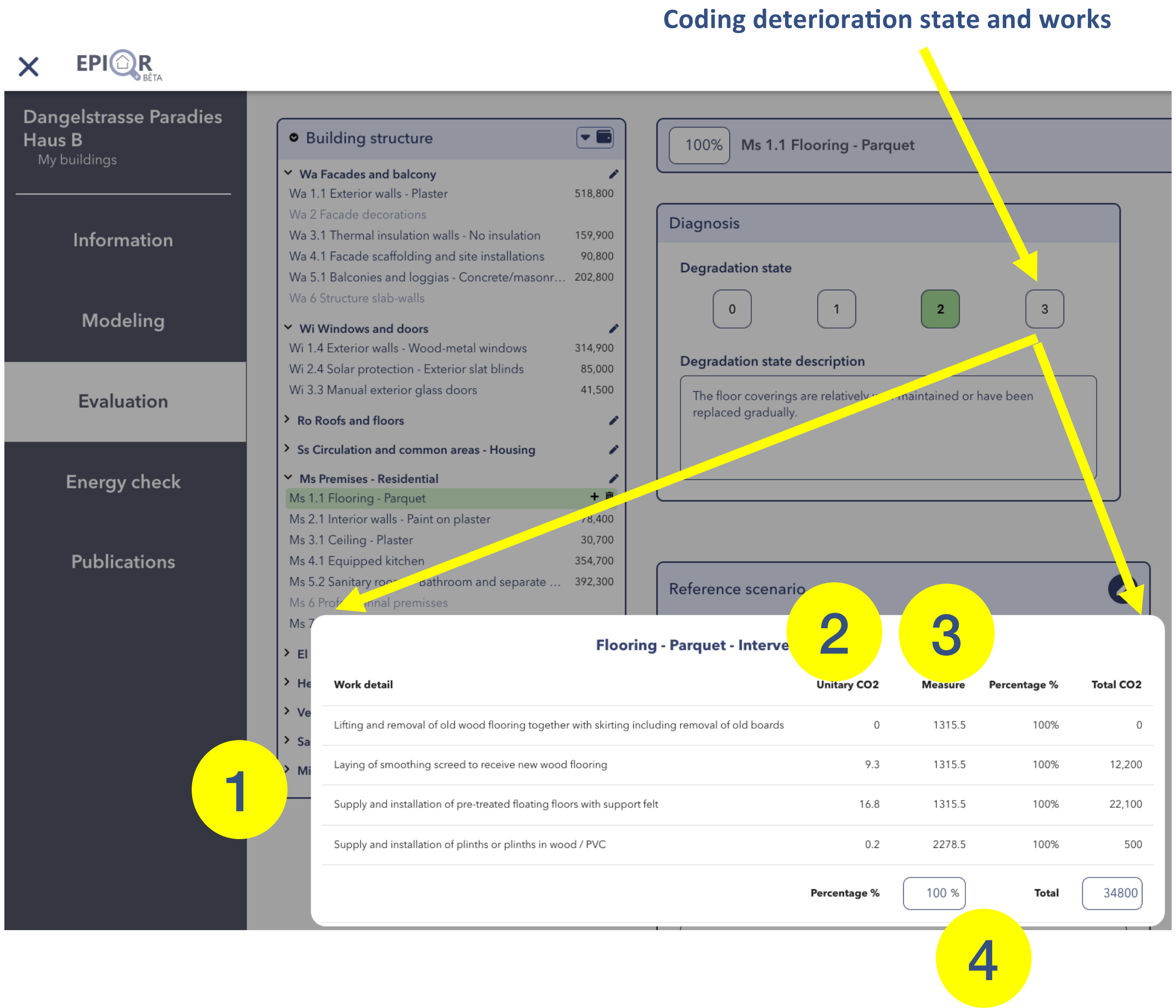
Coding deterioration state and works



- EPIQR+ is a mature method developed 25 years ago by EPFL in an EU research project to calculate renovation costs.
- In a recent EU research project, the method was upgraded and completed to quickly, transparently, and exhaustively calculate indirect CO2 emissions.
- The precision of the cost calculation has been proven over 25 years with a margin of ± 15%.
- The method models the diagnosis and related refurbishment costs of the building through approximately 50 elements grouped into 10 categories. The user visits the building and assesses the deterioration and obsolescence state of the elements, coding them from 0 (good state, no intervention) to 3 (replacement), passing through 1 and 2 codes for maintenance works.
- The method models all necessary quantities for calculating refurbishment works based on a reference building using 11 dimensional coefficients. A cost database describing all possible renovation works is continuously updated with the market cost of the works. By multiplying the unit reference cost with the reference quantity, the method calculates the renovation cost of a scenario built by the user.
- Recently, the ReCO2st research project calculated the carbon footprint of the database renovation works,. The method can use the same cost methodology to calculate the CO2 emissions of refurbishment scenarios.

→ Diagnosis 1 day of work, calculation of costs and CO2 emissions 2-4 hours

EPIQR+ CO2 : how it works



- Example of calculation of flooring carbon footprint

1. The user visits the buildings and, according to the deterioration state, determines the renovation works. Intervention state 3 corresponds to the replacement of the flooring. Selecting code 3, the method considers 4 (BKB) works to do the job.
2. The software will find the unit emissions for each work in the CO2 emissions database. The CO2 database is linked to the KBOB database and were not present from ecoinvent.
3. The method calculates the quantities of the works through reference ratios according to the dimensional coefficients introduced by the user. For example, 2278.5 linear meters of plinth were calculated from the introduced apartment surface area.
4. The total CO2 emission is the sum of all the described works' emissions weighted by the reference SIA lifespan. The user may adjust the total emissions to match reality more closely or replace them a more project-specific value calculated from other data sources.

- The method is transparent and explicit. It saves the user time and effort by providing unit impacts from the database, transforming impacts from unit impact per kg to the reference quantity calculated by the software, resulting total CO2 impacts of the refurbishment.

→ Diagnosis 1 day of work, calculation of costs and CO2 emissions 2-4 hours

How the user can compare two renovation scenarios

Standard MOPEC scenario

- **Direct Emissions** 6.0 kgCO2/m2.a

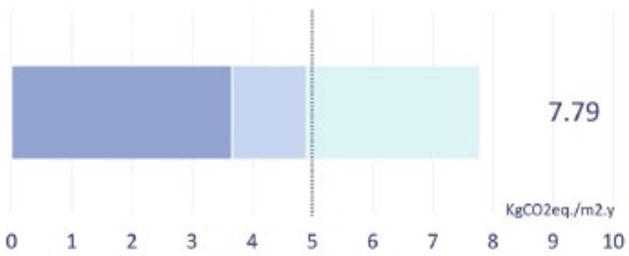
- **Embodied emissions**

Enveloppe et exterieurs	3.11
Aménagements intérieurs	0.52
Installations	0.48
Emission CO2eq. Total	**4.91**

Near Zero energy scenario

- **Direct Emissions** 3.3 kgCO2/m2.a

Enveloppe et exterieurs	3.66
Aménagements intérieurs	0.44
Installations	2.89
Emission CO2eq. Total	**7.79**



Construction 4.91 + use 6.0 kgCO2/m^2.an

Total= 10.9 kgCO2/m^2.an

Construction 7.79 + use 3.3 kgCO2/m^2.an

Total= 10.1 kg.CO2/m2.an

Case study

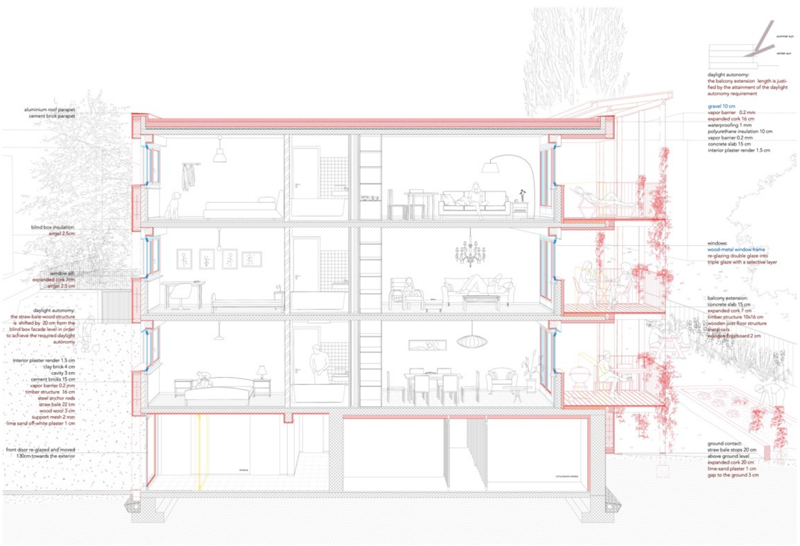
- From GEAK the user calculates the direct emissions – scope 3. In this case 6 kgCO2eq/m^2y standard MOPEC scenario and 3.3 kgCO2/m^2y for the Nzeb scenario (similar to Minergie P)
- EPIQR calculates the CO2 indirect emissions of all the works and classifies them according to the 10 EPIQR groups. Finally, results are aggregated into 3 design groups (envelope, interior fittings and installations). In renovation there are rarely works for basement and structure.
- The addition of direct and indirect CO2 emissions can be compared to the SIA or cantonal thresholds.

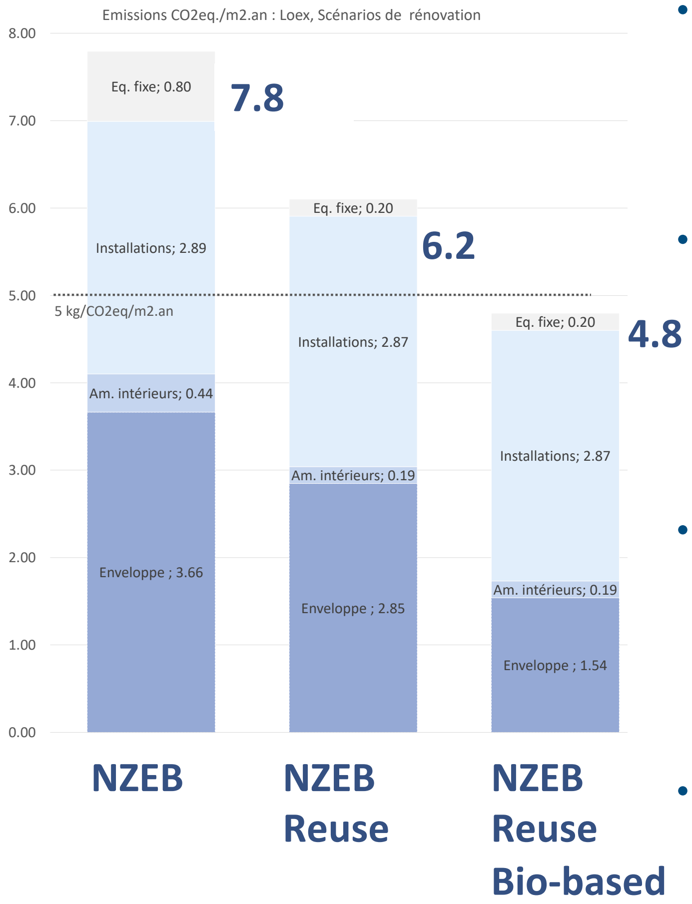
→ The user can very easily compare the indirect emissions of 2 or 3 renovation scenarios.

Example of optimisation using bio-based materials en reuse

NZEB scenario

		KgCO2eq/m2.a
Fa	Murs extérieurs et balcons	1,67
Fe	Fenêtres et portes	1,16
To	Toitures	0,68
Ss	Circulations et surfaces secondaires	0,15
Sp	Surfaces utiles principales	1,23
El	Eléctricité	2,26
Ch	Chauffage	0,14
Ve	Ventilation et climatisation	0,47
Sa	Sanitaires	0,03
Total de emissions		**7,79**

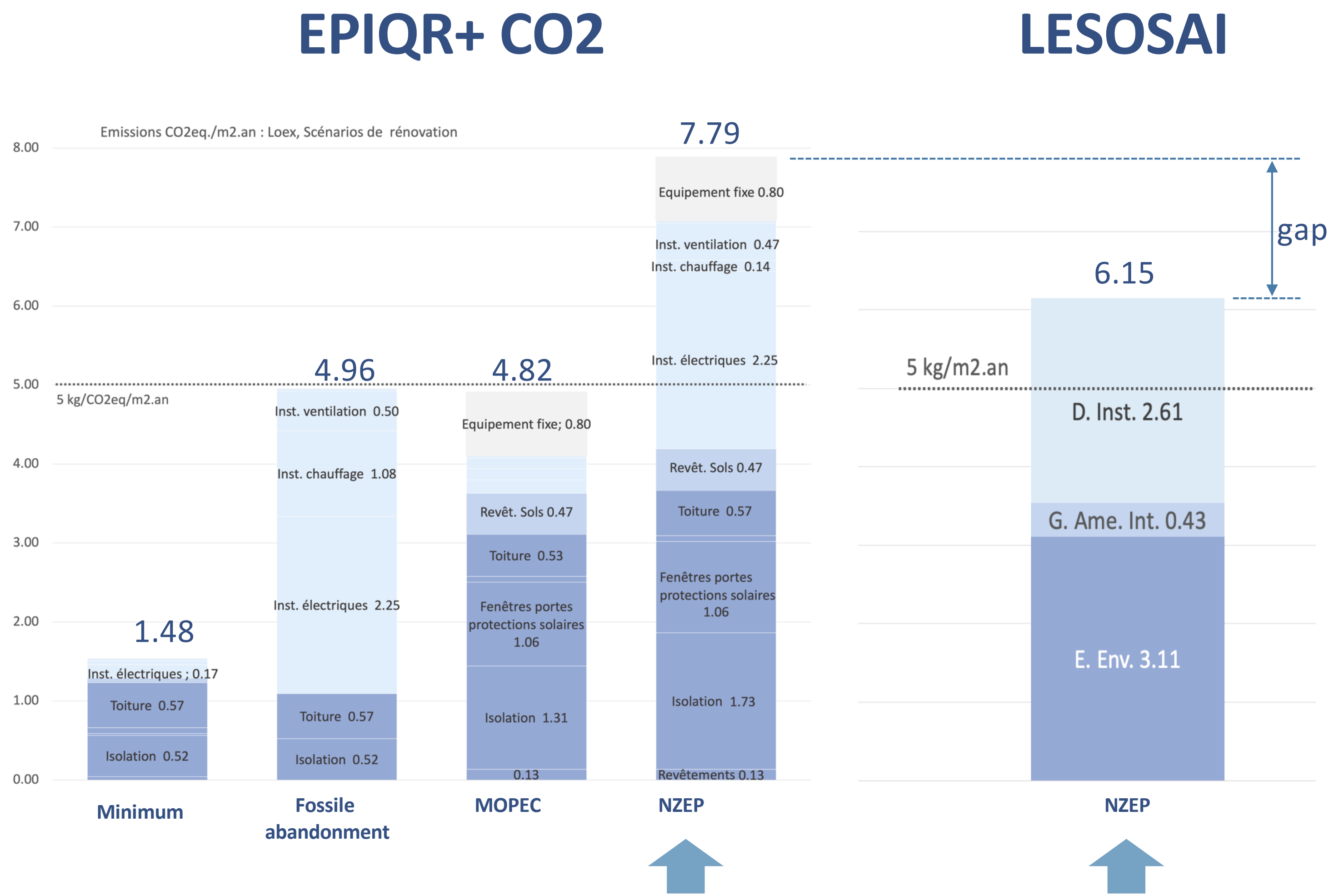




- Maria Loizou used EPIQR+ and LESOSAI in her EPFL master thesis in architecture to optimise the NZEB scenario using bio-based materials and extensive application of preservation and reuse strategies of existing materials.
- As we can see from the previous slide, for this case study, investing in deeper renovation, higher insulations thickness, and more installations for renewables can lead to a very slight benefit in terms of carbon footprint (10.1 instead of 10.9 of a sober MOPEC scenario).
- Maria preserved the sanitary fittings and reused the window frames in the second scenario reducing the indirect emissions to 6.2, still not respecting the limit of 5 kgCO2eq/m²y. EPIQR+ CO2 has a function helping the user to identify all potential reusable materials and calculates automatically the quantities.
- The final scenario uses straw instead of mineral wool for insulation, wood structure for the new balconies and cork for roof insulation additional to preservation and reuse strategies. The software shows that combination of all strategies may bring the total emissions to the desired level.
- EPIQR+ possibility to identify reusable materials and compare easily renovation scenarios saves time and makes optimisation process easy.

→ Easy comparison of renovation scenarios makes EPIQR+ CO2 a powerful optimisation tool.

Comparison of EPIQR+ CO2 results with LESOSAI



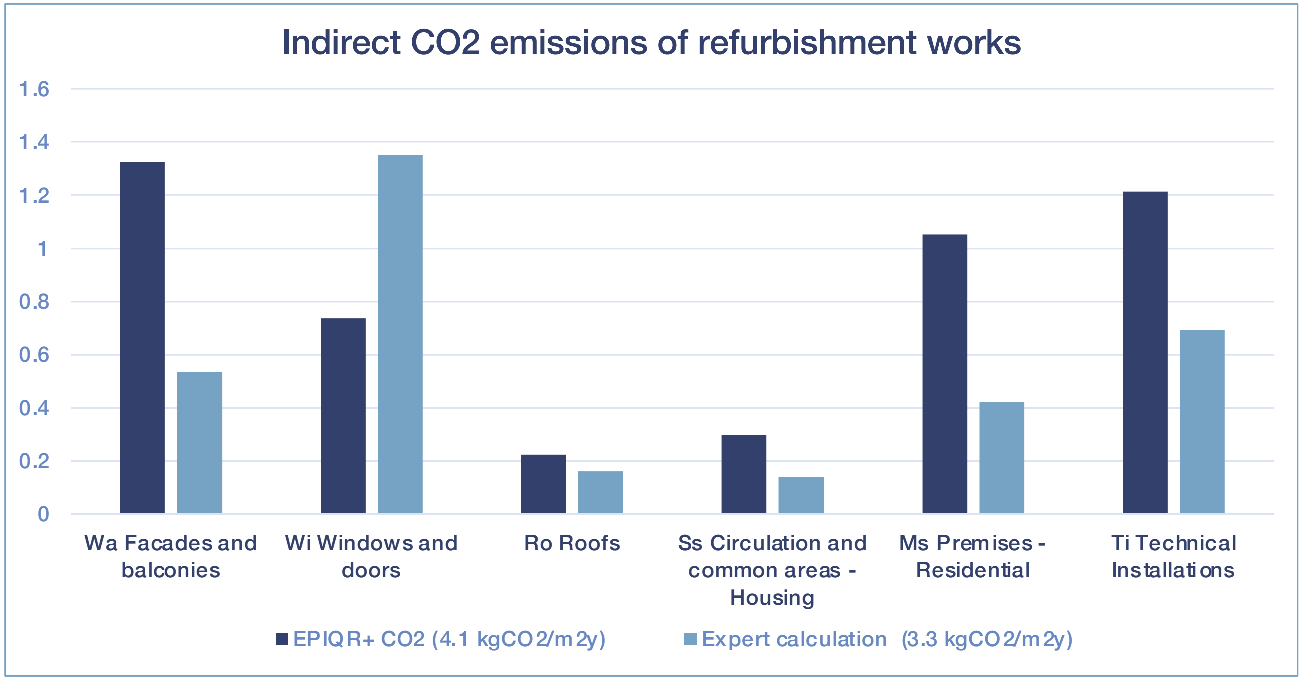
- In the framework of other studies, we compared the results of the reference building between EPIQR+ CO2 and LESOSAI.
- Although both software use KBOB as reference database, when there are no values in KBOB, EPIQR+ refers to ecoinvent and other data sources to complete (for example elevators, fire protection and interior fixe fittings in gray in the chart)
- In the graphs we may compare the NZEP scenario simulated with LesoSai and EPIQR+ CO2.
- The most important difference is the exhaustivity of the two methods. Several installations choices are missing in LESOSAI or a roughly aggregated value is used coming from KBOB. EPIQR+ considers everything. For example, window sills are nowhere introduced, solar protection, or differenciation of insulation near the ground etc.
- The result is that for the same renovation scenario EPIQR+ CO2 calculates 7.79 while LESOSAI 6.15 $kgCO2/m^2y$. It is not an error. It is simply a different approach with higher degree of exhaustivity in EPIQR.

→ The degree of exhaustivity between the two method gives significant difference in the result.

Comparison of EPIQR+ CO2 and expert calculations on a real renovation (R1)

Cost comparison

Résumé des coûts	EPIQR+	General quote	
Fa Murs extérieurs et balcons	972'400	862'989	11%
Fe Fenêtres et portes	441'400	341'771	23%
To Toitures et planchers	62'200	69'630	-12%
Ss Circulations et communs - Logement	540'600	525'268	3%
Sp Locaux - Habitation	999'100	1'019'656	-2%
El Electricité	239'100	218'535	9%
Ch Chauffage	399'300	360'780	10%
Ve Ventilation et climatisation	92'400	120'047	-30%
Sa Sanitaires	173'100	195'444	-13%
Di Securité, transport, divers	91'200	52'050	43%
Couts des travaux (HT)	**4'011'000**	**3'766'171**	**6%**

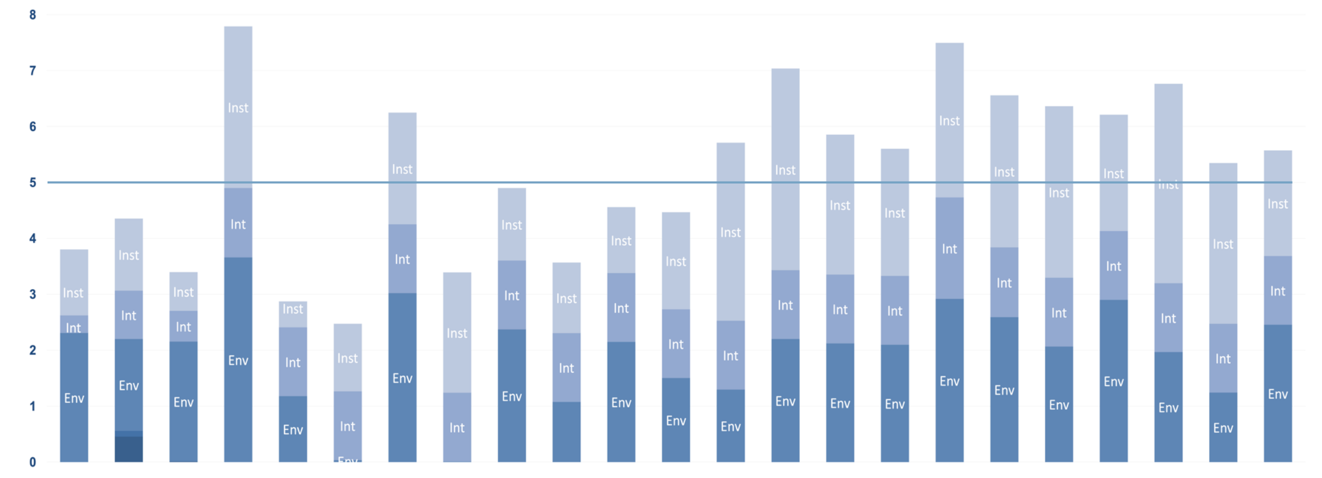


- Several validation analyses comparing calculated and actual refurbishment costs have shown a correspondence with deviations of less than ±15%. To further verify the validity of these findings, we selected a German Swiss building, aiming to confirm the alignment of real costs in another region and to calibrate the comprehensiveness of the considered works.
- We observe a very good correspondence between the cost prediction within the limits of the method validity. This proves that the considered renovation works present good degree of correspondence.
- Similar findings were observed in the comparison with LESOSAI data. However, a significant issue of exhaustivity emerged in the EPIQR+ CO2 calculation, which showed global renovation impact of 4.1 kgCO2/m2y compared to the expert value of 3.2 kgCO2/m2y. This discrepancy was compounded by an overestimation in the expert's evaluation of window impacts, as the building utilised "renovation windows" with lower environmental impacts than standard windows.
- The exhaustivity problem extends to premises and technical installations, as evidenced by the cost analysis. With 1,000,000 units of work out of a total cost of 3,766,000, it is implausible for the resulting CO2 footprint to range only between 0.4 kgCO2/m2y to 1.1 kgCO2/m2y according to EPIQR+.
- It's important to contextualise this difference. A decade ago, the primary purpose of carbon footprint analysis was not necessarily to meet a specific limit value but rather to compare alternatives. Therefore, experts often focused on the most impactful elements for simplicity's sake.

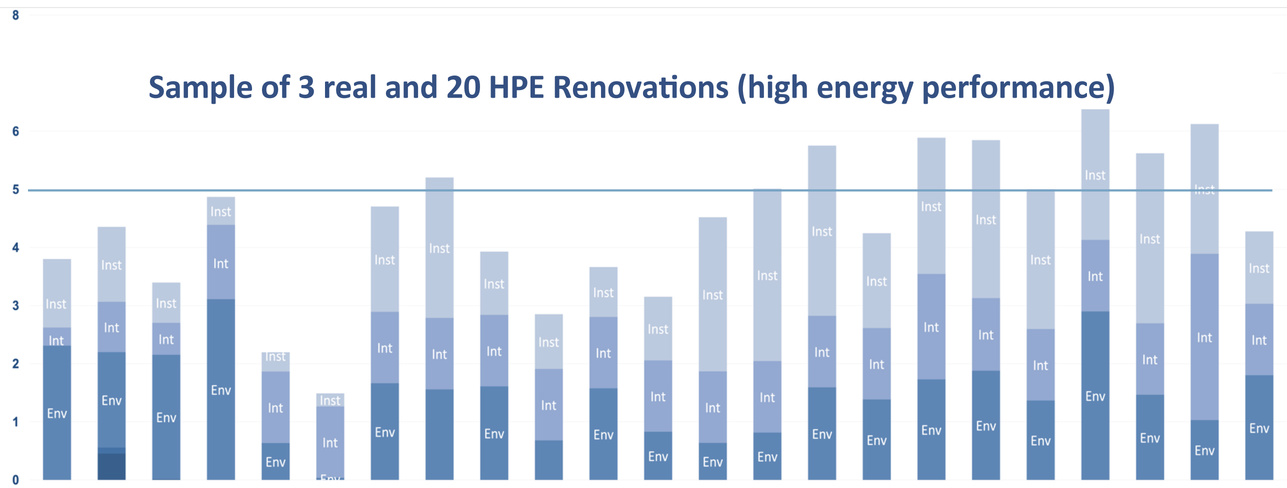
→ We need to transition from the comparative approach used in the 2000s to a more comprehensive and thorough calculation method.

Impacts of 3 real projects and 20 renovation scenarios (EDYCE project)

Sample of 3 real and 20 THPE Renovations (very high energy performance)



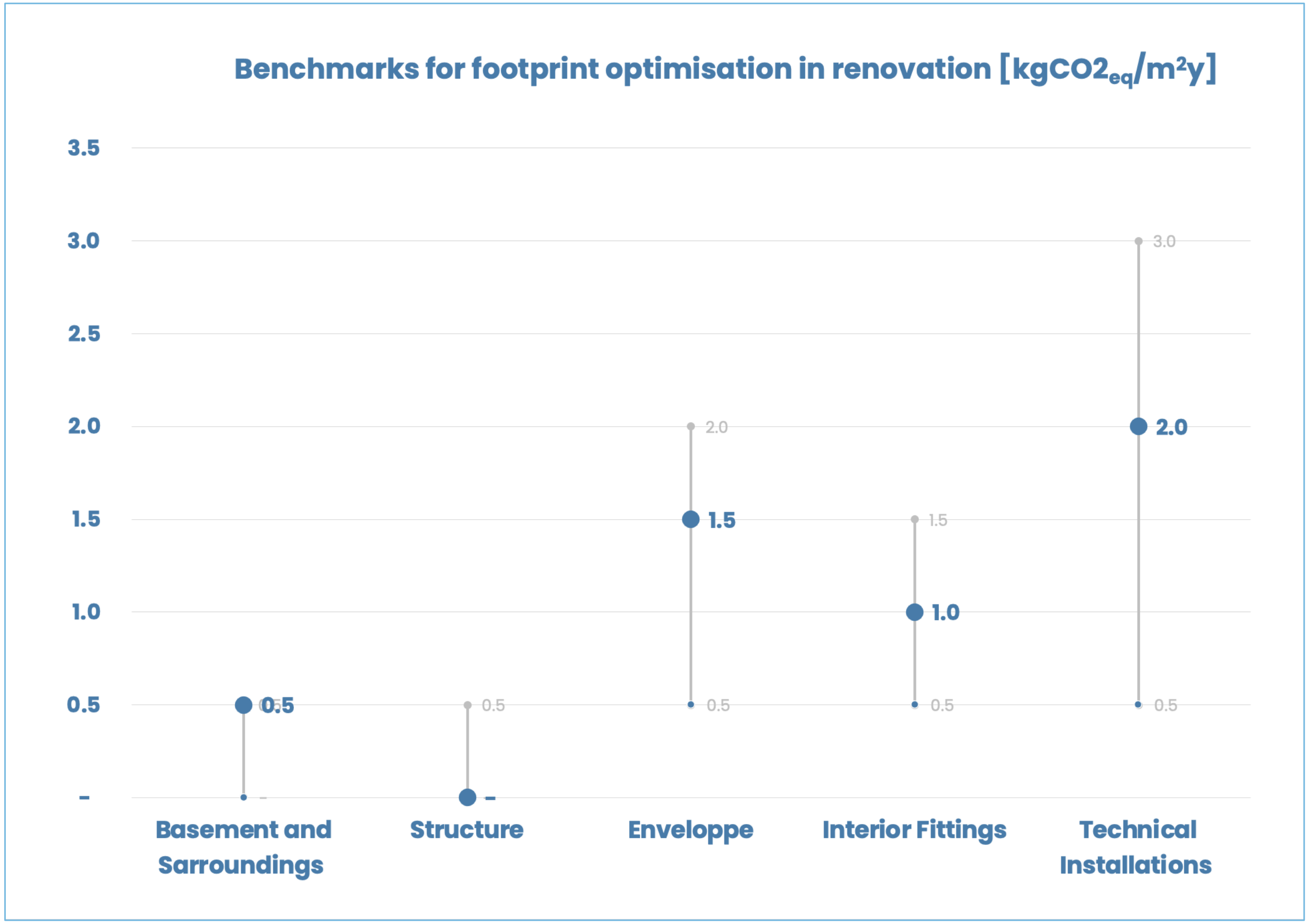
Sample of 3 real and 20 HPE Renovations (high energy performance)



- We used the carbon footprint analysis of 3 renovations (different calculation methods) and 20 refurbishment scenarios calculated with EPIQR+ CO2, once at Geneva HPE standard (MOPEC) and once at THPE (nZEP).
- From the results, it's evident that achieving very high energy performance ambitions makes it challenging to meet the limit of 5 kgCO2/m2y. The second graph illustrates that this challenge persists even for the MOPEC standard in some buildings.
- The lower values observed in the "expert" calculations (the first three on the left of the chart) highlight a significant issue with exhaustivity that needs to be addressed.

→ It will be difficult to comply to 5 kgCO2/m2y with the current renovation practices.

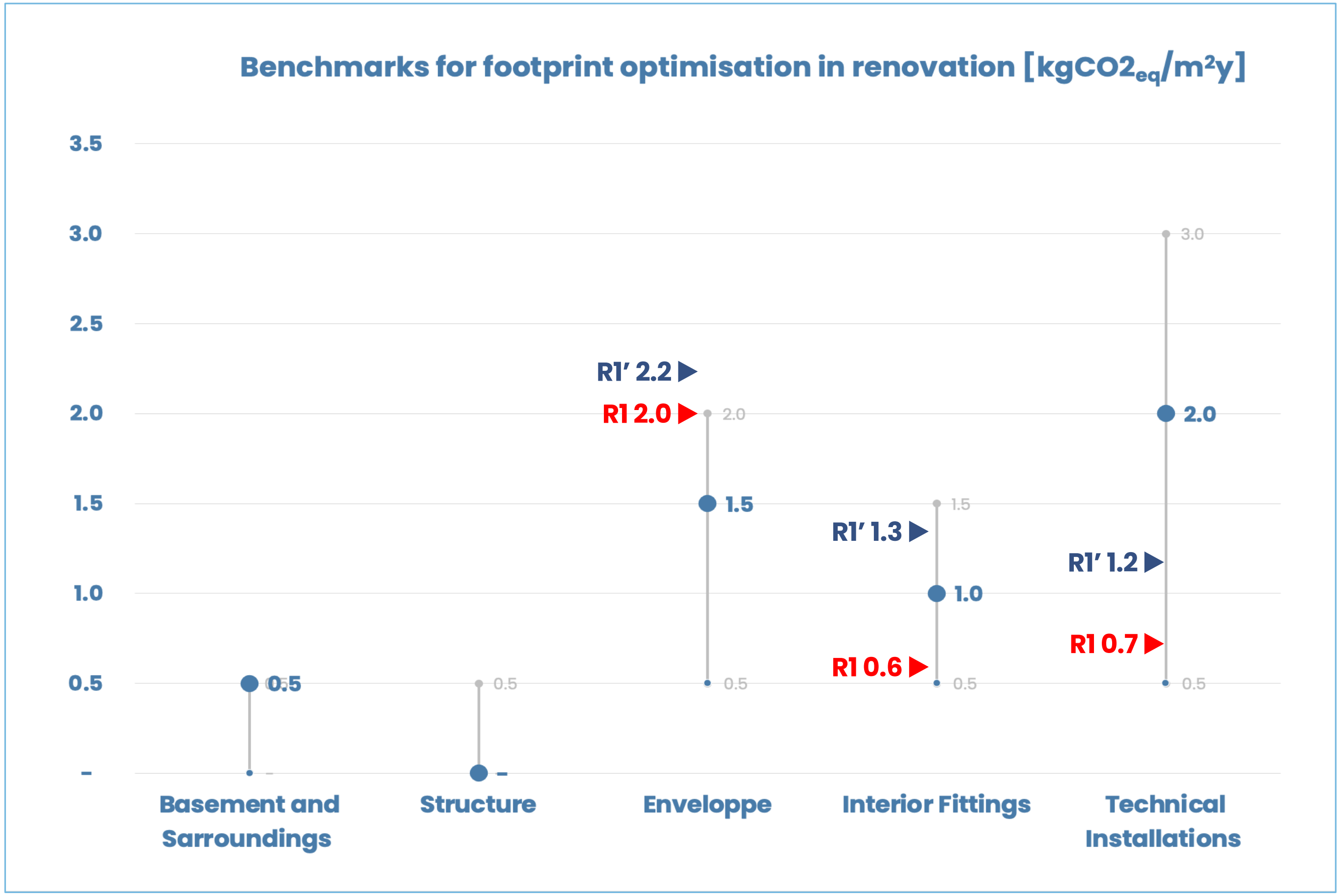
Proposed benchamk values for renovation optimisation



- For technical installations we kept the same values as for new buildings but taking into account EPIQR+ exhaustivity (lifts, fire protection, all sanitary fittings, low current etc.)
- For interior fittings we have a lower value, than for new construction. Generally interior walls, floor and roof coverings are preserved. In renovation this group presents a high potential of reuse.
- The envelope values of a new and renovated building are the same. Although there is a higher optimisation potential in refurbishment, insulation materials, facade cladding, windows, roof insulation and covering are similar or the same.
- The combined total of envelope, fittings, and installations reaches 4.5. This leaves a remaining budget of 0.5 within the limit of 5 kgCO2/m2y. This surplus is occasionally required for interventions in the building's surroundings or even for structural adjustments, especially if compliance with earthquake regulations is necessary.

→ In refurbishment projects, the primary impacts typically occur in the areas of the envelope, interior fittings, and installations.

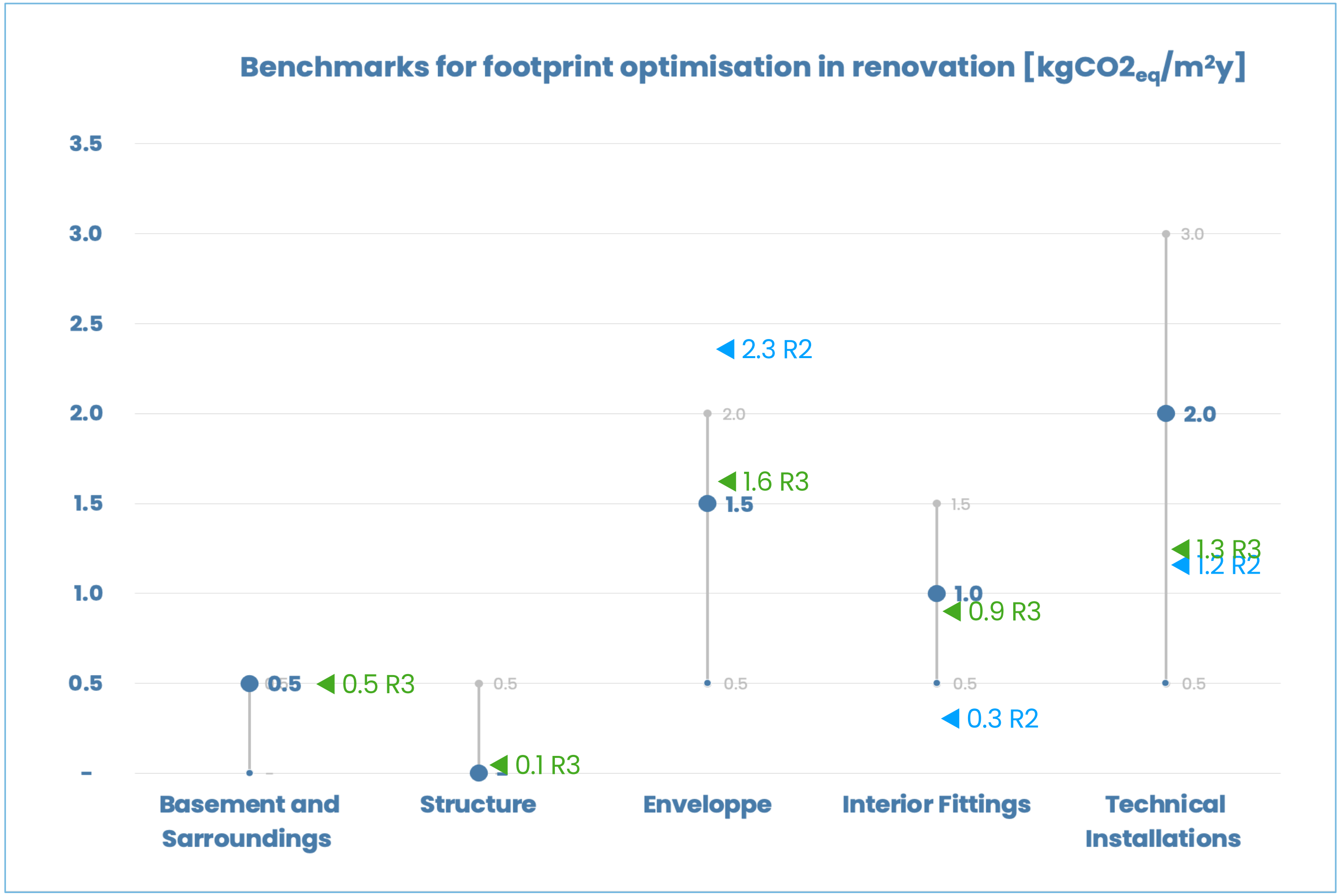
Comparison of carbon footprint of R1 calculated by experts and EPIQR+ (R1’)



- This is the first «expert» building analysed in detail in the previous discussion. As previously mentioned, there is a significant issue with exhaustivity specially for interior fittings and installations in the experts' calculations. Additionally, the footprint of windows was overestimated.
- All values fall within the benchmark range. The technical installations in the building are modest, with the ground heat pump having minimal impact on the installation footprint. The ventilation system is also modest, and no additional renewable energy sources were installed. If photovoltaic panels were installed, the CO2 results from EPIQR+ would be around the middle of the range. Furthermore, savings were achieved by preserving the elevators.
- The interior fitting's footprint according to EPIQR+ CO2 is double that of the experts' calculation. Even the EPIQR+ calculation is not exhaustive. Converting several one or two room apartments into larger ones involves much heavier work than simple renovation and refreshing of interior surfaces. These transformation works are not accounted for in the EPIQR model.
- The modest intervention for the envelope and preservation of roof insulation kept the footprint for this category within normal levels. However, there is an issue with the unit footprint of windows in the expert values. They consider 235 kgCO2eq/m2 for windows, while the 2022 kBOB standard considers 121.5, including venetian blinds.

→ R1 is an example of a restrained refurbishment with modest installations, resulting in a low carbon footprint despite a complete renovation of the entire apartment.

Comparison of carbon footprint calculated by experts fro R2 and R3.

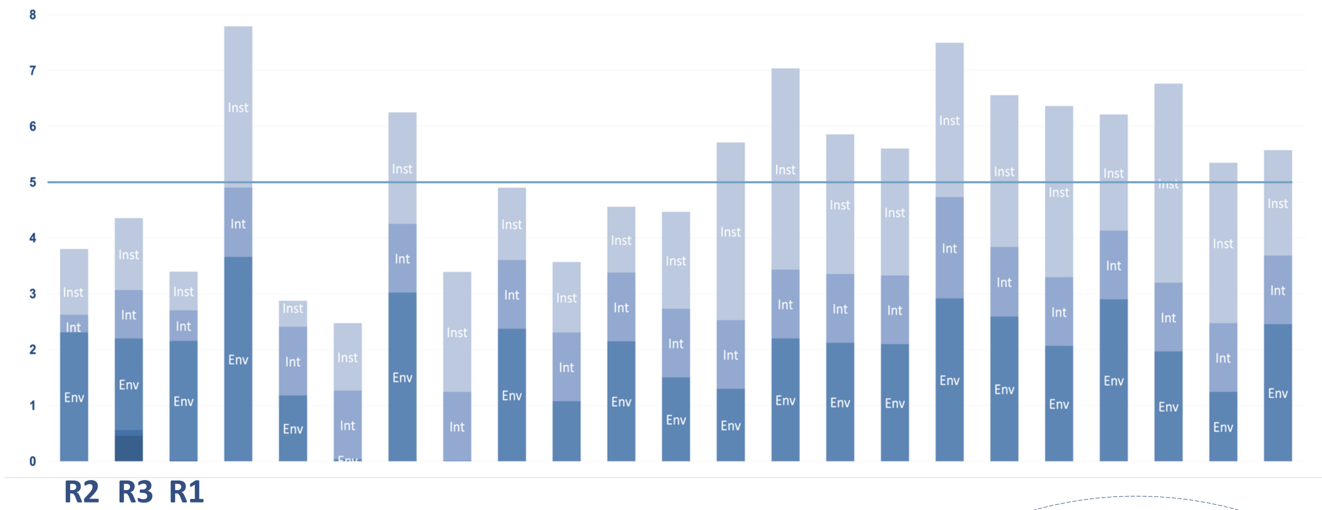


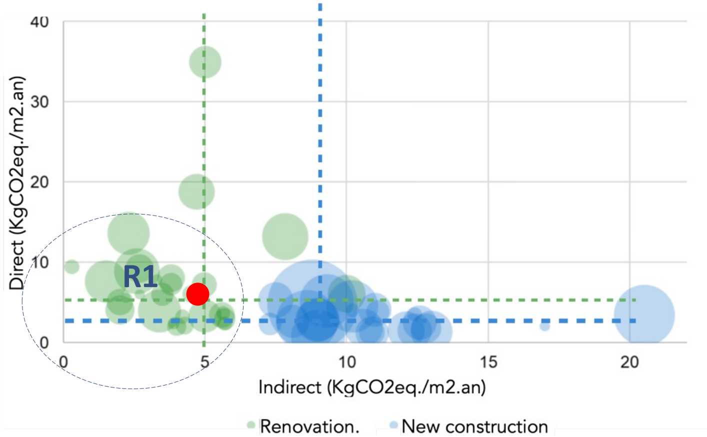
- Experts assess the R2 and R3 projects as having low installation impacts. However, if the quality of calculations is as not consistent as R1, these favorable assessments may be inaccurate.
- The carbon footprint of interior fittings in R3 is around the benchmark average, whereas in R2 it is notably lower. Based on experience, interior fittings pose the highest exhaustivity challenge.
- While envelope values appear to be high or very high, it's essential to verify the unit impact. In R3, some impacts are attributed to basement and surroundings, which involve additional work for structural reinforcement.
- Overall, both projects show low indirect CO2 emissions. Further investigation into exhaustivity could be valuable to determine if this is a widespread issue.

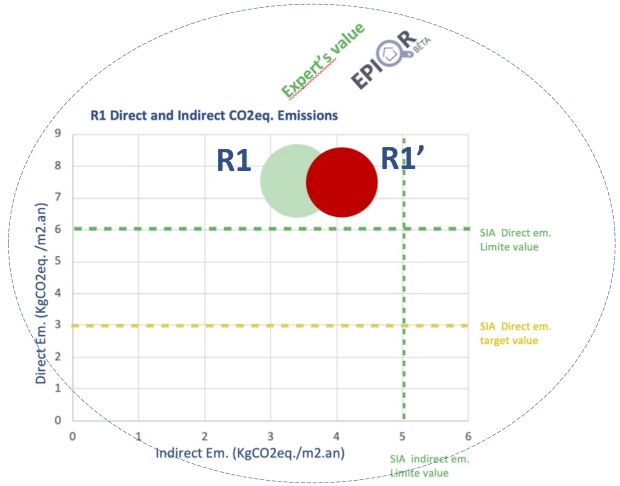
→ R2 and R3 present in general low indirect CO2 emissions. Poor exhaustivity is non excluded.

Statistical comparisons of 3 real refurbishment projects

Sample of 3 real renovations and 20 nZEP Renovation scenarios







- When comparing the impacts of the three renovation projects to the theoretical nZEP scenarios of the 20 buildings analysed within the framework of the EDYCE project, it is evident that their impacts consistently fall below the SIA target value.
- Although R1 exhaustive analysis and re-calculation with EPIQR+CO2 gives 4.1 kgCO2/m2y instead of 3.3 from the expert, the project is still a sober project respecting the SIA limit value.
- However, systematic underestimation might mislead strategic decisions or project choices.
- A lack of thoroughness was primarily noted in the carbon footprint assessment of interior fittings and technical installations. Within the interior domain, fittings account for 25% of the renovation cost, and initial efforts to reuse materials in this area, such as interior doors, kitchen and toilet fixtures, ceramics, and floor coverings, demonstrate significant potential.
- Accurate and comprehensive calculations for installations are crucial for guiding towards more efficient strategies, especially in areas with significant potential.
- It's worth emphasising that optimising the carbon footprint during refurbishment aligns with optimising investment and life cycle costs.

→ Real refurbishment projects show that it is relatively easy to remain < 5 kgCO2eq/m2y. However the figures and exhaustivity need verification.

Summary and discussion of the findings.

- Analysing the carbon footprint of 10 new eco-buildings and several refurbishment projects of high energy performance intervention scenarios we built a decision aid tool proposing design benchmarks for the 5 low carbon design categories of Geneva new low carbon construction Law (LCI art 117, 118).
- We used the aggregated and disaggregated carbon footprint of the analysed buildings to understand the design choices and imagine optimisation potential to test the feasibility of SIA 390 target value of 7 $kgCO2_{eq}/m^2y$ for new buildings and limit value of 5 and 9 $kgCO2_{eq}/m^2y$ for refurbishment and new projects respectively. We found that almost all the analysed buildings respect the limit SIA values but no realised new residential or school building > 2000 m^2 may prove reaching the target value.
- In new buildings basement and structure are responsible for half or more of the carbon footprint, however, calculation methods, software and database values are the most imprecise for these elements. Designer practice is limited to a declarative material choice, wood, mixt structure, bio-based material, however, what counts equivalently to material impact is the consequences of the choice on other building elements, especially fire and noise protection for wood negatively and for concrete positively. For concrete structure and underground constructions a reduction strategy can be equivalent to material shifting while for wood, encapsulation for fire protection and screed thickness for noise absorption can rise the global impact to similar levels as this of non-optimised concrete constructions.
- For refurbishment, as the basement and structure impact categories present generally zero values, interior fittings and technical installations impacts become predominant. Preservation and reuse are efficient strategies for the interior fittings and sobriety for technical installations. However, the state of the art neglected the impacts of those elements and database values are the most incomplete, global, and unreliable. Exhaustivity in expert calculations for refurbishment projects is a serious problem that could lead to wrong targeting and decisions.
- Linking carbon impact to costs could be a remedy to the exhaustivity problem and cost optimisation could be a serious lever for carbon footprint optimisation, making converge traditional building economics and ordinary Capex analysis with life cycle CO2 and cost analysis and with circular economy.
- Although the state of the art for carbon footprint assessment is incomplete, for some elements and life span values unreliable or inconsistent, it remains a useful tool for both optimisation and CO2 budget control. Disaggregated values into responsibility categories may help not only to question and make accountable design choices, but also to question and reinforce calculation reliability.
- With 1.3% new constructions, 0.2% demolitions, and 0.8 to 3% current and future renovation rates (Ge Stats 2022) refurbishment activities will generate significantly higher CO2 emissions than new buildings.

Construction de nouveaux logements, photo RTS

Démolition de la caserne des Vernets, Photo GHI

La rénovation du Lignon primée 2022, photo Tribune de Genève

→ Carbon footprint benchmarking is a powerful CO2 and life cycle cost optimisation tool