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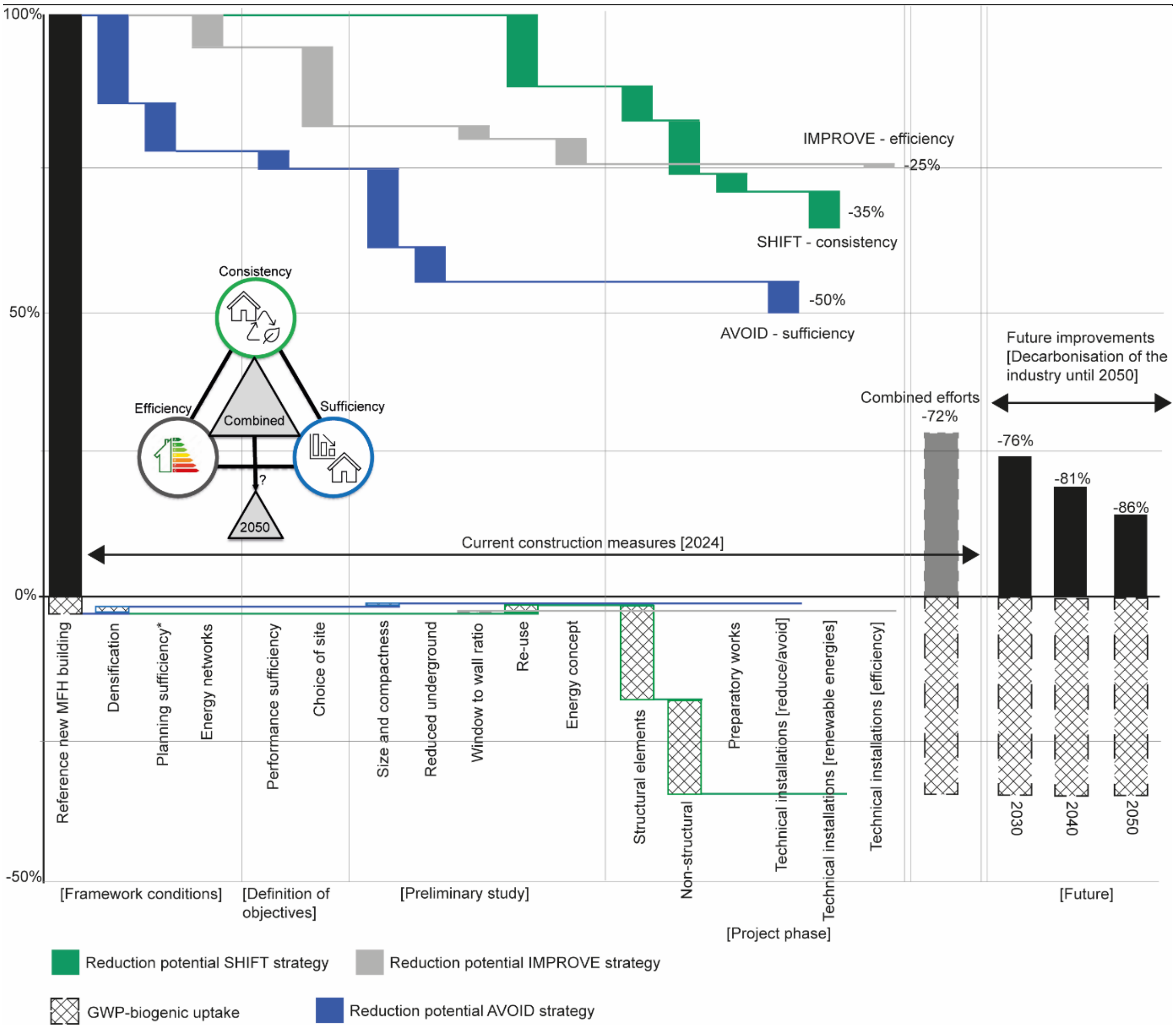
Netto-Null Treibhausgasemissionen im Gebäudebereich NN-THGG
Net-zero GHG emissions in the building area

Bottom-up approach (research question F2)



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Summary

This study is part of the “Net-zero greenhouse gas emissions in the building area” research project of the Swiss Federal Office of Energy. The present research question F2, focusing on a bottom-up view, aims to define net-zero greenhouse gas (GHG) strategies, establish benchmarks, and guide stakeholders towards net-zero practices at building scale. The project objectives include identifying measures to reduce GHG emissions from construction and operation at building scale, formulating strategies for achieving net-zero GHG by 2050, assessing these strategies from a social, economic, and technical point of view, and classifying building standards in relation to net-zero targets. A systematic approach, including a literature review, logical grouping, and data collection, was employed to identify measures for greenhouse gas emissions reduction and their effectiveness. Existing recommendations and scientific literature were reviewed to have a comprehensive list of measures available. Results throughout the report are based on a life cycle assessment approach. Measures are assessed considering their relevance in relation to emissions at building scale and the limitations involved with the available data and the implementation of single measures. Finally, recommendations are drawn for each measure, offering a detailed perspective on the challenges and opportunities in the pursuit of net-zero construction practices. The measures are then assessed with feasibility indicators for economic, social, and technical dimensions. The feasibility assessment aims to provide an indication on the degree of enabling and barrier conditions for the swift implementation of the measures to achieve net-zero at building level in a life cycle perspective. In accordance with the feasibility results, measures are finally combined into strategies reflecting different levels of efforts from different stakeholders and different societal perspectives. In parallel to the assessment of measures and strategies to reduce GHG emissions, building standards and labels available in the Swiss context are examined to highlight potential discrepancies with the net-zero targets.

A key takeaway from our analysis is the recognition that achieving net-zero emissions at the building scale is a complex task. The stark reality is that no single measure, in isolation, possesses the capability to attain net-zero status unless, of course, we cease construction activities altogether or achieve a complete decarbonization of the energy supply including supply chain emissions. This underscores the need for a holistic approach that integrates a combination of measures, carefully tailored to address specific constraints, requirements, and opportunities. Single measures have the potential to achieve an average 15% reduction in greenhouse gas emissions in a reference new multi-family house building while a holistic approach of utilizing the full range of measures could bring down the impact by up to 72% today.

While the feasibility of these measures and strategies is, for the most part, within reach from a technical perspective, the primary obstacles lie in social and economic constraints. The implementation of net-zero practices in the building sector faces challenges rooted in societal attitudes, economic considerations, and the inertia of existing systems. Overcoming these hurdles requires a concerted effort from various stakeholders, including policymakers, industry leaders, designers, and the public.

The current context of standards and labels is not yet specifically directed towards net-zero greenhouse gas emissions. The new prSIA 390/1 standard (under revision) is aligned with net-zero targets in that it proposes specific greenhouse gas limits and targets for construction and operation although the pathway to net-zero is currently only mentioned in an annex of informative nature. Discrepancies in methodologies, boundaries, and target definition exist between existing standards and labels and a harmonization work is needed.

In conclusion, the path to net-zero greenhouse gas emissions from buildings is within our grasp, provided we can navigate the complicated landscape of social and economic constraints. As we move forward, it is imperative to not only prioritize technical feasibility but also to foster an environment enabling the swift and effective implementation, ensuring that our collective efforts pave the way for a more sustainable and resilient built environment.

Zusammenfassung

Diese Studie ist Teil des Forschungsprojekts «Netto-Null Treibhausgasemissionen im Gebäudebereich» des Bundesamts für Energie. Die vorliegende Fragestellung F2, die sich auf eine Bottom-up Betrachtung konzentriert, zielt darauf ab, Strategien für Netto-Null Treibhausgasemissionen zu definieren, Benchmarks festzulegen und die Beteiligten auf Netto-Null Praktiken hinzuweisen.

Zu den Projektzielen gehören die Suche nach Massnahmen zur Verringerung der Treibhausgasemissionen aus Erstellung und Betrieb von Gebäuden, die Festlegung von Strategien zur Erreichung von Netto-Null-Treibhausgasemissionen bis 2050, die Bewertung dieser Strategien aus sozialer, wirtschaftlicher und technischer Sicht sowie die Klassifizierung von Gebäudestandards in Bezug auf Netto-Null-Ziele. Ein systematischer Forschungsansatz, der eine Literaturrecherche, eine logische Gruppierung und eine Datenerhebung umfasste, wurde angewandt, um Massnahmen zur Reduktion von Treibhausgasemissionen und deren Wirksamkeit zu ermitteln. Existierende Empfehlungen und wissenschaftliche Literatur wurden geprüft, um eine umfassende Liste von Massnahmen zur Verfügung zu haben. Die Ergebnisse in diesem Bericht basieren auf einem Lebenszyklusansatz. Die Massnahmen werden unter Berücksichtigung ihrer Relevanz in Bezug auf die Emissionen auf Gebäudeebene und der Einschränkungen, die mit den verfügbaren Daten und der Umsetzung der einzelnen Massnahmen verbunden sind, bewertet. Schliesslich werden für jede Massnahme Empfehlungen erstellt, die einen detaillierten Überblick über die Herausforderungen und Chancen bei der Realisierung von Netto-Null-Bauweisen geben. Die Massnahmen werden dann anhand von Machbarkeitsindikatoren für wirtschaftliche, soziale und technische Aspekte bewertet. Die Machbarkeitsstudie soll Aufschluss darüber geben, inwieweit die Voraussetzungen für eine rasche Umsetzung der Massnahmen zur Erreichung von Netto-Null auf Gebäudeebene in einer Lebenszyklusbetrachtung gegeben sind. In Übereinstimmung mit den Ergebnissen der Machbarkeitsstudie werden die Massnahmen schliesslich zu Strategien zusammengefasst, die die unterschiedlichen Aktivitäten der verschiedenen Interessengruppen und die verschiedenen gesellschaftlichen Perspektiven widerspiegeln. Gleichzeitig mit der Beurteilung von Massnahmen und Strategien zur Reduktion der Treibhausgasemissionen werden die in der Schweiz verfügbaren Standards und Labels untersucht, um mögliche Diskrepanzen zu den Netto-Null-Zielen aufzuzeigen.

Eine der wichtigsten Schlussfolgerungen aus unserer Analyse ist die Erkenntnis, dass das Erreichen von Netto-Null-Emissionen auf der Gebäudeebene eine komplexe Aufgabe ist. Die Realität sieht jedoch so aus, dass keine einzelne Massnahme für sich genommen in der Lage ist, den Netto-Null-Status zu erreichen, es sei denn, wir stellen die Bautätigkeit ganz ein oder erreichen eine vollständige Dekarbonisierung der Energieversorgung einschliesslich der Emissionen der Lieferkette. Dies verdeutlicht die Notwendigkeit eines ganzheitlichen Ansatzes, der eine Kombination von Massnahmen umfasst, die sorgfältig auf die spezifischen Einschränkungen, Anforderungen und Möglichkeiten zugeschnitten sind. Einzelne Massnahmen haben das Potenzial, die Treibhausgasemissionen in einem Referenz-Mehrfamilienhaus Neubau, um durchschnittlich 15 % zu senken, während ein ganzheitlicher Ansatz, bei dem die gesamte Bandbreite an Massnahmen genutzt wird, die Auswirkungen um bis zu 72 % reduzieren könnte. Während die Machbarkeit dieser Massnahmen und Strategien aus technischer Sicht grösstenteils in Reichweite ist, bestehen die wesentlichen Hindernisse in sozialen und wirtschaftlichen Bereichen. Die Umsetzung von Netto-Null-Praktiken im Baubereich steht vor Herausforderungen, die in der gesellschaftlichen Haltung, wirtschaftlichen Überlegungen und der Trägheit bestehender Systeme begründet sind.

Um diese Hürden zu überwinden, bedarf es gemeinsamer Anstrengungen verschiedener Interessengruppen, darunter politische Entscheidungsträger, Industrievertreter, Planer und die Öffentlichkeit. Der aktuelle Kontext von Standards und Labels ist noch nicht speziell auf Netto-Null-Treibhausgasemissionen ausgerichtet. Die neue Norm prSIA 390/1 (in Überarbeitung) ist insofern auf die Netto-Null-Ziele abgestimmt, als sie spezifische Treibhausgasgrenzwerte und -ziele für Erstellung und Betrieb vorschlägt, obwohl der Weg zu Netto-Null derzeit nur in einem rein informativen Anhang erwähnt wird. Zwischen den bestehenden Standards und Labels bestehen Diskrepanzen in Bezug auf

Methoden, Grenzen und Zieldefinitionen, so dass eine Harmonisierung erforderlich ist. Zusammenfassend lässt sich sagen, dass der Weg zu Netto-Null Treibhausgasemissionen von Gebäuden in greifbarer Nähe ist, vorausgesetzt, wir können uns in dem komplizierten Umfeld der sozialen und wirtschaftlichen Einschränkungen zurechtfinden.

Auf unserem Weg nach vorn müssen wir nicht nur die technische Machbarkeit in den Vordergrund stellen, sondern auch ein Umfeld fördern, das eine rasche und wirksame Umsetzung ermöglicht und sicherstellt, dass unsere gemeinsamen Anstrengungen den Weg für eine nachhaltigere und widerstandsfähigere bebaute Umwelt ebnen.

Résumé

Cette étude fait partie du projet de recherche « Net-zéro émissions de gaz à effet de serre dans l'environnement bâti » de l'Office fédéral de l'énergie. La question de recherche F2, axée sur une approche ascendante, vise à définir des stratégies de net-zéro émissions de gaz à effet de serre, à établir des références et à guider les parties prenantes vers des pratiques net-zéro à l'échelle des bâtiments. Les objectifs du projet comprennent l'identification de mesures pour réduire les émissions de la construction et de l'exploitation à l'échelle des bâtiments, la formulation de stratégies pour atteindre net-zéro d'ici 2050, l'évaluation de ces stratégies d'un point de vue social, économique et technique, et la classification des standards et labels par rapport aux objectifs net-zéro. Une approche systématique, comprenant une revue de la littérature, un regroupement logique et une collecte de données, a été utilisée pour identifier les mesures de réduction des émissions de gaz à effet de serre et leur efficacité. Des recommandations existantes et des travaux scientifiques ont été examinés afin d'avoir une liste exhaustive de mesures disponibles. Les résultats tout au long du rapport sont basés sur une approche d'analyse du cycle de vie. Les mesures sont évaluées en tenant compte de leur pertinence par rapport aux émissions à l'échelle des bâtiments, des limitations liées aux données disponibles et de la mise en œuvre de mesures individuelles. Enfin, des recommandations sont formulées pour chaque mesure, offrant une perspective détaillée sur les défis et les opportunités dans la poursuite de pratiques de construction net-zéro. Les mesures sont ensuite évaluées avec des indicateurs de faisabilité pour les dimensions économiques, sociales et techniques. L'évaluation de la faisabilité vise à fournir une indication du degré de conditions facilitantes et de barrières à la mise en œuvre rapide des mesures pour atteindre net-zéro au niveau du bâtiment dans une perspective de cycle de vie. Conformément aux résultats de faisabilité, les mesures sont finalement combinées en stratégies reflétant différents niveaux d'efforts de différentes parties prenantes et perspectives sociétales différentes. En parallèle à l'évaluation des mesures et des stratégies de réduction des émissions de gaz à effet de serre, les normes et labels disponibles dans le contexte suisse sont examinés pour mettre en évidence les écarts potentiels par rapport aux objectifs net-zéro.

Une conclusion importante de notre analyse est la réalisation que l'atteinte d'émissions net-zéro à l'échelle des bâtiments est une tâche complexe. La réalité est qu'aucune mesure unique, prise en isolation, ne possède la capacité d'atteindre le statut de net-zéro à moins, bien sûr, que nous ne cessons toute activité de construction ou que nous n'atteignions une décarbonisation complète de l'approvisionnement énergétique, y compris les émissions de la chaîne d'approvisionnement. Cela souligne la nécessité d'une approche holistique qui intègre une combinaison de mesures, soigneusement adaptées pour répondre à des contraintes, exigences et opportunités spécifiques. Les mesures individuelles ont le potentiel de réaliser une réduction moyenne de 15% des émissions de gaz à effet de serre dans un immeuble résidentiel multifamilial neuf de référence, tandis qu'une approche holistique utilisant l'ensemble des mesures pourrait réduire l'impact jusqu'à 72% aujourd'hui.

Alors que la faisabilité de ces mesures et stratégies est, pour la plupart, à portée de main d'un point de vue technique, les principaux obstacles résident dans les contraintes sociales et économiques. La mise en œuvre de pratiques net-zéro dans l'environnement bâti est confrontée à des défis liés aux attitudes sociales, aux considérations économiques et à l'inertie des systèmes existants. Surmonter ces

obstacles nécessite un effort concerté de la part de diverses parties prenantes, notamment les décideurs politiques, les leaders de l'industrie et le public.

Le contexte actuel des normes et labels n'est pas encore spécifiquement orienté vers les émissions net-zéro de gaz à effet de serre. La nouvelle norme prSIA 390/1 (en révision) est aligné sur les objectifs net-zéro en proposant des limites spécifiques de gaz à effet de serre et des objectifs pour la construction et l'exploitation, bien que le chemin vers net-zéro soit actuellement mentionné uniquement dans une annexe de nature informative. Des écarts existent entre les méthodologies, les limites et la définition des objectifs entre les normes et labels existants, et un travail d'harmonisation est nécessaire.

En conclusion, le chemin vers des émissions net-zéro de gaz à effet de serre provenant des bâtiments est à notre portée, à condition que nous puissions naviguer dans le contexte compliqué des contraintes sociales et économiques. Au fur et à mesure que nous avançons, il est impératif de ne pas seulement prioriser la faisabilité technique, mais aussi de favoriser un environnement permettant une mise en œuvre rapide et efficace, en veillant à ce que nos efforts collectifs ouvrent la voie à un environnement bâti plus durable et résilient.

Main findings

Overall, the following key findings are highlighted from this work:

Measures for GHG reduction at building scale

The potential reductions in GHG emissions presented in this work primarily focus on residential and office buildings, which constitute the majority of both current and future building stocks. While other building typologies may exhibit different potentials and limitations, comprehensive studies on these types are currently lacking.

- Extension of existing buildings instead of building new is a measure with strong potential to reduce GHG emissions (ca. 20% lower embodied emissions including strengthening of existing structure). Costs, social co-benefits, maturity, and absence of risk play in favour of this measure while public acceptance, technical scalability, and complexity of implementation might hinder its deployment.
- Renovating existing buildings instead of building new can potentially reduce GHG emissions in the building sector. The feasibility of the measure is evaluated as easy from a social and technical perspective but might find barriers from an economic perspective. New buildings could be avoided but the need for new surface should be considered at building stock level.
- Measures impacting the size and shape of buildings and elements taken in the preliminary design phase (compactness, reduce underground, window to wall ratio) do not find barriers from a technical and costs perspective but are hindered by public acceptance and employment/economic growth point of view. A lack of public awareness on the importance of these measures as well as a lack of incentives to implement them hinder the feasibility of these measures at large scale.
- Optimizing structural elements (dimensioning and shifting to low carbon) can save 10% of GHG embodied emissions compared to a reference building but is generally associated with higher costs and more difficult implementation (technical complexity) in the design process.
- Shifting to biobased materials in structural and non-structural elements potentially reduces GHG embodied emissions by ca. 20% and 30% in a reference MFH and SFH respectively and increases biogenic global warming potential (GWP) uptake by ca. 30% and 50% of the reference MFH and SFH initial GHG emissions respectively.

- Average GHG emissions of a multi-family house reference building can be reduced by 72% with current applicable measures (68% in embodied GHG emissions and 85% in operational GHG emissions).
- Decarbonization of the industry could potentially reduce the embodied emissions of a building further in the future (ca. 50%).

Strategies for net-zero buildings

- An overall “AVOID” strategy, tackling sufficiency measures at building scale (e.g.: reduce surface per inhabitant, reduce size of buildings, undergrounds, and energy consumption) can bring down GHG emissions of a reference multi-family house by 50%. This strategy is mainly hindered by social acceptance and employment effects/economic growth feasibility indicators.
- The “SHIFT” strategy focuses on consistency measures to generally shift practices towards renewable sources (e.g.: biobased materials and renewable energies). The feasibility of the strategy finds high social acceptance and co-benefits but is hindered by costs and technical complexity of implementing the measures at large scale.
- The “IMPROVE” strategy tackles efficiency measures by improving existing practices. Partially these measures are directly applicable at building scale (e.g.: window to wall ratio, energy concept, efficiency of installations) with a limited range of GHG reduction potential. Measures concerning the framework conditions (extension of renewable energy networks and decarbonisation of the industry) have high potential to reduce GHG emissions in this strategy but are not directly applicable at building scale and rely on long-term changes happening at political level. Therefore, these measures are assessed as difficult from a costs and technical complexity point of view.

Feasibility assessment

- Very few indicators for the feasibility of measures are assessed as difficult and all the measures in question concern the framework conditions for the design process:
  - Costs for decarbonizing the industry and extending energy networks,
  - Public acceptance in planning sufficiency,
  - Simplicity of implementation, operation, and maintenance for decarbonizing the industry from a technical perspective.
- Technical indicators suggest implementation conditions to quickly and simply scale up measures in the early design phase with the exception of re-use measures.
- Project phase measures score high in the maturity level but medium-low in the simplicity of implementations and are generally associated with higher costs.
- The feasibility assessment of measures in the phase “definition of objectives” showed good implementation conditions from a technical perspective but barriers from an economic and social perspective.

Building standards and labels

- The current context of Swiss standards and labels is not yet specifically directed towards net-zero greenhouse gas emissions.
- Discrepancies in methodologies, system boundaries, and target definition are found in existing standards and labels and a harmonization work is needed.

Contents

Abbreviations

CFS	Cold-formed steel
CLT	Cross-laminated timber
eBKP-H/eCCC-Bât	Element-based building construction costs plan German : Elementbasierter Baukostenplan Hochbau French : Code des coûts de construction Bâtiment
EN	European Norm
EnDK	Conference of the cantonal directors of energy German: Konferenz Kantonaler Energiedirektoren
EPD	Environmental Product Declaration
EPS	Expanded polystyrene
ERA	Energy Reference Area
F2	Research question / Fragestellung
FOEN	Federal Office for the Environment
FSC	Forest Stewardship Council
GEAK / CECB	Cantonal energy certificate for buildings German : Gebäudeausweis der Kantone French : Certificat énergétique cantonal des bâtiments
GFRP	Glass-fiber reinforced polymer
GHG	Greenhouse gas
GWP	Global Warming Potential
HPC	High-performance concrete
HVAC	Heating, ventilation and Air Conditioning
IPCC	Intergovernmental Panel on Climate Change
KBOB	Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren
KIG	Bundesgesetz über die Ziele im Klimashutz, die Innovation und die Stärkung der Energiesicherheit
LCA	Life Cycle Assessment
LWC	Light-weight concrete
MFH	Multi-family house
MuKEn / MoPEC	German : Mustervorschriften der Kantone im Energiebereich French : Modèle de prescriptions énergétiques des cantons
OSB	Oriented strand board
PC	Prestressed concrete
PEFC	Programme for the Endorsement of Forest Certification
PS	Polystyrene
PV	Photovoltaic
RE	Renewable energy
sDA	Spatial Daylight Autonomy
SDG	Sustainable Developement Goal
SFH	Single-family house
SFOE	Swiss Federal Office of Energy

SIA	Swiss association of engineers and architects German: Schweizerischer Ingenieur- und Architektenverein
SNBS	Standard Nachhaltiges Bauen Schweiz
TCC	Timber Concrete Composite
UHPC	Ultra-high-performance concrete
UNEP	United Nations Environment Programme
WE	Housing unit
WP	Work Package
WWR	Window to wall ratio

1 Introduction

1.1 Background information and current situation

The building sector holds a significant responsibility in the current climate crisis, contributing to 40% of global greenhouse gas (GHG) emissions (Ritchie, Rosado and Roser, 2020). Consequently, it plays a pivotal role in achieving climate neutrality by 2050 as stipulated in the Paris Agreement (United Nations / Framework Convention on Climate Change, 2015). Despite the urgency, progress towards carbon-neutral construction has been notably lagging over the past five decades. Although developments in the building sector have optimized the operational efficiency of new buildings, research shows that the embodied emissions are yet to be mastered (Röck *et al.*, 2020). In the federal law relative to the objectives for climate protection (KIG 2023, art. 3 and 4) targets for the building sector have been set to 82% reduction compared to 1990 by 2040 and 100% by 2050. However, the building sector, in this case, excludes scope 3 emissions and it is therefore necessary to expand the boundaries to the building area and focus on a life-cycle approach at building scale.

Switzerland attributes circa 48% of the end energy consumption (Swiss Federal Office of Energy (SFOE), 2022) and 33% of the overall CO_2 emissions (i.e.: 26% of the GHG emissions) to the operation (Federal Office for the Environment FOEN, 2023) of the existing building stock. This impact is mainly due to the high share of energy-inefficient and fossil-fuels dependent buildings (Federal Statistical Office, 2023). These figures reinforce the importance of renovation as a key measure to reduce GHG emissions of the overall building stock. In October 2020, the European Commission introduced its renovation wave strategy as a component of the European Green Deal. The primary objectives include doubling the annual renovation rate by 2030 and promoting deep energy renovations (European Commission, 2020). Switzerland has implemented various financial and regulatory instruments to mitigate emissions from its building stock. Since 2008, a CO_2 tax (The Federal Council, 2012) has been in operation to encourage a reduction in fossil fuel consumption. Additionally, the Building Program (The Federal Council, 2016) has been established to stimulate the energy renovation of building envelopes and the efficient use of renewable energies through economic incentives.

Furthermore, Swiss cantons are required to enact laws and regulations aimed at reducing emissions from both existing and new buildings. For instance, many cantons have instituted limitations on heating needs and specified minimum percentages of renewables when changing heating systems in residential buildings. In the most recent review report (Swiss Federal Office for the environment and Swiss Federal Office of Energy, 2023) covering the period from 2016 to 2020, circa 20% decrease in operational CO_2 was reported, attributed in part to milder climate conditions but also to implemented reduction measures.

It is crucial to note, however, that the existing policy framework exclusively concentrates on enhancing energy efficiency and reducing energy consumption, with no explicit mention of materials and their associated emissions, despite representing about 30% of Swiss building-related emissions (Swiss Federal Office of Energy, 2011). Deep energy renovations, which involve a substantial portion of renewed elements (e.g., roofs, technical installations, facades, etc.), necessitate a life cycle perspective on emissions to avoid a transfer from operation to embodied. Studies emphasize the importance of including embodied emissions when evaluating renovation strategies (Almeida and Ferreira, 2015, 2017; Lasvaux *et al.*, 2015, 2017; Almeida, Ferreira and Barbosa, 2018). If the renovation rate increases without addressing embodied emissions, cumulative national GHG emissions could rise until 2050 (Priore, Jusselme and Habert, 2022). The literature emphasizes that the key component of energy-related renovations is the energy source of the heating system (Galimshina, Moustapha, Hollberg, Padey, *et al.*, 2021) and adding fossil-derived insulation once the heating source is decarbonized might be counterproductive (Mosquini, Tappy and Jusselme, 2022). Nevertheless, recent studies highlight solutions that could enable the optimal (costs and GHG emissions) renovation of typical Swiss buildings, resulting in less than 3 $kgCO_{2eq}/m^2.yr$ for embodied and operation (Galimshina, Moustapha, Hollberg, Lasvaux, *et al.*, 2021).

On an industrial front, strides have been made in enhancing energy efficiency within cement and steel production plants over the last 50 years. However, a contrasting picture emerges when viewed from a building's perspective. While efforts have been invested, the use of materials per square meter has remained relatively constant, coupled with an alarming trend of increasing the built surface area per person. This lack of substantial progress fails to yield clear benefits from a carbon perspective.

In Switzerland, the rarity of new constructions emitting less than 600 $kgCO_{2eq}/m^2$ embodied emissions in their life cycle (phases A1-A3 – production, B4 – replacement, C – end of life) underscores the uphill challenge. When factoring in a 60-year lifespan, this translates to an approximate emission of 10 $kgCO_{2eq}/m^2.yr$ (Priore, Habert and Jusselme, 2023). Nevertheless, recent studies evaluated new construction strategies to bring embodied emissions below 5 $kgCO_{2eq}/m^2.yr$ over the life cycle by avoiding carbon intensive building elements, shifting to low-carbon biogenic materials, and improving the design (Priore, Jusselme and Habert, 2023).

While these examples fall short of achieving absolute carbon neutrality (0 $kgCO_{2eq}$), they indicate immediate steps that could result in a 50% reduction in emissions from current average values. This immediate reduction is needed while waiting for the decarbonization of the industry and the implementation of negative emissions technologies to attain net-zero emissions by 2050 at national scale. Additionally, temporary storage of carbon in buildings can delay emissions and buy crucial time in the urgent climate crisis while identifying and consolidating mechanisms to make the storage permanent by avoiding re-emission at the end of life and ensuring an increase in carbon pool (built environment and forest systems) (Hill, 2019).

It is imperative to recognize that the net-zero objective raises a dual inquiry: What does a net-zero building or renovation entail, and when can we realistically expect to witness the widespread realization of such projects considering current practices, markets, and normative barriers? Any delay in implementation of emission reduction measures poses the risk of surpassing critical climate thresholds.

1.2 Purpose of the project

Within this context, the Swiss Federal Office of Energy (SFOE) launched in 2022 the "Net zero greenhouse gas emissions in the building area" project[1]. The overarching goal of the entire project is to develop a unified definition of net zero GHG in the building area. This definition aims to gather a unanimous acceptance from all stakeholders, establishing a foundational framework for the formulation of benchmarks and targets. This report addresses research question F2 "Bottom-up approach" of the project.

1.3 Objectives

The report aims to answer the specific research questions (in German "Fragestellung") formulated in the call for proposals:

- F2.1 What technical and non-technical measures to reduce GHG emissions from construction and operation exist at the level of individual buildings, differentiated by new construction and existing buildings (incl. refurbishment)? The measures can concern the building itself and/or their supply chains (specially building material manufacturers).
- F2.2 Which strategies (combination of measures) are suitable for achieving net zero for individual buildings by 2050?
- F2.3 How are these strategies assessed from a constructional and economic point of view?

[1] https://www.aramis.admin.ch/Texte/?ProjectID=52363

- F2.4 How should the various building standards and labels (MuKEn 2014, GEAK, Minergie, SNBS, as well as the SIA efficiency path) be classified in relation to the net zero target and what are the methodological differences between them?
- F2.5 To what extent do the limits and targets of these standards meet the net zero target for individual buildings?
- F2.6 Quantification on concrete examples on different building categories.

The overall goal is to guide net zero construction practices, considering both operational and embodied emissions, and to give insight in the alignment of building standards and labels with net zero targets until 2050.

2 Procedures and methodology

The research question F2 is organized into four main Work Packages (WP), with the initial focus on data setup and context establishment for detailed modelling in subsequent WPs as shown in Figure 1.

WP1a addresses the interface of the building sector with energy and industry sectors. The aim is here to evaluate the evolution of embodied GHG emissions over time, incorporating decarbonization scenarios for electricity, cement, and steel sectors up to 2050 based on existing data and literature.

WP1b identifies technical and non-technical measures to reduce GHG emissions in construction and operation and evaluates the feasibility of the identified measures based on economic, social, and technical indicators.

WP1c classifies building standards in view of net zero targets, considering operational vs. embodied emissions and energy vs. CO_{2eq} focus. It identifies minimum design criteria and compares them with decarbonization measures.

WP2 examines existing building types to extrapolate measures, strategies, potentials, and barriers to reduce GHG emissions.

WP3a examines the combination of measures based on WP1 and WP2 for achieving net zero by 2050 for different building types. Building types identified in WP2 are used as base case scenarios to assess the potential of the measures identified in WP1b in achieving net zero goals.

WP3b compares net zero target scenarios with standards and labels and examines the consequences of using standards, especially in renovation. The WP evaluates how standards and labels may hinder or align with net zero targets.

WP4 summarizes results into a comprehensive report with recommendations for building design and standards. The focus is on residential (single-family and multi-family) and office buildings, encompassing both new construction and renovation. The recommendations provide insights into exemplary buildings fulfilling net zero targets and suggest improvements aligning building standards with net zero goals.

The F2 research question is conducted in strong collaboration with the other research questions of the project. Methodological basis for the overall project is identified and clarified in research question F0[2]. Exchange of bottom-up data from F2 (i.e. environmental impact of construction elements based on building types identified in WP2 and measures of WP1b) with top-down building stock modelling of F1 was necessary. Strategies to reduce GHG emissions at building scale identified in F2 are used in F3 to assess possible implementation paths.

[2] https://www.aramis.admin.ch/Default?DocumentID=70739&Load=true

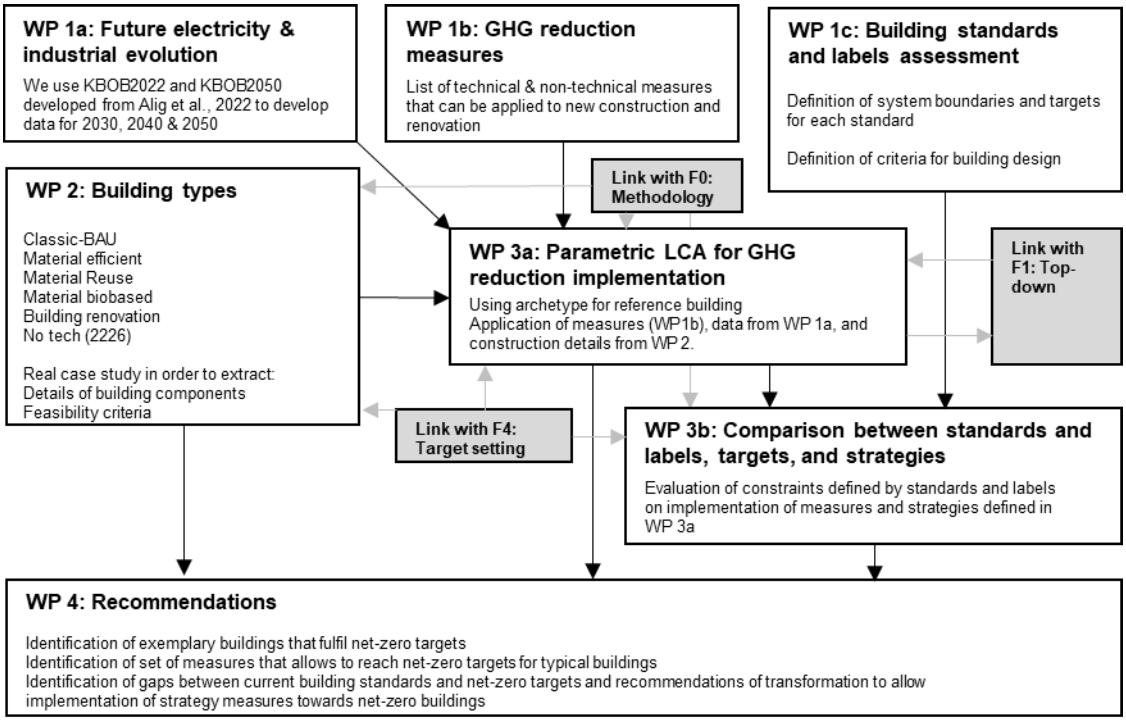


Figure 1: Organization of WPs in the research question F2 workflow.

2.1 Carbon reduction measures

In addressing F2.1 in WP1b, a systematic approach was employed to identify potential technical and non-technical measures aimed at reducing GHG emissions at building scale. This approach was based on a preliminary list of measures. The preliminary list is, in a second step, extended and consolidated with a literature review on existing recommendations. The identified measures are then grouped according to existing categorization systems. Data is then collected to quantitatively and qualitatively support the relevance, the boundaries, and the limitation of the identified measures. Finally, the measures are described in single sections of this report and recommendations are drawn.

Literature review on existing recommendations

Recommendations to reduce GHG emissions in the building sector can be found in the SIA technical documents, in the reports related to available labels, as well as in the scientific literature. The following documents, reports, and literature are used to this purpose.

SIA 2032 – Annex B

The SIA 2032 is the Swiss standard for embodied emissions and the environmental assessment of the construction of buildings. Annex B of this standard reports the influencing factors, in terms of embodied emissions, according to the design phases. The factors are categorized into the following 3 main categories:

- Create the appropriate political framework conditions: promoting densification and request life cycle assessments,
- Reduce energy demand: transform instead of new, optimise volumes, reduce underground construction, reduce demand of surface, simple structural concepts, appropriate window-to-wall ratio, rational management of resources, appropriate façade finishing, separation of systems, flexibility of use, reduced use of glass and metal facades, reduce installations, use of resistant and easy maintenance materials, short transport distances,

- Quality control: control of execution.

Furthermore, 3 main strategies are mentioned to reduce GHG Life Cycle emissions:

i. Reduce quantities: ranging from reducing the overall size of construction works (sufficiency in surfaces i.e. GHG per person or per building), reducing the size and compactness of built volumes, reduce underground constructions, and use simple structural systems.

ii. Less embodied emissions per quantity: choice of construction type (heavy, mixed, light), choice of materials.

iii. Resistance and long-life spans: separating systems in construction elements, resistance and maintenance, adaptability, reduce technical installations.

Conference of the cantonal directors of energy (in German: Konferenz Kantonaler Energiedirektoren – EnDK)

The conference of the cantonal directors of energy publishes regularly reports with recommendations regarding the sustainable construction and operation of buildings. For new constructions, the report of 2021 "efficient constructions" reports details about the following main topics:

- Energy and building: including embodied energy, comfort, and general concepts,
- Form and envelope,
- Envelope of highly insulated buildings,
- Technical installations.

Further documents are also available for renovations such as "correct energetic renovations of multi-family houses" or "renovation of buildings – how to reduce by half the energy consumption in a single-family house".

Finally, focused reports on the embodied emissions of buildings are available. 10 main recommendations are reported in the case of new constructions to reduce the embodied emissions:

- Increase the service life of buildings and its components,
- Reduce the size of construction elements,
- Limit the size of underground floors,
- Implement straightforward and logical load bearing structures,
- Enhance the synergies between functions,
- Optimise slabs and roofs,
- Be reasonable about the window-to-wall ratio,
- Use of lightweight insulation materials,
- Alternative materials for internal non-load bearing walls,
- Optimise technical installations to reduce the amount.

Minergie

Minergie is a label which main aim is to certify sustainable construction. From 2022 the label expanded its boundaries to include embodied emissions in their assessment and not only operational energy and emissions. The label does not explicitly state recommendations or measures to reduce emissions of buildings but rather sets targets to be met to get the certification. On the other hand, a tool is available for a simplified estimation of the embodied emissions of a building and a selected list of options (or measures) is available. The following options are available:

- Envelope factor,

- Type of foundation works,
- Size of underground floors,
- Type of construction,
- Load-bearing capacity of structure,
- Window-to-wall ratio,
- Thickness of slabs.

SIA2040

The SIA 2040 main purpose is, similarly as with the labels, to set emission targets for new constructions and renovations. In the complementary documentation, influencing factors can be found in the same way as in the SIA 2032. The influencing factors for the embodied emissions are the same stated in the SIA 2032. In addition, influencing factors for the operational emissions are also added:

- Create the appropriate political framework conditions: Promoting densification, encourage a regional energy planning, promote renewable energies,
- Reduce energy demand: transform vs. new, compact heated volumes, reduce demand for cooling, high solar gains, well insulated envelope, reduce thermal bridges, grouping functional rooms in plan (e.g., rooms with water access – e.g., bathrooms), accessible ducts,
- Cover energy demand optimally: high share of renewable energies, use of on-site renewable energies; heat recovery concepts, simple and effective energy concepts, efficient lighting, efficient appliances,
- Quality control: in execution and in operation.

Evaluation of Embodied Energy and CO_{2eq} for Building Construction (IEA EBC Annex 57) – Subtask 4: Case studies and recommendations for the reduction of embodied greenhouse gas emissions from buildings (2016)

Subtask 4 of the IEA EBC Annex 57 group established a list of strategies to reduce embodied emissions in the design of buildings based on scientific literature and groups them in the following 4 main groups:

- Reduce the quantity of resources/materials implemented along the life cycle (light constructions, form and conception of plans, flexibility and adaptability, low maintenance and long-life span, and reuse of structures),
- Substitution of traditional material with low carbon alternatives and natural materials (including reuse and recycling),
- Reduce the impact of the construction phase,
- Concepts to reduce the impact of end of life.

Logical grouping of measures

The selection and grouping of measures for the purpose of the current project is strongly influenced by the references described in the previous sub-section. No separation of measure is done between measures influencing operational emissions and those influencing embodied emissions, as done in the SIA 2040, as it is concluded that most, if not all, measures applied at building scale influence both dimensions and both need to be included in any analysis concerning GHG emissions. A grouping of measures is here done based on the technical degree and design phase required by the measure. Non-technical measures are seen as measures applicable in early-design phases which do not necessarily require high levels of technical assessment. Technical measures are more focused on the material level and more technical concepts such as renewable energies and low-tech concepts. For clarity the measures are grouped according to the design phases (definition of objectives, preliminary study, project phase, and tendering in accordance with SIA112) representing the moment in time the decision is or should be taken to have the highest potential impact. It is worth noting that some measures/decisions are often discussed from early design phases but only defined later in the project and that some overlap between the phases happens often in the practice. For example, the general statical system and load-bearing materials are often already mentioned and discussed in the definition of objectives (or during the competition process when applicable) but the final definition and dimensioning happen only in the project phase and a relevant degree of freedom is still possible in-between. Therefore, measures are grouped only based on the phase where the definite decision is taken.

An initial phase is included, as mentioned in the SIA recommendations, called “framework conditions”. This phase represents a set of measures and/or conditions that can highly influence GHG emissions at building scale but are not influenceable during the design of a building. In this phase an additional “condition” is added, which is not mentioned in the literature review, approaching the future development of the industry which will have an evident influence on the GHG emissions of our buildings.

Data collection

Based on the selected measures, data was collected within the working group and the existing literature. Priority was given to recent studies and studies using similar methodologies in their assessment. The data gathered covered impact assessment of building elements, of building case studies, and of studied variables on modelled archetypes (e.g., parametric modelling of archetype with variables such as number of floors, size of windows, materials used, etc.).

When categorizing building elements, results are aligned with the eBKP-H/eCCC-Bât (Elementbasierter Baukostenplan Hochbau) structure and classification, wherever possible. This approach ensures a consistent framework for assessing and evaluating building elements and to coherently share results with other research questions.

Defining system boundaries and limitations

In case some elements are missing or some deviation to the standard method and database are used, it is clearly mentioned in the reported results. Furthermore, the GHG reductions are calculated in relation to specific case studies or boundary conditions. It is not possible in the framework of this project to evaluate all possible building types, structural spans, and site conditions. Therefore, the boundaries conditions are always mentioned and must be considered when referring to the specific results. The limitations of generalizing the stated results are mentioned at each measure.

Description of measures

Measures are described individually with the following main elements:

- Relevance of the measure and influencing factors,
- Recommendations,
- Limitations,
- Examples.

The relevance of each measure is described for both new construction and renovations as well as embodied and operational emissions. If recommendations and limitations of the measure differ based on type of work and/or emissions, a specification is added.

The quantification of impacts of the measure, in most cases, refers to selected case studies under specific conditions. For this reason, the main indicators of the case study used (type of building, size, and main structural material) are mentioned and a reference is added, whenever possible to the building typologies described in Appendix 7.1 of this report.

Examples are added to the description of measures, when possible, to further support the relevance of the measure under specific conditions.

2.1.1 Building types

As mentioned in the previous sub-section, building types are used in this project to exemplify, with existing case studies, what is already being done in the practice towards net-zero buildings to answer research question F2.6. The building types chosen do not, per se, represent net-zero buildings but do showcase specific measures and elements that need to be explored further to achieve the goal. The building types gathered from concluded or on-going projects of the team members serve as a basis to extract specific building elements and associated impact to be shared with F1 for the building stock modelling. Furthermore, when relevant, the same building types are used as reference to describe specific measures applied at building scale. The detailed assessment of the building types is reported in Appendix 7.1, with the main parameters of the building and the calculated GHG emissions. It must be noted that a lack of data on building typologies other than residential and office was encountered. Although residential and office buildings do represent the majority of the building stock and new construction activities, further typologies (i.e. industrial, education, hospitals, etc.) need to be examined further and average impacts and potential reduction might differ from the typologies studied in this report.

2.1.2 Life Cycle Assessment method

In this report, the focus is exclusively on measures that are applicable to or have a distinguishable impact at the individual building level. To ensure rigorous quantification at the individual building level, the Life Cycle Assessment phases and approach, as outlined in EN 15978:2011 (Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method) and SIA 2032:2020, are used. The standard lifetimes of building (60 years) and of components (20, 30, and 40 years) as reported in the SIA2032:2020 are used to establish replacement rates over the life cycle. This approach does not allow to test the lever of an increased lifetime identified and discussed in F1.

The chosen impact assessment method is in accordance with IPCC 2013, with climate change as the selected impact category. For consistency, GWP100 (global warming potential of GHG over 100 years) is used as the primary indicator, measured in kilograms of CO_2 equivalent (kg CO_{2eq}).

In quantifying the environmental impacts related to the production and end-of-life of construction materials, as well as the supply of energy, data from the KBOB 2009/1:2022 database is drawn. The reporting of environmental impacts in the KBOB is not strictly aligned with EN 15804 (Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products) but it is, to this day, a widely used database in the Swiss context. The KBOB reports only impacts for phase A (production) and C (end-of-life) for the products listed and GWP impact indicator is not separated into fossil, biogenic, and total for the different phases but only GWP-fossil is indicated. In some instances, specific construction products used in the case studies were not included in the KBOB database and Environmental Product Declarations (EPDs) were directly taken from the producers instead. It is also worth noting that in some instances, prior collected studies quantifying impact levels may have relied on older versions of the KBOB database. When updates were not feasible, relative values are used to maintain the comparability of results within this work.

The biogenic carbon content (in kgC) is extracted from the KBOB 2009/1:2022 database and converted into carbon dioxide according to EN 16449 to indicate the GWP-biogenic indicator as per EN 15804+A2. The indicator is reported separately in line with the requirements outlined in EN 15804 +A2 and F0 specifications. Biogenic CO_2 uptake is added in the production phase and biogenic CO_2 release is reported at end-of-life phase. Furthermore, in line with F0.3.B, in case the permanent storage of the biogenic carbon content is legally ensured, or proven, biogenic CO_2 release can be considered zero. Therefore, in the framework of this project, biogenic CO_2 uptake is presented throughout the results as an indication of the potential negative emissions together with the remark "a corresponding emissions of CO_{2eq} shall be accounted for during end-of-life phase unless the permanent storage of the biogenic content is legally set/proven".

The environmental impacts of reusing building elements are calculated according to the approach "Zusatzaufwand" ("Additional efforts") proposed by (Pfäffli *et al.*, 2022), which is the recommended method in this project (see research question F0.4). Environmental burdens are assessed for each of the various activities involved in the process-chain of reusing a product associated to modules A1 to A3 and C1 to C4. It includes dismantling, intermediate transport, reconditioning, storage, waste treatment of material losses, and at the end-of-life phase. No transport to site in module A4 nor installation in module A5 are assessed to allow a consistent comparison with new construction products according to SIA 2032:2020 calculations. A default scenario assumes a supply to the site using a 16-32 tons truck over a distance of 50 km for all the new elements and reused elements lacking specific transportation information.

2.1.3 Future electricity & industrial evolution

To account for future evolution of electricity and industry sectors, life cycle GHG emissions are developed from 2020 to 2050 at a 10-year time interval at the construction material or component level (Appendix 7.2). The 2020 emission values are from KBOB database 2022, specifically Oekobilanzdaten_ Baubereich_Donne_ecobilans_construction_2009-1-2022_v3.0.xlsx[3], and the 2050 values are from the project “LCA of climate friendly construction materials” in 2020, specifically “LCA data on the future production of building materials”[4]. Values between 2020 and 2050 are linearly interpolated at a 10-year interval. However, due to discrepancies in material/component availability between the two references above, the selection of materials/components was restricted to those available in the reference for 2050 values. In other words, the values of 79 products (Appendix 7.3), which are in the list of KBOB 2022 are not interpolated between 2020 and 2050. 48 of them are brand-specific products, and 31 of them are generic products. For each material or component, GHG emissions are divided into two segments: emissions from manufacturing (A1-A3, according to EN 15978), and emissions from end-of-life treatment and disposal (C1-C4, according to EN 15978).

2.2 Parametric LCA for net-zero strategies

To answer research question F2.2 in WP3a, a parametric approach is used to assess the impact of measures at building scale and define combination of measures suitable to achieve net-zero (i.e.: “strategies for net-zero buildings”). The characteristics of the building types identified in WP2 and from the literature and projects used to identify the measures (energy reference area, number of floors, main structural system and materials, energy system, etc.) are used as reference input parameters to establish the initial archetypes in the parametric model. The initial archetype is necessary to establish a common reference to which GHG reductions are applied to. The parametric model is then set-up with predefined algorithms to create the bill of quantities, the operational consumption, and energy system of the archetype. GHG emissions are then automatically extracted from the model. The measures described in WP1b are applied to the archetypes as variable parameters in the model to assess the potential reduction in GHG emissions compared to the initial archetype. The studied measures can have an impact directly in the bill of quantities/energy consumption or on the impact indicators associated with these quantities. The overall flow is presented in Figure 2. To better understand the process, an example is added in the flow of Figure 2 with red dotted lines. The example shows the initial building characteristic “envelope factor” set at 1.5 affecting the total surface area of exterior walls in the reference archetype (1964m^2). The envelope factor is a variable parameter in the parametric model and the measure “compact design” (see section 3.1.8) reduces this variable to a minimum (0.9 in Figure 2). This reduction brings down the surface area of exterior walls to 948m^2 in the bill of quantities of the parametric model and results in an equivalent 52% reduction of GHG emissions of the exterior walls.

The parametric model is based on a simplified Excel tool which establishes in a first step the bill of quantities of the archetype based on pre-established algorithms and using basic building characteristics

[3] 302 materials/components, available at: https://www.kbob.admin.ch/kbob/fr/home/themen-leistungen/nachhaltiges-bauen/oekobilanzdaten_baubereich.html
[4] 223 materials/components, available at: https://treeze.ch/projects/case-studies/building-and-construction/climat-1

as input parameters. In a second step, the tool calculates GHG emissions for both operation and embodied using pre-established building components and energy performances.

The impact of measures applied to the reference archetype are, firstly, evaluated individually. This shows the relative potential that each measure can have on reducing GHG emissions on the selected archetype. In a second step, measures are combined into strategies towards net-zero buildings. Strategies are based on the three well-known pillars in the field of sustainable development: “sufficiency”, “consistency”, and “efficiency” (Huber, 2000). In the recent UNEP report on building materials and the climate (UNEP, 2023), the strategies are formulated as “AVOID”, “SHIFT”, and “IMPROVE” but are, in principle, following the same core idea.

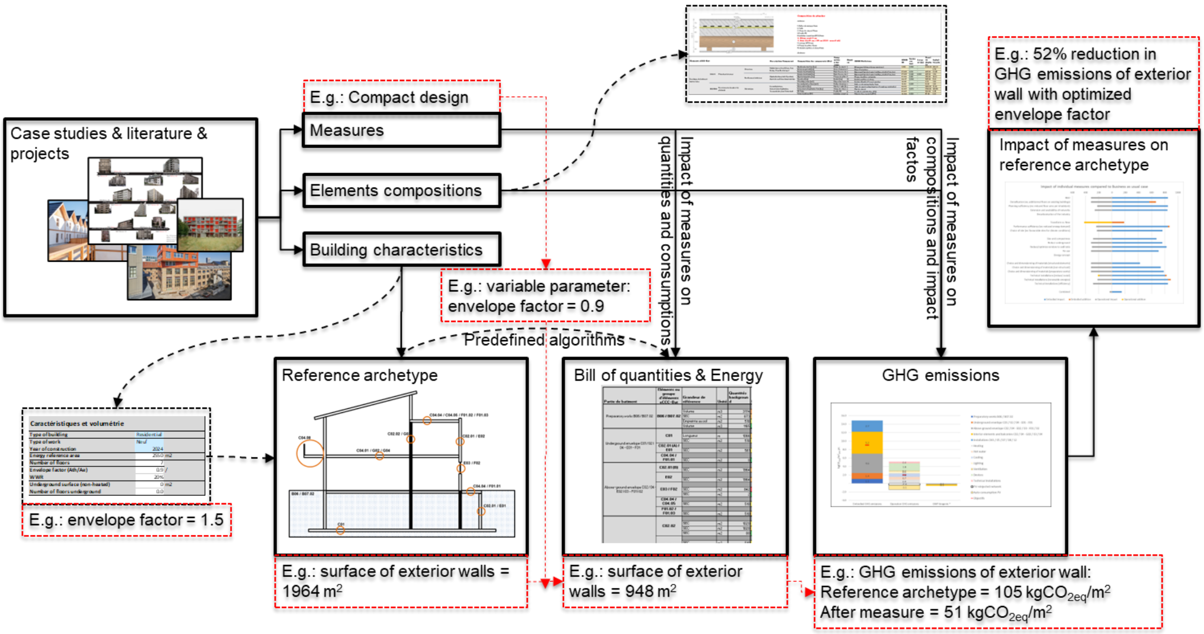


Figure 2: Methodology used for the parametric LCA for the assessment of strategies towards net-zero buildings.

2.2.1 Sensitivity analysis

The sensitivity analysis was mandated as supplementary information to the initial results of this report. This section is therefore added in this reviewed version of the report. The aim is to provide deeper insights into the impact of selected measures on GHG emissions at building scale, comparing the outcomes with the GHG targets identified in the project.

The sensitivity analysis involves testing a range of available choices for selected measures, applied to the reference buildings described in 7.1. Each selected measure is assigned a variability range with up to four options, maintaining consistency. A one-at-a-time approach is utilized to assess each measure’s impact on the reference building individually. Moreover, a set of combined variables is tested to understand their collective influence. Finally, extreme ranges of each measure are cumulated on a best- and worst-case scenario following the sequence of planning phases. The best-case scenario implements the measures chosen for the reduction strategies presented in the previous section.

Only measures in the planning phases (from phase “definition of objectives” to “project phase”) are tested (see Table 2). Measures included in the phase “framework conditions” are excluded as not deemed pertinent in the scope of this analysis. The specific measures “choice of site” and “energy concept” are also excluded from the analysis as, partially, the effects are already included in other measures (e.g., renewable energies availability and efficiency). Finally, the “Re-use” measure is not included due to the lack of sufficient data and tools for assessing feasible scenarios, although its relevance for GHG emissions reduction is discussed in 3.1.11.

The range of variability of each measure is defined based on current available practices. The functional comparability of the variability levels for each measure is, as much as possible, ensured through model adjustments when needed (e.g., variation in insulation material adjusts thickness for comparable U-values). Nonetheless, some limitations to the model are still present and would require more advanced simulations and studies.

The models used as reference cases for multi-family house and single-family house are based on estimated average building typologies characteristics. Variations in these initial base levels may affect the sensitivity of the measures applied. Similarly, changing the sequence of combined measures will also affect the sensitivity (e.g., opting for simple excavation works after deciding to avoid underground floors will have less impact than if we were planning two underground floors).

2.3 Feasibility assessment

To evaluate the feasibility of the measures proposed in this report (research question F2.3), a systematic approach is used. The harmonised approach to assessing feasibility used by the IPCC (IPCC, 2021) is taken as a reference. The aim of the assessment is to identify enablers and barriers from an economic, social, and technical perspective in the implementation of the identified measures to reduce GHG emissions at building scale in Switzerland. It also provides insight into the effort needed (through policy actions or investment directions) to reduce or remove current barriers. Three feasibility dimensions are assessed in this work: economic, social, and technical.

Table 1: Indicators used to assess the feasibility of the economic, social, and technical dimensions.

Dimension	**Economic**	**Social**	**Technical**
	Financial costs and economic effects:	**Public engagement and support, and social impacts:**	**Extent to which the technology can be implemented at scale soon:**
Indicators	Costs now, in 2030 and in the long term	Social co-benefits	Technical scalability: can the option be scaled up quickly
	Employment effects and economic growth	Public acceptance: extent to which the public supports the option and changes behaviour accordingly	Maturity: R&D and time needed to implement the option
			Simplicity: is the option technically simple to operate, maintain and integrate
			Absence of risk

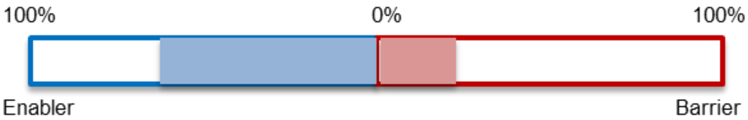
In the frame of this project, indicators were identified from the literature (IPCC, 2018, 2021) to reflect the specific context, levers, and constraints of the Swiss building sector. Table 1 summarizes the indicators used for each dimension. From an economic perspective, costs (now, mid-term, and long-term) and effects on employment and economic growth are evaluated to determine the level of enabling or hindering conditions of these indicators for the implementation of each measure. From a social perspective, social co-benefits and public acceptance are used as indicators. Social co-benefits refer to the positive interactions or synergies provoked by the measure in the building, related infrastructure, or users. Public acceptance reflects the extent to which the public would support the measure and/or would change behaviour accordingly. From a technical perspective, indicators focus on the level of maturity (is the measure ready?), the speed of scalability (can the measure be scaled up quickly?), the simplicity of operating the measure, and the absence of risk in scaling up and implementing the measure.

The evaluation is then performed with a 1 to 5 grading system for each indicator and each measure:

1: The indicator hinders the feasibility of this measure
2: The indicator could potentially hinder the feasibility of this measure
3: The indicator has neither a positive, nor a negative effect on the feasibility of the measure, or the evidence is mixed
4: The indicator could potentially enable the feasibility of the measure
5: The indicator enables the feasibility of this measure

A first evaluation is performed by the team members of F2 separately based on the results from completed and on-going projects and individual experience in the sector. Results are then analysed to identify discrepancies and variabilities in the assessment of single measures and to conduct a first interpretation of the feasibility evaluation.

At this level, individual assessments are aggregated using the standard weighted sum method to identify the relative level of enabling or hindering conditions of the indicator for each measure (Figure 3). For example, the costs' indicator of the analysed measure can present both enabling and hindering conditions, based on the results of the first evaluation the relative level is calculated in both directions. The indicator would be considered 100% enabler in the case all responses of the evaluation were graded 5, vice versa, the indicator would be 100% barrier if all responses were graded 1. Grades 4 and 2 would increase the level in either direction with a lower weight than their counter grades 5 and 1. While grade 3 works as a neutral weight, meaning that it decreases the level in both directions.



$$Enabling\ Level\ [\%] = \frac{\sum x.w}{max}$$

$$Barrier\ Level\ [\%] = \frac{\sum x.w}{max}$$

Grade (x)	Weight (w)
5	1
4	1
3	0
2	0
1	0

Grade (x)	Weight (w)
5	0
4	0
3	0
2	2
1	5

Figure 3: Standard weighted sum method used to evaluate the levels of enabling and barrier conditions of the feasibility indicators on the measures to reduce GHG emissions.

The final assessment is presented with a five-level grading system: easy, moderate-easy, moderate, moderate-difficult, and difficult. The following definitions are used for the interpretation of results:

- Easy: more than 50% of enabling levels and 0% barriers. This suggests a strong agreement that the indicator could potentially enable the implementation of the measure.
- Moderate-easy: 0% barriers but less than 50% enabling OR more than 50% enabling but presence of barriers as well. In this case, there is a relative agreement that the indicator brings enabling conditions but barrier and/or mixed evidence are also present.
- Moderate: Both enabling, and barriers levels are between 0% and 50%. There is low agreement and/or mixed evidence in the evaluation of this indicator for this measure.

- Moderate-difficult: 0% enabling but less than 50% barriers OR more than 50% barriers but presence of enabling as well. There is a relative agreement that the indicator brings barrier conditions but enabling and/or mixed evidence are also present.
- Difficult: more than 50% of barrier levels and 0% enabling. This suggests a strong agreement that the indicator could potentially hinder the implementation of the measure.

Finally, a “blank” grade is also possible in case all responses were graded 3. These indicator-measure results are treated as lack of evidence or mixed assessment and are not discussed further. More in detail assessments should be carried out to better understand the specific reasons.

2.4 Building standards and labels assessment and comparison in view to the net-zero target

In relation to research question F2.4 "How should the various building standards and labels (MoPEC/MuKEn 2014, CECB/GEAK, Minergie and Minergie-ECO, SNBS and the SIA efficiency path) be classified in relation to the net-zero target and what methodological differences do they exhibit? and research question F2.5 “To what extent do the limit and target values of these standards meet the net-zero target for individual buildings?”, the methodological approach developed here consists in comparing the existing labels and standards according to a list of criteria.

Given that the current labels and standards do not systematically use a full “LCA approach” which is a pre-requisite in the context of net-zero targets, the comparison conducted in this study starts with “basic” criteria able to distinguish a label only focusing on direct energy use and related emissions from a label already encompassing the whole life cycle of a building.

List of labels/standards and criteria used to compare them in a view to the net-zero target

The list of building standards and labels included in this analysis are the following:

- SIA 380:2015
- SIA 2031:2016
- SIA 2032:2020
- SIA 2040:2017
- SIA 390/1:2023, version submitted to public consultation (June 2023), not final
- MoPEC/MuKEn 2014
- CECB/GEAK 2.1.0 (March 2023)
- Minergie-(P/A) before 2023 and Minergie-(P/A) from September 2023
- Minergie-Eco 2023
- SNBS 2.1
- SNBS 2023
- SméO - Energie
- SméO “Energie-Environnement”

Each label or standard is classified according to the following criteria:

- Type of project assessed (e.g., new construction, renovation)
- Life cycle stages / system boundaries
    - construction-related aspects distributed over the life cycle from raw material supply to the factory gate and to other life cycle stages up until the end-of-life

- operational energy use-related aspects like heating, domestic hot water, other electricity uses related to the building or to the users

- Building category assessed (e.g., residential, office, others...)
- Reference document for the calculation method and requirements
- Method to define the energy related indicators (e.g., LCA-based, national factors...) and the reference/source
- Type of indicators included (GHG emissions (with only fossil), total primary energy, non-renewable primary energy, other energy indicators (e.g., weighted final energy), total environmental impacts expressed in ecopoints (UBP))
- Reference unit to report the indicator for the building (e.g., per m^2_{ERA}, per person...)
- Type of assessment / benchmarking (e.g., by means of classes like A, B, C...., comparison with target values, comparison with limit values, in points...) and if relevant, details of the assessment / benchmarking can be added: for example, the scope of the assessment: global for different impact related sources (construction, operation, mobility...), or by domain (e.g., only operational energy use) or by component (i.e. if only part of the building is assessed)
- Requirement for the building project (quantitative values to comply with)
- Other requirements (carbon storage in building, accounting for reuse...) or additional requirements in each label/standard that can be relevant to position the label/standard in a view of net-zero target.

The summarized results over these criteria aim to assess the suitability of each label or standard in achieving the target of net-zero life cycle GHG emissions of buildings. The primary objective is to address the question: "Does the building label or standard guide toward or away from a net zero target?"

This evaluation encompasses an analysis of the methodological assumptions and prerequisites of the label/standard, in particular with regard to the methodological aspects presented in research question F0, and along with the carbon reduction measures they incorporate. The labels and standards are analysed based on whether they contribute to achieving net-zero buildings or, conversely, impede the reduction of life cycle GHG emissions of buildings.

3 Results and discussion

3.1 Measures for GHG reduction at building scale

The following section presents the selected measures for GHG reduction at building scale. Table 2 shows the full list of measures assessed, the reference to the literature and the type of work (new construction or renovation) they refer to.

Table 2: Selected measures to reduce GHG emissions at individual building scale.

Phase	List of measures	New construction	Renovations	SIA 2032 / SIA 2040	EnDK	Minergie	SNBS	Annex57
Framework conditions								
	Densification (ex. additionnal floors on existing buildings)	■		x			x	
	Planning sufficiency (ex: reduced floor area per inhabitant)	■		x			x	
	Extension and availability of networks	■	■	x				
	Decarbonisation of the industry	■	■					
Definition of objectives								
	Transform vs. New	■		x			(x)	
	Performance sufficiency [ex: reduced energy demand]	■	■	x			x	
	Choice of site [ex: favourable sites for climate conditions]	■					x	
Preliminary study								
	Size and compactness	■		x	x	x		x
	Reduce underground	■		x	x	x		
	Reduce/optimize window to wall ratio	■		x	x	x		
	Re-use	■	■					x
	Energy concept	■	■	x			x	
Project phase								
	Choice and dimensioning of materials [structural elements]	■		x	x	x	x	x
	Choice and dimensioning of materials [non-structural]	■	■	x	x	x	x	x
	Choice and dimensioning of materials [preparatory works]	■				x	x	
	Technical installations [reduce/ avoid]	■	■	x	x			
	Technical installations [renewable energies]	■	■	x	x	x	x	
	Technical installations [efficiency]	■	■	x	x	x	x	
Tendering								
	Suppliers [environmental performance and reduce distances]	■	■	x			(x)	

Figure 4 highlights the potential impact on GHG reduction of the selected measures along the design phases, including the initial framework conditions.

Measures in phase “framework conditions”

Political conditions framing the built environment significantly impact GHG emissions. These conditions involve promoting densification in urban planning, encouraging sufficiency in building ordering, planning, and usage, fostering the development of low-carbon and efficient networks, and prioritizing the decarbonization of energy grids and industry.

Measures in phase “definition of objectives”

During this early design phase, key decisions are made to establish the goals, needs, requirements, and strategic parameters that will guide the design process. At this stage possible solutions and availability of specific opportunities and constraints are analysed. The level of detail at this stage can vary, but it generally involves establishing the project’s overall vision, purpose, and performance criteria.

Measures in phase “preliminary study”

In the preliminary study phase, design options are evaluated in terms of size and shape of the building and re-use and energy concepts are put in place.

Measures in phase “project phase”

The “project phase” involves defining all elements to a level sufficient to start the tendering process, thus ranging from a pre-project level to a construction project level. This includes choice and dimensioning of structural, non-structural, and preparatory works as well as technical systems.

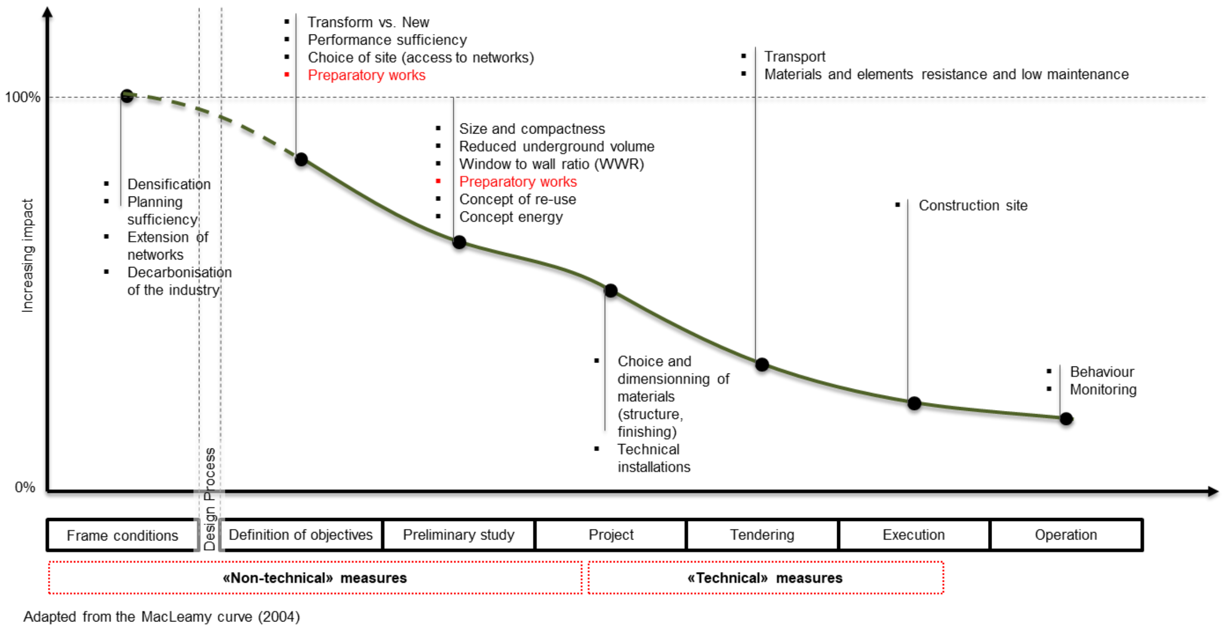


Figure 4: Measures to reduce GHG emissions along the design phases.

In the following sub-sections, each measure is described individually.

3.1.1 Densification

Relevance of the measure and influencing factors

Densification is a strategy that involves increasing the building density within a given area, often by building vertically (e.g. adding storeys to an existing building or building new mid/high rise buildings as opposes to build many small buildings one next to the other). The measure is relevant for:

Reduced Urban Sprawl: Densification aims to make more efficient use of existing urban infrastructure and reduce the extension of urban sprawl, which can lead to longer commutes and increased transportation emissions. By concentrating development in urban areas, people have better access to public transportation, reducing the need for individual car use and lowering associated emissions.

Efficient Land Use: Densification encourages the use of previously developed or underutilized land, reducing the need to clear new land for construction and extensive preparatory works which together with underground construction accounts for more than 15% of GHG embodied emissions of a standard multi-family house as shown in Figure 5.

Energy Efficiency: Denser urban areas often benefit from improved energy efficiency. Buildings that share walls and/or have low surface to volume ratios can be more energy-efficient due to reduced heat loss and energy consumption. Additionally, shared infrastructure such as district heating and cooling systems can be more energy-efficient in densely populated areas.

It is important to note that the extent to which densification reduces construction emissions can vary based on local policies, building practices, and the specific implementation of densification strategies.

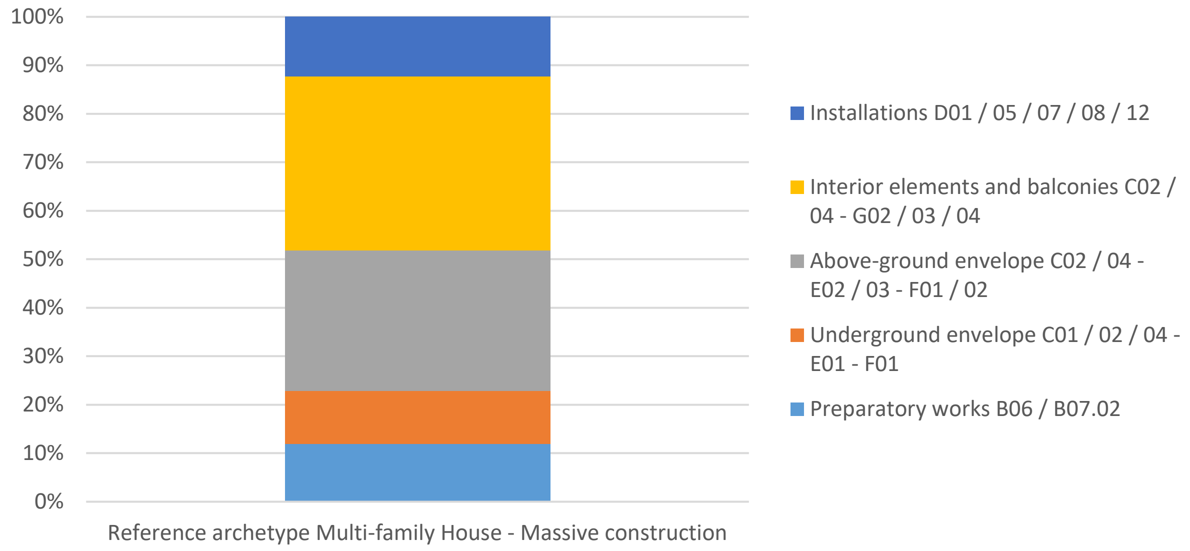


Figure 5: Relative GHG embodied of building parts of a reference multi-family house archetype. Preparatory works and underground envelope account for more than 20%.

Recommendations

Extension of an existing building increases habitable surface area while avoiding expanding built area (urban sprawl) and by making use of existing structures. In terms of GHG emissions from the building construction (as defined by SIA 2040), raising the height may result in lower emissions as intensive foundation works are not required. However, structural strengthening of the existing building may be necessary, and different combinations of construction elements are available for these extensions. The addition of multiple floors is possible, and it is recommended to follow the floor plan (and structural charges) of the existing plan to avoid extra strengthening and additional GHG emissions. In all cases, timber construction for the added storeys is recommended to reduce GHG embodied emissions and lower construction weight.

Limitations

Adding storeys does not need new underground floors or new foundation construction. However, it may require strengthening of existing building components (walls, above all, possibly slabs and foundations), for earthquake actions, above all. Note, however, that strengthening of existing shear walls is often already necessary for a building renovation without the addition of storeys (Zwicky, 2023), due to lower or inexistent requirements in older building codes. Height limitations (beyond 30 m of building height fire police regulations change significantly) and shading of neighboring buildings may limit the number of floors that can be added. In addition, the existing roof structure often needs to be demolished to construct the additional storeys.

Examples

A two-storey addition on an existing building is common practice today. Adding more storeys is often constrained by construction permit and fire police regulations (i.e.: residential zone planning and building height exceeding 30 m).

Embodied carbon and construction cost evaluations of generic construction element combinations for additional storeys on existing buildings, including the necessary strengthening measures in the existing building (Uboldi *et al.*, 2021; Zwicky, 2022, 2023) show that, for a floor plan layout closely following the one of the existing building, the embodied carbon ranges from 5.1 $kgCO_{2eq}/m^2.yr$ (or 305 $kgCO_{2eq}/m^2$, respectively) for timber solutions with a weight of 320 kg/m^2 to 7.0 $kgCO_{2eq}/m^2.yr$ (or 420 $kgCO_{2eq}/m^2$, respectively) for floor slabs made of prestressed concrete beams and polystyrene (PS) “hourdis” combined with sandwich walls made of ultra-high-performance concrete (UHPC) and integrated insulation made of expanded polystyrene (EPS), resulting in a weight of 610 kg/m^2. Using normal-weight concrete construction for the additional storeys, the GHG emissions amounts to 365 kgCO_{2eq}/m^2 and the weight is maximum with 1280 kg/ m^2. Using light-weight concrete (LWC) increases embodied GHG emissions by approx. 10%. For a most economic option, lightweight or normal-weight concrete construction is advised but being only 5-10% less than timber solutions. Using cold-formed steel profiles in slab and wall elements provides the lowest construction weight of approx. 290 kg/m^2 and results in a GHG emissions of 360 kgCO_{2eq}/m^2 and in about 20% cost increase. For all solutions, strengthening of existing elements accounts for approx. 10-15% of the total GHG emissions, the rest being associated to the embodied carbon of the additional storeys itself, while a large majority of that strengthening already necessary for the building without additional storeys. Using lightweight profiles made of GFRP (glass fibre reinforced polymers) in floor and wall elements leads to an increase in embodied GHG emissions of 30-80% compared to other construction methods.

Using a more flexible floor plan layout on a two-storey addition increases the embodied GHG emissions by up to 20 kgCO_{2eq}/m^2 and affects rankings of governing construction elements. Timber solutions remain those with the lowest embodied carbon (5.0-5.3 kgCO_{2eq}/m^2.yr., with a preference for wooden frame floors), followed by lightweight steel and lightweight steel-concrete composite structures (+20%). Lightweight concrete is the most cost-efficient solution (-5% compared to timber) but comes with a 45% increase in GHG emissions and a mass of 1050 kg/m^2.

In terms of number of added storeys, the normalized GHG emissions of a four-storey extension are lower compared to a two storeys because the relatively high embodied carbon of the roof becomes less significant compared to the impact from internal floors. For a storey addition with restricted floor plan layout, the GHG emissions are around 4.7-6.6 kgCO_{2eq}/m^2.yr. or 280-395 kgCO_{2eq}/m^2, respectively. Timber construction exhibits the lowest embodied carbon, followed by lightweight steel and lightweight steel-concrete composite solutions (+20%). Opting for cold-formed steel construction achieves the lightest storey addition (around 290 kg/m^2, about 10% less than timber), with GHG emissions and construction cost approximately 20% and 25% higher than timber solutions, respectively. Lightweight or normal concrete is the most cost-efficient option (up to 10% lower than timber) but results in a 25-35% increase in embodied carbon and increased mass of 880-1300 kg/m^2.

Using a free floor plan layout in a four-storey addition, timber construction with wooden frame floors and cross-laminated timber (CLT) curtain walls still show the lowest embodied carbon, coming along with the lowest mass of around 375 kg/m^2. Opting for concrete in this scenario may allow to decrease cost by some 5% but increases the GHG emissions by 30-50%.

3.1.2 Planning sufficiency

Sufficiency, alongside efficiency and consistency, is a sustainability concept that can also be applied at building scale. The concept of sufficiency lies in avoiding the demand in the first place in contrast to efficiency which is about meeting the demand with the least resource and consistency that meets the demand with low carbon/renewable sources (Huber, 2000). Planning sufficiency as a framework condition translates into space/surface per person (Wilson and Boehland, 2005).

Relevance of the measure

Planning sufficiency as a framework condition in the built environment, such as limiting the surface area per inhabitant, has little impact on the GHG emissions of individual buildings with current indicators expressed per m^2 of reference area (Büro für Umweltchemie GmbH, 2022). Nevertheless, it can have several positive, direct, and indirect, influences on the emissions at building scale if appropriate indicators are used (Wilson and Boehland, 2005; Huebner and Shipworth, 2017; Sandberg, 2018; Ellsworth-Krebs, 2020; Gaspard *et al.*, 2023):

- Reduced resource and energy consumption**:** Limiting the surface area per inhabitant prescribes an efficient use of space and a tendency to more compact design. This, in turn, reduces the demand for building materials and energy consumption per energy reference area.
- Smaller building footprints (surface given by the perimeter on the ground) and efficient land use: Smaller surface areas per inhabitant typically result in smaller building footprints. Therefore, to an efficient use of available land, reducing urban sprawl.
- Impact at building stock level: Limiting the surface area per inhabitant will reduce the demand for new construction, therefore reducing the impact at national level.

The measure is highly relevant in the context of GHG emissions reduction, especially considering the current trend of increasing floor area per capita in new buildings (Ellsworth-Krebs, 2020). The literature suggests potential energy consumption savings of up to 27% in the United Kingdom (Huebner and Shipworth, 2017) and 29% in a study covering the European Union by reducing floor capita to 30m^2/per person from an initial 45 m^2/per person (Bierwirth and Thomas, 2019). From a material perspective, demand for construction materials could be halved in the 2015-2050 period when sufficiency measures are implemented in France (Gaspard *et al.*, 2023).

Recommendations

To grasp the effect of sufficiency measures at building scale, different indicators must be used to include the number of inhabitants or workers relative to the built surface. In the same lines, targets for GHG emissions should include a system of bonus or incentive for sufficiency as proposed by the SIA2040.

Implementing sufficiency principles at building scale involves “(a) optimizing the use of buildings, (b) repurposing unused existing ones, (c) prioritizing multi-family houses over single-family houses, and (d) adjusting the size of buildings to the evolving needs of households by downsizing dwellings” (IPCC, 2021). Older multi-family buildings tend to have lower surfaces per room and could therefore be in line with sufficiency measures when transformed and repurposed.

To foster the adoption of this measure, government and policy makers can ensure the establishment of regulations and incentives (IWSB - Institut für Wirtschaftsstudien Basel, 2016) as well as urban planning guidelines. Real estate developers can also promote mixed-used developments and businesses and employers embrace flexible working spaces.

Limitations

Current impact indicators (GHG emissions reported per m^2 of energy reference area) at building scale do not account for inhabitant density. For this reason, from a planning perspective, there is currently no incentive in applying this measure. An exception to this statement is the targets proposed in the SIA 2040, which allowed a distinction between targets with or without occupancy regulations. Though, unless regulated or restricted, smaller individual space remains a voluntary or involuntary decision by users and/or building owners.

Examples

Some initiatives have already implemented sufficiency measures for rental conditions by adding a minimum number of inhabitants according to the size of the apartment:

Hunziker Areal, Zürich

ABZ Richtlinien

Subsidized housing, city of Zürich

In a study conducted by the city of Zurich in 2012, it emerged that by reducing the standard individual space by one-third, savings of approximately 15% in GHG emissions across all areas (construction, operation, mobility) can be achieved for both new constructions and renovations as shown in Figure 6. If combined with sufficiency in operation and mobility behavior, emissions per capita can be almost halved (Stadt Zürich, 2012).

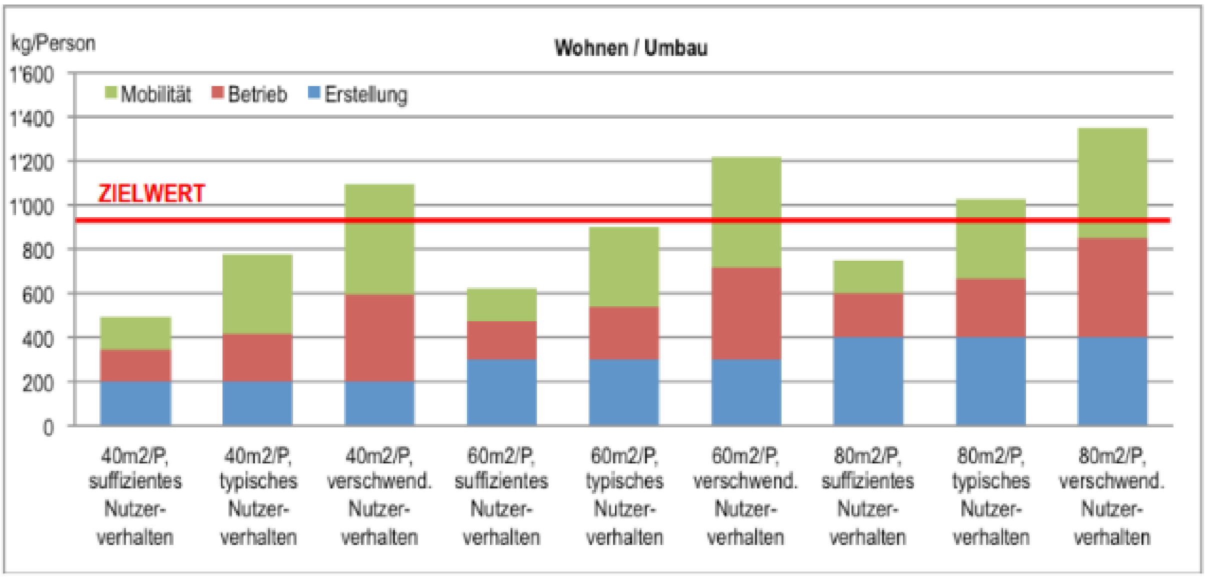


Figure 6: GHG emissions (construction, operation, mobility) per capita for three different user behaviors. (Stadt Zürich 2012)

3.1.3 Availability of energy networks and renewable energies promotion

Energy networks are a vital component of numerous national energy systems, seamlessly linking energy producers and consumers. They capitalize on the temporal and spatial variations in energy generation and consumption, while also capitalizing on economies of scale where feasible. The future evolution of these networks is driven by a dual objective of decarbonizing the supply while preserving the security and affordability of it (Oduro and Taylor, 2023).

Relevance of the measure and influencing factors

District energy infrastructure is the only method for harnessing low-exergy, low-grade waste heat or free cooling sources to provide end-user services like heating, cooling, and hot water in buildings (United Nations Environment Programme, 2015). The availability of such networks can have a significant impact on the emissions of individual buildings in the following ways:

- Access to renewable energy sources: buildings connected to energy networks often have access to a mix of energy sources, including renewable ones. The connection to district energy networks also gives the flexibility of increasing the renewable share without changing the system at individual building scale.
- District heating and cooling: energy networks can provide district heating and cooling systems, which are more energy-efficient than individual systems (United Nations Environment Programme, 2015). Furthermore, connecting to a district heating requires the installation only of a small exchanger, limiting the number of boilers being installed and freeing surface space in the building.
- Depending on the energy source, district heating options can result in lower emission factors than installing wood-based boilers or heat-pumps (Figure 7). Especially in the case of existing gas boilers, switching to the average Swiss district heating network cuts emissions by 4.
- Grid stability and energy storage: buildings connected to electricity networks benefit from grid stability and, in some cases, energy storage solutions. This can allow for better integration of intermittent renewable energy sources like wind and solar, which can help reduce the reliance on fossil fuels.

Furthermore, nationwide laws banning the installation of new fossil heating systems (already implemented in some cantons) would highly reduce GHG operational emissions, especially in the case of renovations.

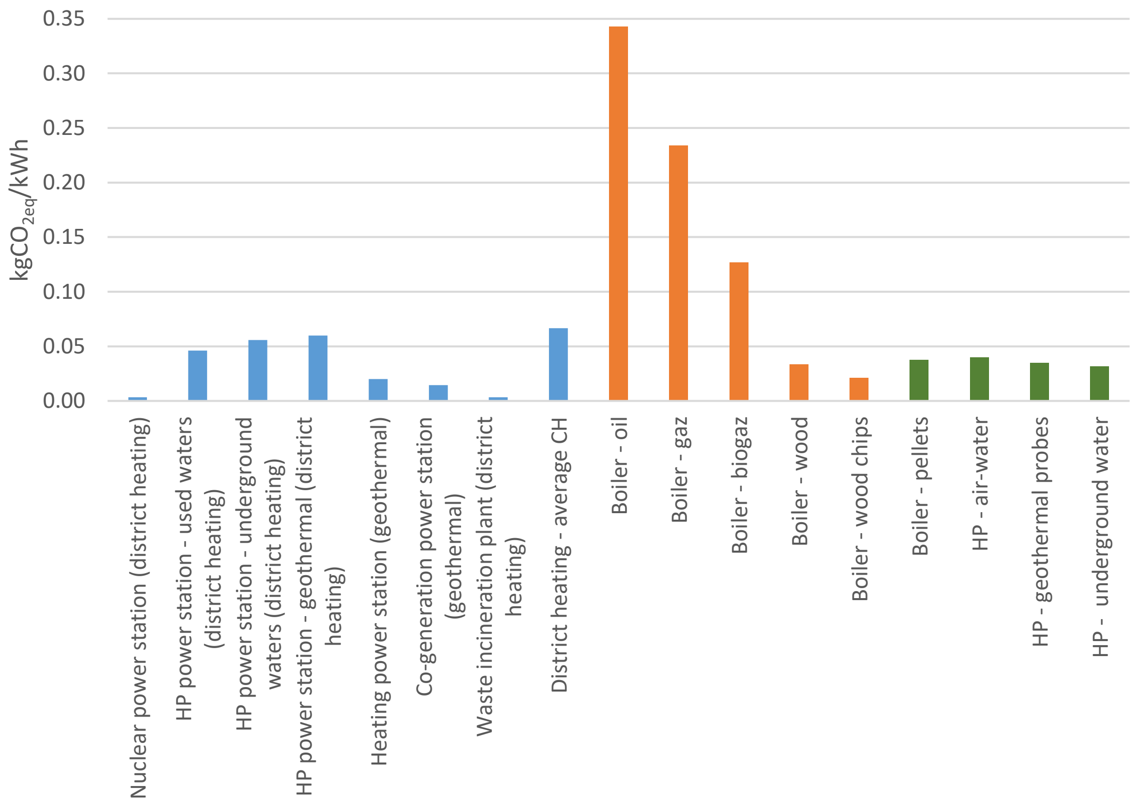


Figure 7: Emission's factors for energy sources (data: KBOB 2022) divided into district heating options (blue), boilers (orange), and Heat Pumps – HP (green).

Recommendations

From the government and policy makers perspective, promoting regional energy planning and renewable energies encouraging the establishment of district heating networks based on renewables should be prioritized and incentivized. From the perspective of individual building planning, new constructions or expansions should be prioritized along renewable networks developments while renovations should strategically assess the current and future availability of fossil-fuel-free energy.

Limitations

Current limitations are present in the development of regional energy plans, especially with regard to district heating deployment. Technical and economic limitations are a barrier to quickly scale up the availability of integrated regional district networks. Additionally, although energy networks have the potential to increase the share of renewable energies and give the flexibility to the single building to increase this share without changing technical system, the availability of renewable sources to feed these networks at large scale is uncertain. Finally, from a building scale perspective, this measure is not directly implementable in the design of a building but rather affects the context conditions of the project.

Examples

The following examples and sources can further exemplify the relevance of this measure:

Zernez: https://www.zernezenergia2020.ch/home/ ; (Orehounig *et al.*, 2014) https://www.energieschweiz.ch/erneuerbare-energien/fernwaerme/; (energieSchweiz, 2018)

https://www.bfe.admin.ch/bfe/de/home/versorgung/statistik-und-geodaten/geoinformation/geodaten/thermische-netze.html

3.1.4 Decarbonisation of the industry

The decarbonisation of the industry is added as a relevant measure in the framework conditions of the design and renovation of buildings as it depicts the carbon intensity of the supply chain of the building sector over the analysed period. This measure is to be taken only as an additional effort to achieve net-zero targets in 2050 and not as a single measure to decarbonize buildings now. Firstly, the decarbonization of the industry will only happen in the future and requires challenging and uncertain changes along the whole supply chain. Secondly, waiting for a future change is not aligned with the concept of a carbon budget and the pathway goal to net-zero which requires a steady and drastic reduction curve until 2050.

Relevance of the measure and influencing factors

This measure is highly relevant at the building scale due to its potential to significantly reduce the embodied carbon emissions of construction materials and, consequently, the emissions associated with building construction and renovation. With current estimations of the industry's development (section 2.1.3), embodied emissions of buildings could be decreased by an average 50% or more by 2050 (Figure 8).

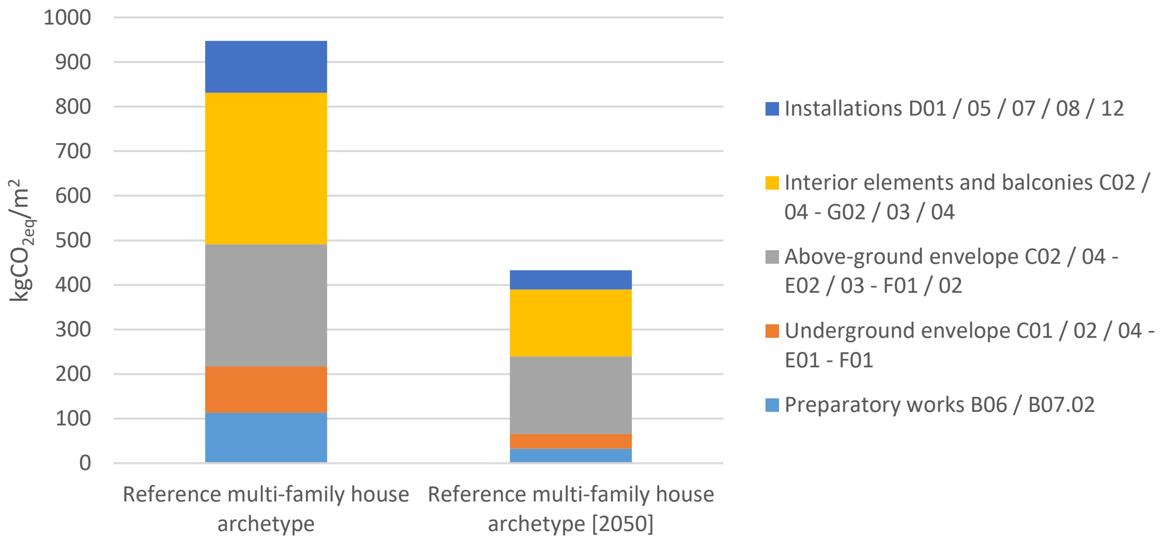


Figure 8: Reduction potential of a reference multi-family house with a concrete structure (Reference multi-family house archetype in Appendix 7.1) with estimates of materials production reduction in 2050.

Recommendations

To effectively leverage this measure for GHG reduction in individual buildings, the following recommendations are essential:

- Incentivize industry measures: encourage and incentivize the construction and energy industry to adopt more sustainable and low-carbon practices. This can be achieved through government policies, financial incentives, and industry standards that promote the use of environmentally friendly processes.
- Prioritize immediate action: while decarbonizing the industry is a crucial long-term goal, it is essential to prioritize efforts to decrease emissions today. Measures that can be implemented

immediately, such as improving energy efficiency, using renewable energy sources, and shifting to low carbon materials, should not be overshadowed by the longer-term industry decarbonization goal.

Limitations

It is important to acknowledge the limitations associated with decarbonizing the industry at the building scale. Estimating the exact emissions of decarbonizing the industry on individual building emissions is challenging. Projections for the industry's development and its potential to achieve a 50% reduction in embodied carbon by 2050 carry uncertainties. Substantial industrial improvements require strict regulation. Finally, as a framework condition measure, the potential of this measure only affects the context in which the building is being designed but no active lever is available at building scale.

3.1.5 Transform vs. new

Relevance of the measure and influencing factors

Transforming existing buildings instead of building new is highly relevant in the current Swiss built context. On one side demolishing buildings is perceived as a waste of existing resources and unnecessary release of emissions. On the other hand, the economic and social environment often treats existing buildings as obsolete and building a new efficient building seems more efficient. Generally speaking, renovations release less emissions (especially in the upfront construction/embodied side) than demolishing and building a new building (Zimmermann *et al.*, 2023). Here are some key aspects to consider:

- Reduction in structural element emissions: transforming existing buildings instead of demolishing and building new can lead to a substantial reduction in emissions related to structural elements which represent almost 40% of GHG embodied emissions of a reference multi-family house as depicted in Figure 9. When you renovate a building, you often retain its original structure, reducing the need for new materials and construction-related emissions.
- Prevention of preparatory works emissions: the preparatory works required for new construction, such as excavation and foundation preparation, can result in substantial emissions. By choosing to transform an existing building, you can avoid these emissions, contributing to a more sustainable approach.
- Preservation of initial investments: existing buildings represent a significant investment from the materials and resources used in their construction. By renovating and repurposing these structures, you preserve the value previously invested.

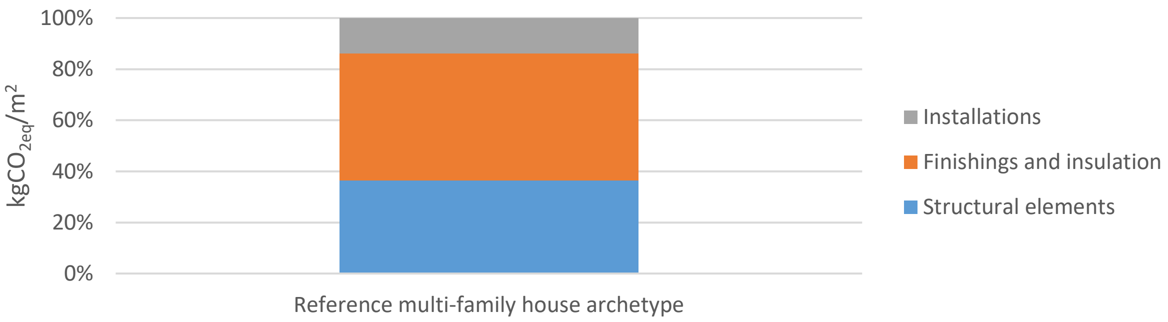


Figure 9: Relative GHG embodied of structural elements, finishings, and installations of a reference multi-family house archetype.

Recommendations

To make the most of this measure and ensure its effectiveness, consider the following recommendations:

- Evaluate transformation alternatives: when deciding between transforming an existing building and constructing a new one, an in-depth evaluation of projects preserving the existing building compared to alternatives with a new building must be carried out to identify the optimal level of preservation. Comparative LCAs will help in the decision-making process.
- The main GHG contributor in existing buildings is operational emissions and especially the fuel choice. Number one priority in the renovation of an existing building (in view of being more efficient than a new building) is to avoid fossil fuels-based heating systems and to switch to efficient systems (e.g., heat pumps) and/or renewable sources.
- Renovation works should follow further recommendations on measures (e.g. low-carbon materials, renewable energies, sufficiency, etc..) to maximize the potential reduction.

Limitations

It is important to recognize that while transforming existing buildings can be an effective emissions reduction strategy, it may have limitations:

- Material choices (technical measure): the choice of materials and construction techniques during renovation can impact the overall emissions outcome. If the transformation process involves the use of carbon-intensive materials, the benefits in operational emissions may be diminished. Prioritizing low-carbon and sustainable materials is essential.
- Building condition: the structural condition of the existing building plays a crucial role. In many cases, older buildings do not meet current safety standards for earthquakes and fire protection. Addressing these safety deficits in the transformation will add to the embodied carbon but allow to profit from synergies in the execution process and provide buildings fit for the future. Assessing the feasibility and potential emissions reductions for each building is essential.
- Economic considerations: economic factors and budget constraints can influence the decision to transform or build new.

3.1.6 Performance sufficiency

Performance sufficiency indicates the early definition of objectives in the design phase relating to reduced energy consumption. For example, early decision of following a Minergie-P standard will ensure a design driven for reduced energy consumption.

Relevance of the measure and influencing factors

Performance sufficiency is a critical measure that can significantly impact the emissions of individual buildings. Opting for a higher level of insulation than minimal regulations (e.g.: Minergie-P/-A) can decrease heating needs to ca. 50% Here are key considerations regarding the impact, recommendations, and related technical measures:

- Early definition of objectives: performance sufficiency starts with the early definition of objectives related to a building's energy efficiency and overall environmental impact. This step is crucial as it lays the foundation for all subsequent decisions and actions throughout the building design and construction process. By establishing clear performance sufficiency goals (e.g. limited consumption value, maximum U-values, minimum RE production, etc..) at the outset, a building can be designed and operated with the utmost efficiency, directly impacting its emissions profile.
- Influence on design decisions: performance sufficiency objectives influence design decisions made during subsequent design phases.

- Compatibility with technical measures: performance sufficiency is not a standalone measure but a foundational principle that underpins various technical measures. All technical measures, such as enhancing technical systems' efficiency, implementing low-tech concepts, and including renewable energies, can benefit from the performance sufficiency approach.

Recommendations

To leverage the potential of performance sufficiency for emissions reduction in individual buildings, consider the following recommendations:

- Early integration of performance sufficiency: integrate performance sufficiency aspects in the early definition of objectives for all subsequent technical measures. Ensure that performance sufficiency goals align with the building's sustainability and emissions reduction objectives.
- Continuous monitoring: implement a system for continuous monitoring and evaluation of the building's performance against established sufficiency objectives. Regular assessment ensures that the building maintains its energy efficiency and emissions reductions over the design process.
- Reducing energy consumption usually comes at an embodied carbon cost for additional insulation thickness, it is recommended to prioritize low-carbon materials to increase the benefit in operation.

Limitations

Sufficiency often requires normative flexibility (set point temperatures, comfort levels, etc…) therefore its implementation is often limited by standard requirements.

3.1.7 Choice of site

Relevance of the measure and influencing factors

The choice of site plays a role in determining which measures can be effectively employed in reducing a building's emissions. It has a direct impact on preparatory works, as the site's characteristics can either simplify or complicate excavation and foundation activities (Figure 10). Site choice also influences the efficiency of technical systems, as environmental conditions, such as exposure to sunlight and wind, can affect the performance of HVAC and renewable energy systems.

- On-site renewable energies: the feasibility and output potential of on-site renewable energy sources, like solar panels and geothermal probes, are heavily reliant on the site's location and characteristics. A favorable site can maximize the utilization of clean energy sources, reducing reliance on non-renewable options.
- Availability of networks: the proximity of a building to existing infrastructure networks, such as public transportation, water, and energy grids, depends on the site choice. This, in turn, affects the building's potential for efficient resource use, induced mobility, and emissions reduction.

Recommendations

To optimize the impact of site choice on individual building emissions, consider the following recommendations:

- Site evaluation: the choice of site must involve a thorough evaluation of site conditions and characteristics. Assess factors such as soil quality, topography, exposure to sunlight and wind, proximity to transportation and utilities, and any environmental considerations.
- Account for site limitations: subsequent decisions related to building design and construction should account for the limitations and opportunities presented by the chosen site. Design choices must align with the unique characteristics of the site to maximize emissions reduction while considering other design criteria.

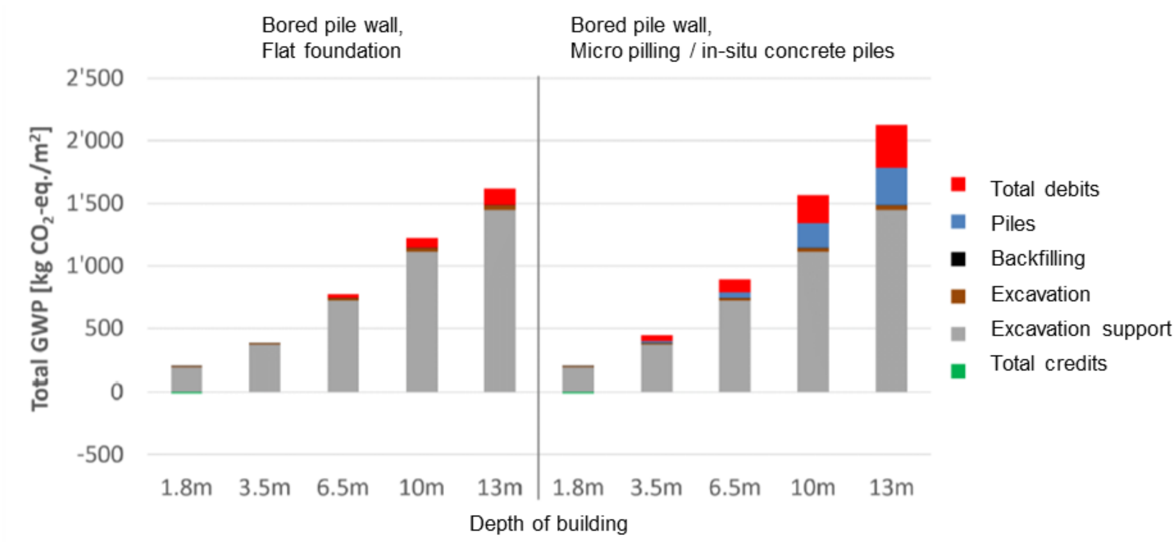


Figure 10: Impact of preparatory works in case ground conditions (water presence) require elaborate pilling foundations (right figure) – figure extracted from Stadt Zürich (2023) (Kuhn, Knecht and Schultheiss, 2023). The construction of the above-ground building is not included in these results. If the construction of the building changes in one of the cases under consideration due to lifting from the ground or sinking into the ground, these changes are considered as credits and debits compared to a reference case (e.g. thicker or thinner walls or adapted materialization).

Limitations

While site choice is influential, it does have its limitations:

- The site is often a given precondition of a project and can't be chosen.
- Limited leverage during design phases: once the site is chosen, the building's design options become somewhat constrained by the site's inherent characteristics. While some design adjustments can be made to mitigate site limitations, the fundamental site choice remains relatively fixed.

3.1.8 Compact design and building size

Compactness of a building can be described with a form factor (envelope surface/ERA) or envelope surface to heated volume ratio.

Relevance of the measure and influencing factors

A compact building presents less heat-dissipating surfaces which in turn results in both lower operational losses and lower embodied emissions for the envelope.

Compactness is expressed using the envelope factor, which is the ratio between the thermal envelope surface of the building (façades, roof, and ground floor) and the energy reference surface (Figure 11).

The larger the ratio of the building's envelope surface to the energy reference surface, the higher the heating energy demand, even with the same thermal protection of the building's envelope. This is why a less compact building must be better insulated than a compact one to achieve the same heating energy demand (Coma *et al.*, 2019). The same way, the larger the ratio the higher the embodied emissions (Figure 12), as more materials are needed (per energy reference area) for the envelope of the building (Lukić *et al.*, 2021).

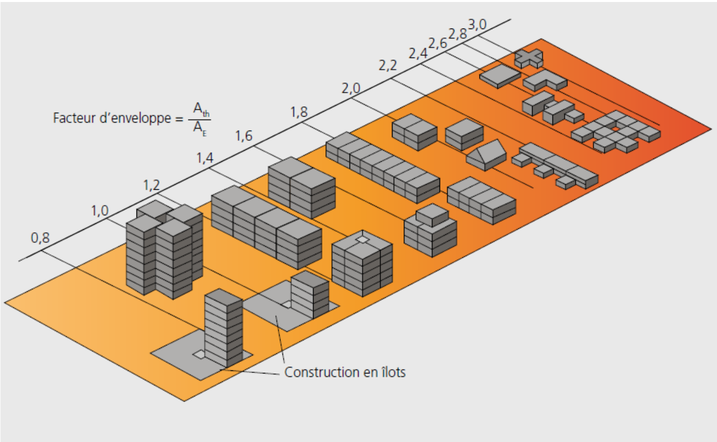


Figure 11: Envelope factor = A_{th}: Envelope surface / A_E: Energy Reference Area – Image taken from SuisseEnergie report on new constructions (Binz *et al.*, 2021).

Recommendations

A compact structure offers several advantages compared to segmented building structures, including a smaller need for construction land, higher population density, reduced costs, simpler construction, lower embodied energy, reduced construction material requirements, less self-shading, lower heating energy demand, and reduced operational costs. It must be noted that the impact of envelope factor on GHG embodied emissions depends on the type of structure utilized: the less embodied emissions in the structural system used the lower the impact of reducing envelope factor.

The building shape also has an impact on embodied GHG emissions (Zwicky and Kellenberger, 2020); a compact brick-shape is better than a U-shape, which, in turn, is comparable to a long flat prism, while a tall prism (i.e., high-rise building) is detrimental to embodied carbon. A moderate-rise brick shape emits slightly less GHG than a higher-rise cube (more material in thermal envelope).

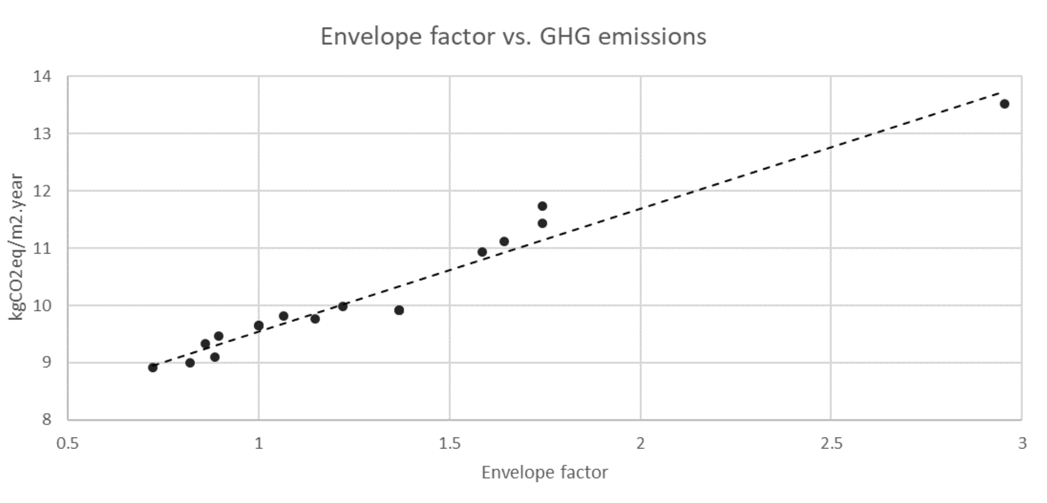


Figure 12: Impact of increasing the envelope factor on GHG construction emissions – results extracted from the simplified Minergie Tool

Limitations

However, compactness does have its limits when it comes to the requirement for sufficient natural lighting and natural ventilation. While heating energy demands are lower in compact structures, the greater building depth also leads to increased electricity needs for artificial lighting. In addition, relatively compact buildings have a smaller envelope surface available for photovoltaic electricity production, which can hinder the implementation of extensive renewable energy production on site.

Examples

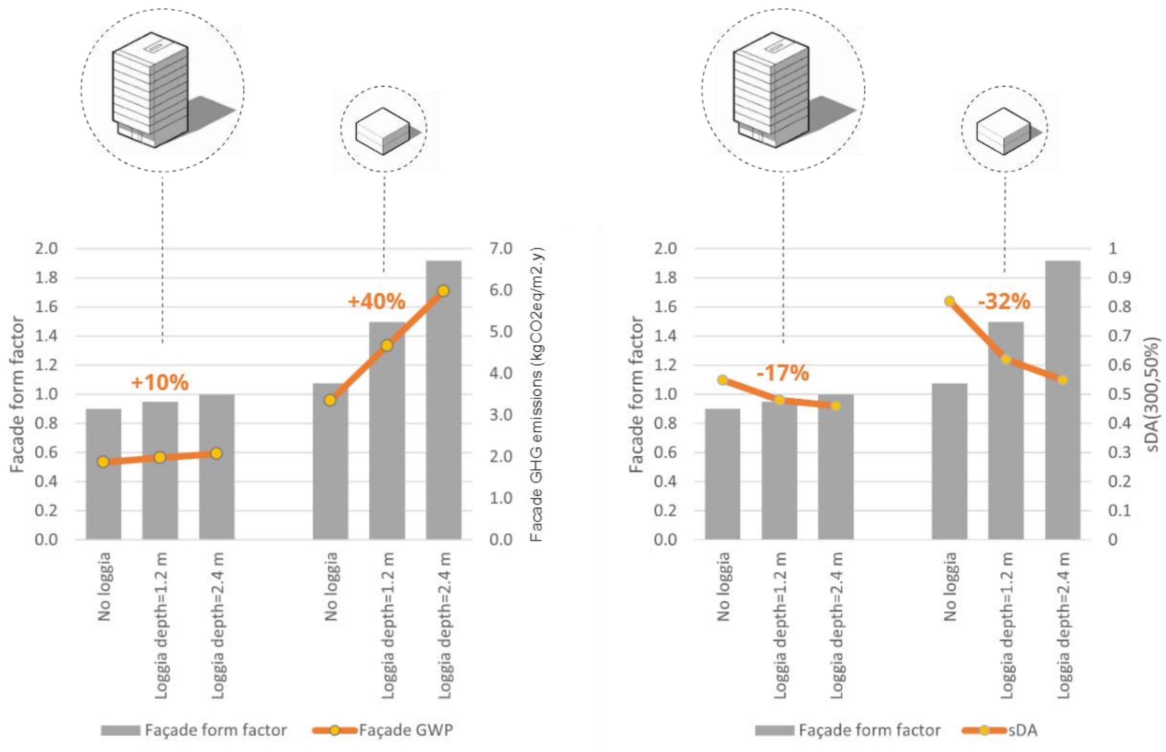


Figure 13: Impact of increasing the façade form factor (residential) by increasing the depth of loggias in the facade on GHG emissions (operation and embodied) and spatial daylight autonomy (sDA) – Light Budget project (Rezaei Oghazi, Jusselme, et Andersen, 2024a)

Incorporating loggias into a building's façade design influences the building's compactness and associated emissions. This effect is more pronounced in smaller structures, such as single-family houses, because it's measured as a ratio against the energy reference area. As explored in the context of the LightBudget Project (Rezaei Oghazi, Jusselme and Andersen, 2024b), a depth of loggias of 2.4 m can increase embodied emissions of the façade by 40% in the case of single-family houses and 10% in multi-family houses (Figure 13). From the same project and figure, one can notice that increasing the depth of loggias also has a negative impact on spatial daylight autonomy (sDA), which might negatively impact operational emissions (increased use of lighting and lower solar heat gains).

As shown in (Zwicky and Kellenberger, 2020) – based on raw data from (Settembrini and Menti, 2013) Unruh (2013) for residential and office new constructions – it is more advantageous for embodied carbon to have a few average size to larger residential buildings rather than several smaller ones to accommodate the same number of housing units. But this scale effect diminishes to negligible with increasing building size at a limit of 10-20 housing units (WE, Figure 14) per building. The same study also indicates that an envelope factor of max. 1.1 should be targeted, while achieving values below 0.7 is rather difficult in practice.

Burying a building in the ground may impact the assessment of different construction sites. Hillside construction has higher embodied carbon for MFH (approx. +20%) than for SFH. For the latter, it does basically not matter if detached or hillside (being worse for GHG emissions in any case, compared to MFH). A MFH, however, should rather be detached than hillside – a practical basis for the decision between two different construction sites, also see section “choice of site”. A building shape of a MFH being trapezoidal with a larger south façade, with a concave south façade, or a terraced shape on two sides result in max. 10% more embodied carbon (Unruh 2013).

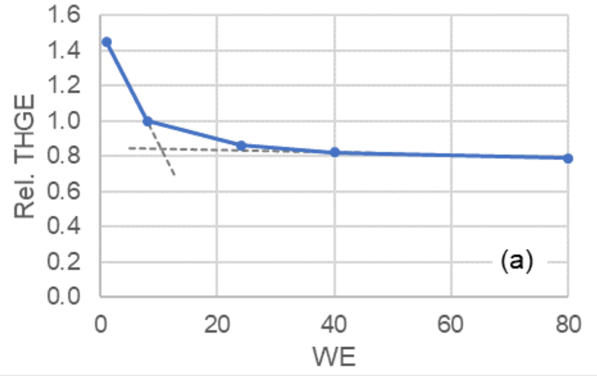


Figure 14: Relative GHG embodied reduction with increasing number of housing units (WE) in residential new buildings

The GHG emissions of buildings obviously depend on the constructed volume (i.e. calculated acc. to SIA 416 (2003)): the larger the volume, the greater the global heating requirements, and the global embodied carbon, Figure 15. However, the volume has more influence on the embodied carbon than on heating needs. As the example buildings evaluated in Figure 15 (Medziti *et al.*, 2019) show, there is a less than linear increase in embodied carbon for buildings with an SIA volume below approx. 15'000 m3, beyond which embodied carbon strongly increases while heating demands remain almost constant.

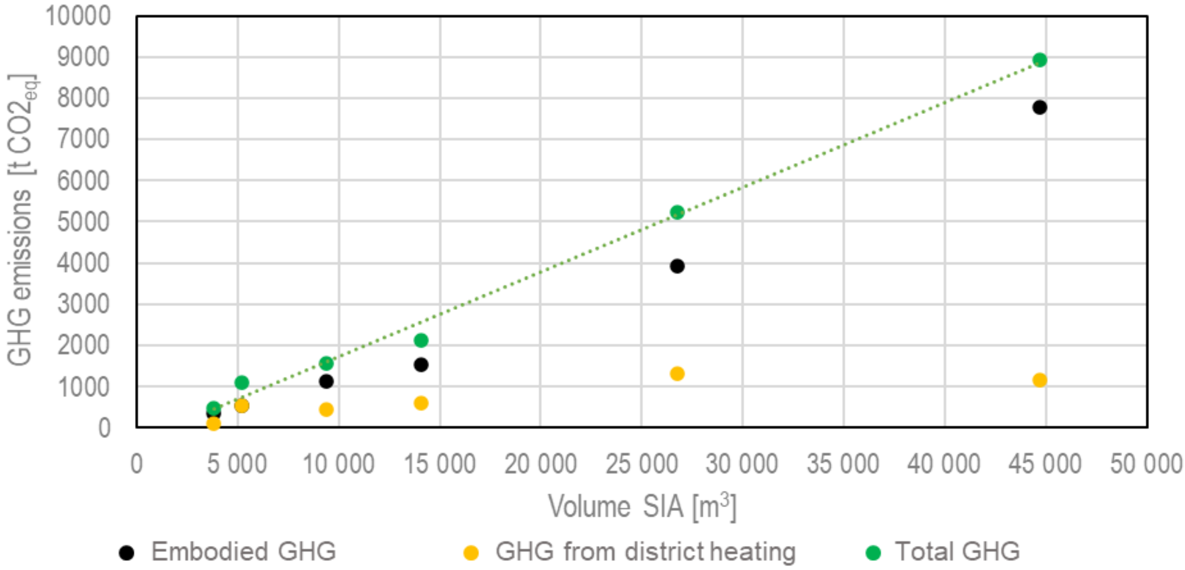


Figure 15: GHG emissions increase with increasing volume of buildings (Medziti *et al.*, 2019). Energy performance remains comparable while increasing volume.

3.1.9 Reduced underground volume

Relevance of the measure and influencing factors

This measure is highly relevant at the building scale as it can lead to a reduction of ca. 20% in embodied GHG emissions compared to a reference building with 1 underground floor (Figure 16). It is particularly impactful because underground construction always entails additional energy and resource use, which adds to the one of the overground building which translates into higher embodied emissions of the latter. By reducing the reliance on underground floors, a substantial decrease in emissions can be achieved.

Depending on the main construction material (e.g., concrete, timber) for a new building, its shape (also see section 3.1.8), and considering that the basement is constructed with concrete, the latter's embodied carbon adds 14-18% (for concrete construction overground), 16-22% (timber construction overground), and 15-21% (timber-concrete composite construction, *TCC*, overground), respectively(Zwicky and Kellenberger, 2020).

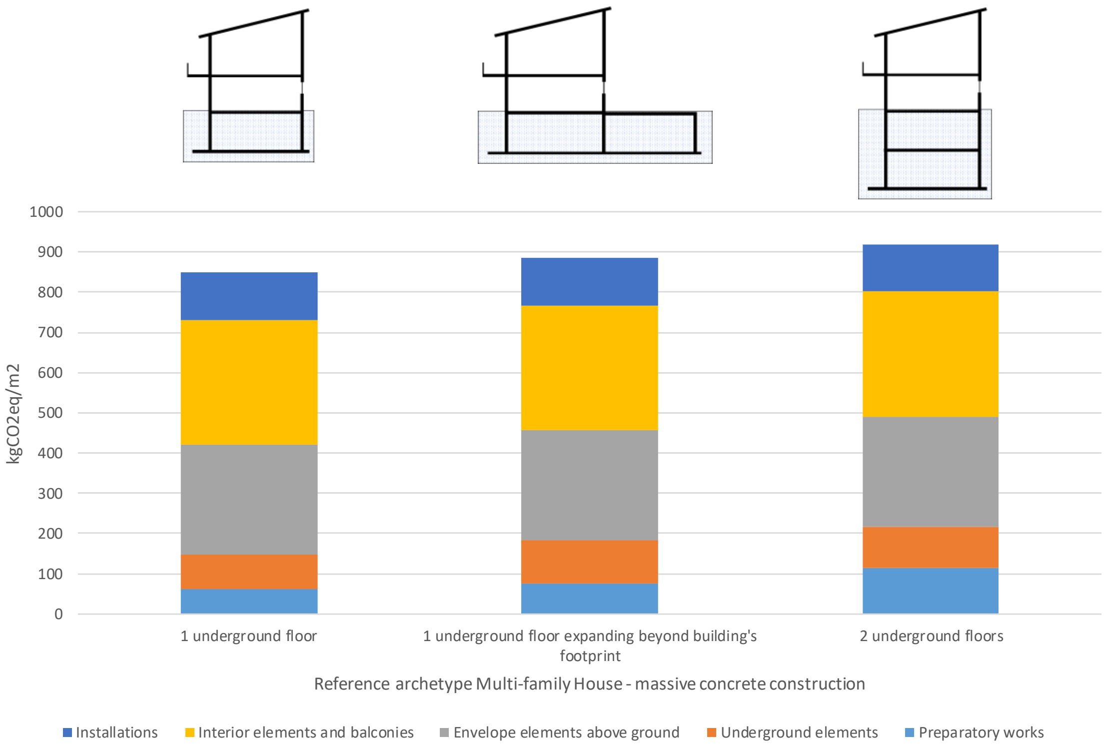


Figure 16: Share of embodied emissions of a reference multi-family house archetype with 3 configurations and size of underground floors. Avoiding underground floors would save impacts from underground envelope and preparatory works, accounting for ca. 20% of emissions.

Recommendations

The following recommendations should be considered:

- Limit underground construction: underground construction should be limited to the necessary minimum to fulfill the building's functional requirements. This may involve reevaluating the need for underground levels and prioritizing above-ground solutions whenever possible. Usually, underground floors are built for parking space, technical rooms, and storage space. Storage space could be placed above ground, on balconies or in the core distribution and therefore benefit from low carbon structures which are more complicated to implement below ground.
- Direct placement: when underground construction is unavoidable, it should be placed directly under the building's footprint. This minimizes energy and materials required for excavation and provides structural advantages, Figure 16.

Limitations

Despite its potential for emissions reduction, the measure does have limitations:

- Minimum parking requirements: local zoning regulations and minimum parking requirements can present challenges to limiting underground construction. In some areas, a minimum number of parking spaces may need to be accommodated, potentially requiring underground parking facilities.
- Limited volume above ground: in densely populated urban areas, the volume available above ground for placing functions such as parking, storage, or technical rooms may be limited. This limitation can make it difficult to entirely eliminate underground floors.

3.1.10 Window to wall ratio

Window to wall ratio (WWR) represents the share of glazed or transparent surface to the overall façade surface of the building. This ratio affects multiple parameters of a building operation and construction from solar heat gains, daylight factors, heat losses, and embodied emissions. Average WWR in Switzerland are identified in previous studies as 15.7% for single-family houses, 25.7% for multi-family houses, 36.5% for office buildings, and 30.9% in schools (Sasso and Patel, 2023). A general increase in WWR is observed in more recent buildings in both residential (Pongelli *et al.*, 2023) and office buildings (Sasso, Chambers and Patel, 2023).

Relevance of the measure and influencing factors

"Window-to-wall ratio" is a measure of great significance at the building scale, showing high impact on both embodied and operational emissions Figure 17. A higher window-to-wall ratio (WWR) in building facades influences operational and embodied emissions through several mechanisms: 1) It allows more natural light, cutting down on artificial lighting; 2) it increases heating needs due to greater winter heat loss, leading to the use of multi-pane glass with higher embodied carbon; 3) it raises cooling requirements to mitigate overheating, often necessitating larger solar shading structures; 4) it offsets some heating demands with increased solar heat gain; 5) it limits the space for integrating photovoltaics into the façade; and 6) it affects embodied emissions through the choice of glazing materials and components.

The sensitivity analysis of 9,000 design options for an 8-storey multi-family house indicates that the loggia depth, window-to-wall ratio (WWR), and glazing characteristics are critical factors, influencing embodied emissions of the facade by 15%, operational emissions by 70%, and spatial daylight autonomy by 60%, respectively (Rezaei Oghazi, Jusselme, et Andersen 2024b).

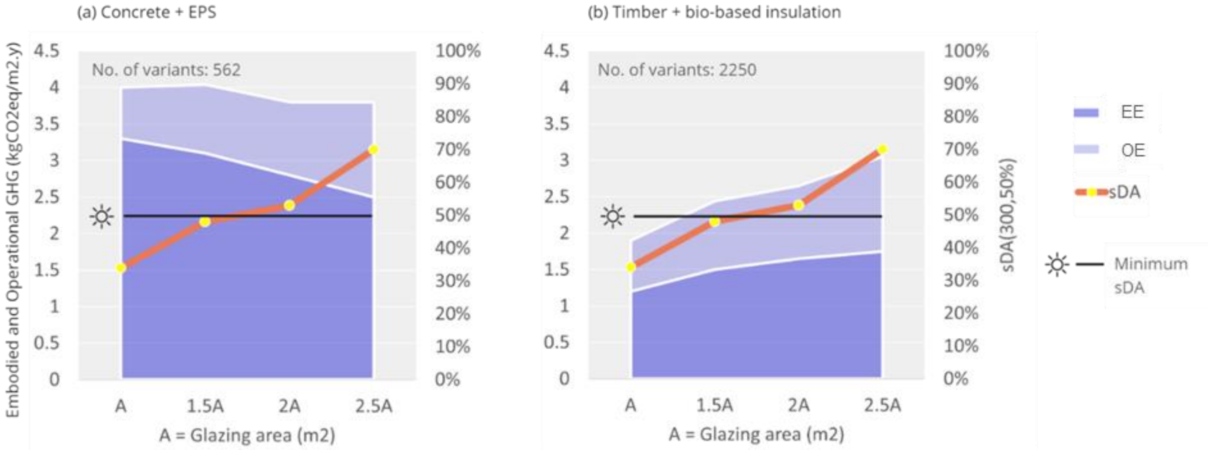


Figure 17: Façade's embodied (EE) and Operational (OE) emissions in relation to an increasing glazed surface for (a) a concrete + EPS façade, and (b) a timber + bio-based insulation facade. Spatial Daylight Autonomy (sDA) is included in the analysis to indicate minimum acceptable levels of daylight. The exploration of variants shown in the figure was conducted in the frame of the LightBudget project.

- Carbon-intensive glass: glass, a primary component of windows, is a carbon-intensive material. The choice of window-to-wall ratio directly affects the quantity of glass used in a building's façade. This ratio can significantly influence the embodied emissions associated with the production and installation of glass components. Choosing a high window-to-wall ratio will generally lead to higher embodied emissions due to increased glass use (Rivera, MacLean and McCabe, 2021). An exception to this general statement can be observed in the case of highly intensive opaque façade (e.g., massive concrete or bricks with EPS or glass wool insulation) construction where increasing its share would deteriorate the whole impact as the opaque façade has a higher impact than the glass surface as shown in Figure 17 (Rezaei Oghazi, Jusselme, et Andersen 2024b).
- Operational emissions: the window-to-wall ratio plays a crucial role in determining a building's energy performance. It affects the amount of natural daylight that enters the building, as well as the level of solar heat gain and thermal losses. Both factors have a direct impact on operational emissions. A higher window-to-wall ratio can lead to greater daylight availability, potentially reducing the need for artificial lighting during the day. Additionally, it can also result in increased solar heat gain, which may elevate the demand for cooling, especially in warm climates but decrease the demand for heating, especially in cold climates. On the contrary, heat losses increase with higher WWR, resulting in higher heating demand.

Recommendations

To optimize the impact of the "window-to-wall ratio" measure while balancing embodied and operational emissions, consider the following recommendations:

- Evaluate the right balance: It is essential to strike the right balance between maximizing the benefits of natural daylight and solar gains and reducing heat losses and embodied emissions. Careful consideration of a building's orientation, depth, climate, and intended use can help determine the optimal window-to-wall ratio. This evaluation should consider both operational and embodied emissions. In early design phases, simplified exploration interfaces and or reference values can help make informed decisions. In more advanced design phases, available energy simulation tools are recommended to better grasp specific design parameters.
- Some studies suggest optimum WWR for South-facing facades between 30% and 40% depending on the climate and occupancy of the building (Chiesa *et al.*, 2019). The results of a parametric study generalized at Swiss residential building scale shows that at least a bilateral daylighting preferably facing South and North, with minimum WWR of 30% is required to meet the spatial Daylight Autonomy of 50%, i,e. the requirement for sufficient daylight based on the EN 17037 European Daylighting Standard (Rezaei Oghazi, Jusselme, et Andersen 2024a).

Limitations

Despite its significant impact, the "window-to-wall ratio" measure has some limitations:

- In existing buildings/renovation projects, the ratio is usually given and can hardly be changed,
- The orientation and number of available facades can vary and is limited by the site of the project,
- Design preferences and aesthetics might lead to a conflict of interest in the optimization of WWR.

Examples

The example building shapes evaluated in (Zwicky and Kellenberger, 2020), with a constant energy reference area, show that increasing the window-to-wall ratio from 35% to 70% increases the embodied carbon by about 10% if concrete or wood construction is applied to usual building shapes. The window-to-wall ratio has a more pronounced effect on embodied carbon (up to 25% increase) if the building is tall (high-rise). Using timber-concrete composite construction, the window-to-wall ratio does hardly affect embodied carbon, independently of the selected building shape.

The evaluation of a series of buildings from practice (Medziti *et al.*, 2019) of largely variable sizes, also see Figure 15, and construction concepts, and considering the same reference location and orientation for comparability, shows that thermal losses are mainly due to windows (between approx. 35% and 50% or 35%, on average) and ventilation (between approx. 25% and 45% or 40% on average) while the rest of the thermal envelope is responsible, on average, for 25% only. This also results in largely variable solar gains (varying from 18 to 91 kWh/m^2 ERA) and heating needs (varying from approx. 0 to 37 kWh/m^2 ERA). In addition, windows strongly contribute to construction cost (approx. 15% to 40% or 30%, on average).

3.1.11 Re-use

Relevance of the measure and influencing factors

The Reuse measure entails repurposing construction products that have already undergone their initial service life, thereby prolonging their overall lifespan. These products may be reused for the same or a different purpose, with their condition determining the requisite reconditioning activities, ranging from simple cleaning to comprehensive repair. Reuse can be applied to all building product categories, from small furniture to load-bearing concrete elements (Collaud *et al.*, 2023; Küpfer, Bastien-Masse and Fivet, 2023).

In general, reusing building products proves more energy and environmentally efficient than new and recycled alternatives, this is because the logistics and repurposing efforts for reused products are comparatively lower than those for manufacturing new items. The environmental impacts associated with reused products are linked to various activities involved in their reuse, including dismantling, transportation, reconditioning, storage, installation, the waste treatment of material losses, and their own waste treatment at the end-of-life. The extent and number of reuse-related activities, along with their intensity in terms of energy, water, and material consumption collectively determine the environmental burdens of reuse. Additionally, it is crucial not to overlook the elimination of losses and waste generated during the repurposing of elements, such as beams shortenings or scraps. These environmental burdens can be important for materials with high specific emissions in their usual end-of-life scenario.

At the scale of a product, several studies indicate that reuse can result in a substantial reduction of GHG emissions, ranging from 80% to 90% when compared to their new equivalents (excluding end-of-life) (Pfäffli, 2020; Stricker *et al.*, 2023) and Reuse-LCA project[5]. Regarding absolute GHG emissions, the Reuse-LCA project identified values ranging from 0.01 to 0.3 kgCO_{2eq}/kg of reused products across several building products and projects. Direct reuse processes involving a streamlined, chain of low-energy and low-material activities, such as human workforce dismantling, local supply, and limited reconditioning (e.g., simple cleaning without modification or losses), yield the lowest GHG emissions figures. Conversely, higher GHG emissions figures may be associated with heavier elements that necessitate more handling activities, and their repair or repurposing may involve material consumption (e.g. paint) or result in waste generation.

Transport activities, predominantly by truck, are often regarded as the primary influencing factor on the impacts of reusing a product. However, this perspective can be nuanced for two reasons. First, as observed in the Reuse-LCA project, various other factors and activities can significantly influence GHG emissions. Therefore, the relative contribution of transport may diminish when efforts such as reconditioning, modification, and losses become more important. On the other hands, results from (Küpfer *et al.*, 2022) and the REMCO HES-SO project[6] concerning the logistic and supply-chain of reuse concrete slabs, indicate that the distance threshold, beyond which the reuse of a concrete slab has more environmental impacts that a new one, ranges between 400 to 1000 kilometres. This threshold varies depending on the overall complexity of the reuse process-chain. Consequently, building products could

[5] Reuse-LCA project : https://www.aramis.admin.ch/Texte/?ProjectID=48238
[6] https://www.hesge.ch/hepia/en/recherche-developpement/projets-recherche/remco

potentially be reused across all of Switzerland while still resulting in lower emissions than new alternatives.

The losses and their end-of-life treatment, whether during dismantling, reconditioning, or construction, can influence the environmental burdens of a reused product, depending on the type of product and the specific end-of-life scenario. Steel serves as an example, with a common end-of-life scenario primarily involving recycling, which has limited GHG emissions compared to other activities. Figure 18 illustrates the previous points with the results of the products reused in the Primeo Energy Cosmos building over "A1-A3 + C1-C4", as studied in the Reuse-LCA project (Frossard et al. 2023).

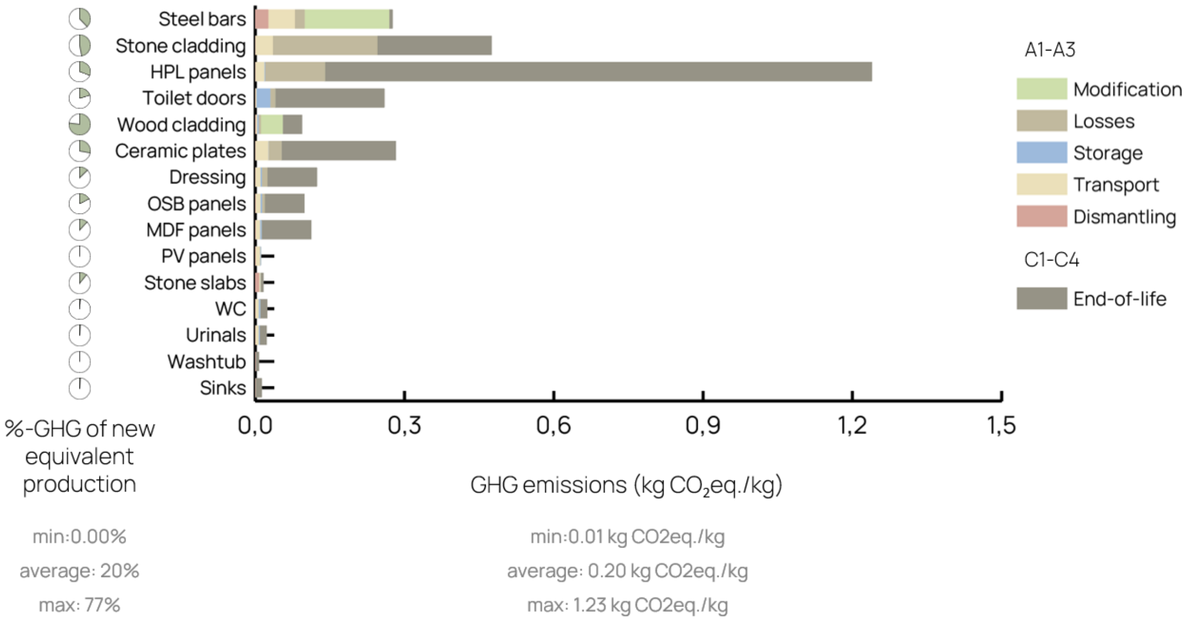


Figure 18: GHG emissions of the products reused in the Primeo Energy Cosmos building studied in the Reuse-LCA project including end-of-life. Dismantling emissions are shown for informative purpose but could be allocated differently.

The (change of) purpose of the reused product and its degraded performance due to ageing should be integrated into the definition of the functional unit to ensure a consistent LCA study and enable comparisons with new alternatives. Conversely, oversimplifying the functional unit by considering only material quantities without accounting for functional performance could introduce bias into the LCA conclusions. An illustrative example of performance degradation easily included in preliminary LCA studies is for old photovoltaic panels, where performance degradation curves are typically documented in their technical specifications. In cases where such documentation is lacking, expert assessment or performance tests can be incorporated.

Dismantling (and its associated wastes and losses) can be viewed as a multifunctional activity, serving both the purpose of dismantling for the provider and the function of supplying reused products (depending on the end of waste status). This raises questions about how responsibilities and burdens from this activity should be allocated, and the effect of this allocation in encouraging either downstream or upstream reuse.

Recommendations

The relevance of the reuse measure at the entire building scale is most pronounced for products categories characterized by high mass and high specific emissions during manufacturing. Therefore, it is advisable to incorporate reuse measures early in project phases to ensure a high proportion of reuse elements in the building. The reuse measure synergizes well with sufficiency or dimensioning measures aimed at reducing material quantities per square meter. In this context, structural design plays a pivotal role in minimizing material usage and maximizing the inclusion of reused elements. Subsequently, the optimization of reuse measure can be achieved by ensuring low emission logistics and repurposing activities, along with a reuse efficiency that minimizes losses and wastes.

Limitations

Several limitations arise from the fact that reuse is not yet a common practice among building actors, including owners, architects, engineers, construction, and deconstruction companies:

- From an LCA perspective, there is a general lack of data regarding activities involved in reuse. This is explained by two factors:
  - with the lack of standardized procedures, LCA data are not available for manual activities related to reconditioning or repurposing.
  - in general building LCA practices and databases, several categories of elements are aggregated, and the impacts of their individual components is overlooked or simplified. This is the case of technical installations like sanitary and ventilation in the KBOB.
- Efforts are needed to make reuse compatible with building norms, certifications and insurance through tests, verifications, or engagement with insurance companies.
- The guarantee of performance of reused materials and the associated responsibilities are critical issues (Knoth, Fufa and Seilskjær, 2022), as highlighted by the frequent reluctance to use products without proper certification and documentation of tested performance.
- Logistic obstacles, such as insufficient storage spaces, hinder the facilitation of connections between offers and demands that may be temporally out of sync.
- Despite the amortization of material costs, the overall cost of integrating reuse in a project can be equal or even exceed that of an equivalent new solution due to additional labor-intensive activities such as dismantling for reuse, sourcing, testing, and verification.

Conflicting interests may emerge, potentially leading to the "greenwashing" of building deconstruction. This could occur if there is an imbalance in promoting reuse in construction over avoiding deconstructions and wastes. Factors motivating reuse other than environmental efficiency, such as financial, cultural, or architectural considerations, could also contribute to this issue.

Finally, a significant limitation to the widespread adoption of reuse in construction in Switzerland comes from the limited availability of reuse elements. Approximately 13’800’000 tons of materials per year are consumed by new residential constructions compared to the 2’700’000 tons per year they generate according to (Heeren and Hellweg, 2019). The fraction that could potentially be reused varies between 0.5% (based on an estimate of 75’000 tons of potentially reusable building materials[7]) and at most 17% (as expected for the circular “UMAR unit” installed in the EMPA’s NEST building documented in (Kakkos *et al.*, 2020). It's important to note that these figures exclude concrete and bricks, which constitute around 80% of the building stock materials (Federal Office for the Environment FOEN, 2015). In the same lines, a study conducted in the city of Baden considers a GHG reduction potential of 3% by 2050 by reuse of building materials[8]. Overcoming the limitations and challenges of effective reuse involves reducing the demand for new building materials, increasing the utilization of elements that are reusable as of today’s technical capacities, and developing new capacities to reuse concrete, brick and other load-bearing elements.

[7] https://www.swissinfo.ch/eng/multimedia/sustainable-building_the-recyclable-building-site-of-the-future/44679344
[8] https://www.aramis.admin.ch/Texte/?ProjectID=51845

3.1.12 Energy concept

Relevance of the measure and influencing factors

Setting up an energy concept at the conceptual design phase holds high relevance for individual building emissions.

- Early influence on energy performance: establishing an energy concept during the conceptual design phase allows for early influence on the building's energy performance. This phase is critical in determining the fundamental principles and strategies that will shape the building's energy efficiency over its entire lifecycle, see also section 3.1.6.
- Site-specific solutions: identify and prioritize energy efficiency and energy systems measures based on the specific characteristics and constraints of the building's site. Factors such as climate, solar exposure, and local energy infrastructure should inform the design choices, see also section 3.1.7.
- On site renewable energies: if a building is designed to rely on renewable energy sources, these choices can be integrated into the design, ensuring a more sustainable and low-carbon energy supply Figure 19. This may involve specifying the use of renewable energy sources and energy-efficient technologies. By integrating these constraints early, the building can be designed to make the best use of these resources.

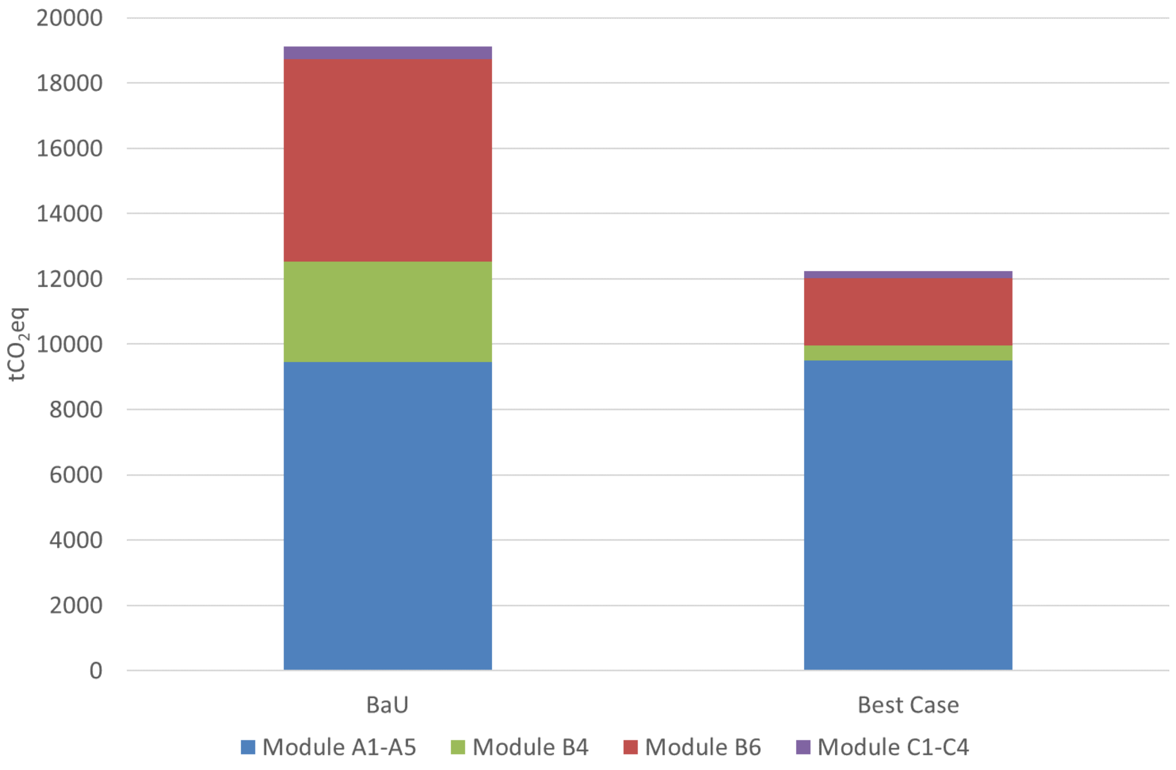


Figure 19: Impact on operational phase of an office building when switching to on-site renewable energies.

Recommendations

- Identify and prioritize energy efficiency and energy systems measures based on site specifications.
- Incentivize and optimize on-site renewable energies.

Limitations

- Design changes in subsequent phases: as the project progresses through subsequent design and construction phases, there is a possibility of design changes that may impact the energy concept. It is important to maintain a clear line of communication and coordination throughout the project to ensure that the energy concept is effectively implemented.

3.1.13 Choice and dimensioning of structural elements

Relevance of the measure and influencing factors

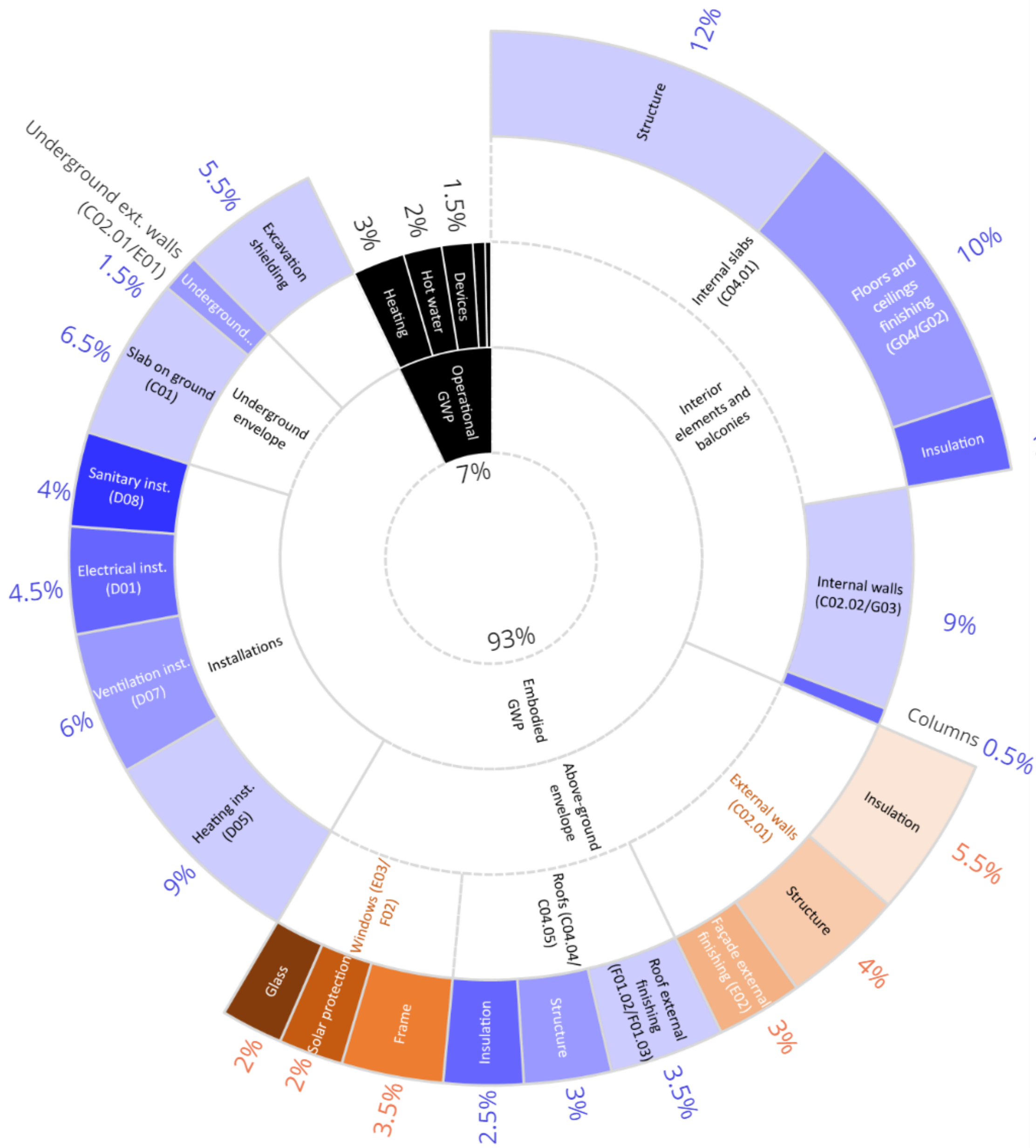


Figure 20: The relative weight of building operational and embodied emissions based on the analysis of 9000 design alternatives for archetypal multi-family houses (Rezaei Oghazi, Jusselme et Andersen, 2024b). Operational GWP considers Swiss average electricity consumption mix (KBOB 2009/1:2022) and equal shares of heat pump, district heating, biomass boiler, and oil boiler in

the design alternatives analysed. The amount of PV also varies in the design alternatives between 0%, 50%, 100% of roof area and 100% + southern façade.

The load-bearing structure has the most significant influence on embodied GHG emissions, followed by insulation, finishings and technical installations (Medziti *et al.*, 2019). Several key factors influence the GHG emissions of structural elements, such as spans, structural system, and the materials used.

In Figure 20 a detailed breakdown of the impact of building elements based on the analysis of 9000 design alternatives for a reference multi-family archetype. The contribution of structural layers accounts for almost 35% of the total GHG emissions of a building (internal slabs, internal walls, external walls, roof, and underground envelope), making it a highly relevant element. The structural component of internal slabs holds 12% of life-cycle emissions alone, making it one of the most impactful components in a multi-storey building.

Furthermore, the choice of material for the structural elements in a building holds the potential to increase biogenic carbon storage when switching to bio-based options. As exemplified in Figure 21 a board stack slab element with Swiss wood could potentially store 17 times more carbon than what it emits in its production and end-of-life. This figure can strongly vary depending on the structural system and dimensioning chosen, massive-high density wood constructions will store more carbon than frame-light density wood elements, but the opposite trend can be true in terms of production emission. As structural elements have longer lifespans (usually matching the overall lifetime of the building) compared to other elements, they can store biogenic carbon for longer periods of time thus contributing to the delay of biogenic emissions in the atmosphere. Carbon stored in buildings could eventually be released in the atmosphere at the end of life if no mechanism is in place to ensure a more permanent stock.

Recommendations

- Reduce spans and optimize the dimensioning of elements to minimize the quantities of materials.
- Embrace low carbon, bio-based, or re-used materials as alternatives.
- Foster advancements in the industry, including the future production of more sustainable materials.

Limitations

Reducing structural spans, optimizing the dimensioning, and reducing quantities of materials in structural elements is often bound to user requirements, regulations, and owner preferences. Although the structural engineer has the potential to “optimize” the structural design, its flexibility is limited.

Shifting to low-carbon materials is also bound to material properties, costs, and project specific preferences, making the measure often difficult in its implementation. Finally, the use of alternative materials with lower emissions is presented with a lack of normative guidelines, requiring more efforts (and costs) to implement in a project.

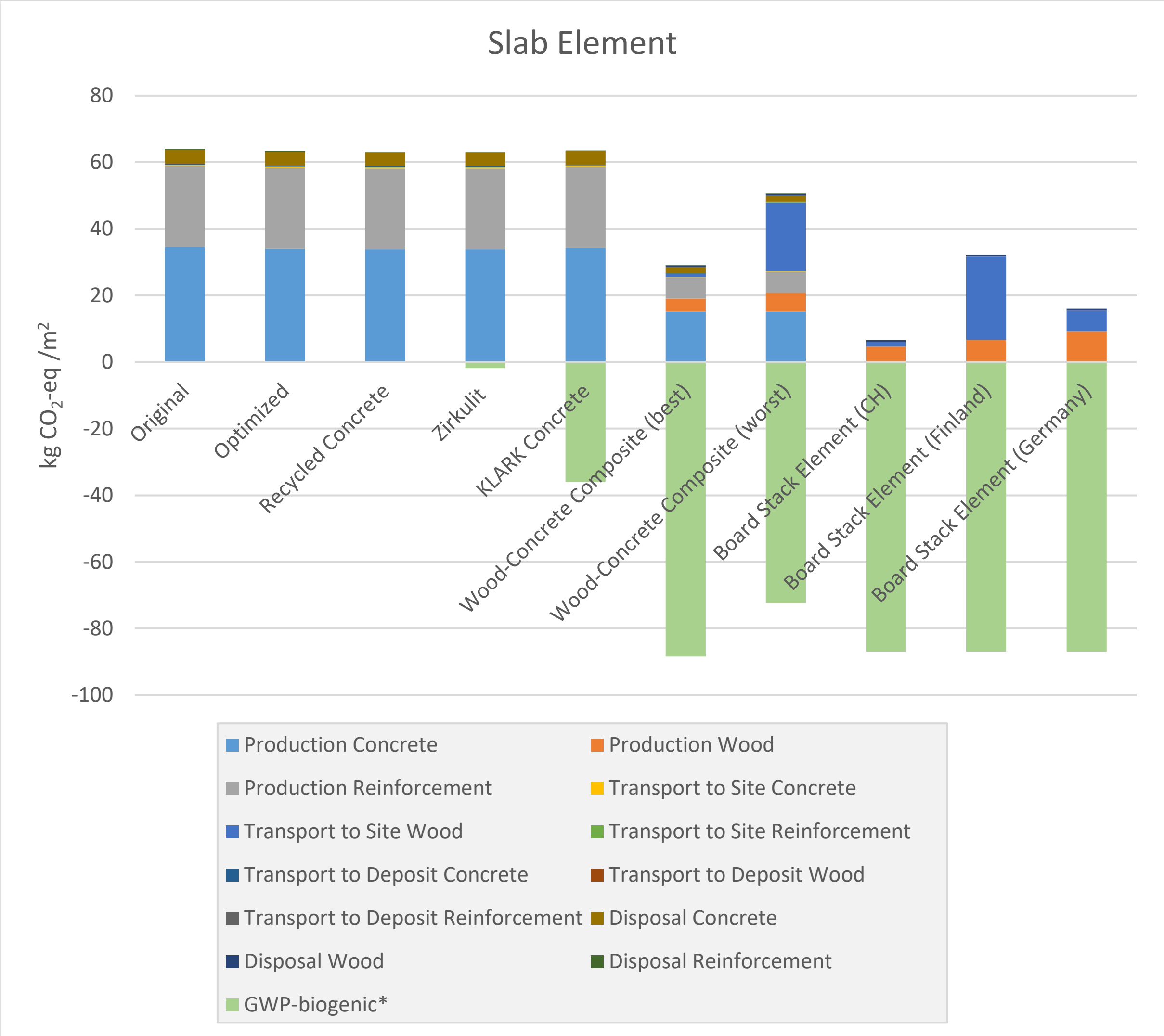


Figure 21: GHG emissions and GWP-biogenic uptake (*negative value to be accounted only in case legally binding permanent storage) of different slab systems for a residential multi-family new construction (spans <6m) (Farner, 2023).

Examples

In the evaluation of different materialisation of structural elements of a typical Swiss multi-family house (Farner, 2023), it is evident that wood-based solutions appear to have lower embodied GHG emissions compared to concrete-based design with comparable structural performance. As shown in Figure 21, the GHG emissions of the slab element can be reduced by more than 80% with a board stack element and built with Swiss wood. From the same figure, it can be noticed that the impact of transport (e.g., wood from Finland) although relevant would contribute to about half of the impact of the concrete slab.

Based on the available Minergie-Tool, the impact of structural spans on GHG emissions can be explored as shown in Figure 22. Increasing spans increases GHG embodied emissions of the building, this effect is more pronounced in the case of concrete structures, where every cubic meter of reinforced concrete added to the element largely increases the overall embodied emissions. Increasing spans in the case of wood-concrete elements has a milder increase in GHG emissions.

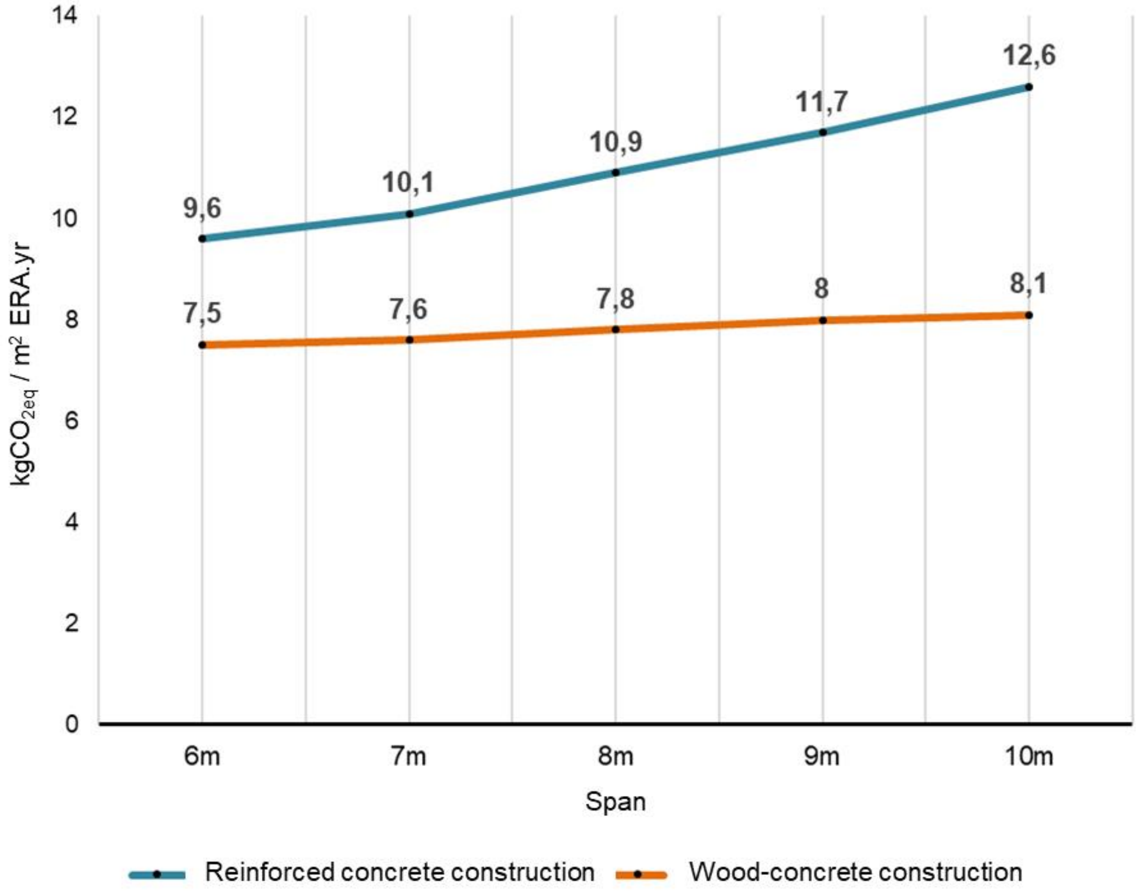


Figure 22: Impact of increasing spans for a concrete structure and a timber-concrete composite structure [based on Minergie-tool].

The evaluation of multiple buildings of largely variable size in Figure 23 (Medziti *et al.*, 2019), also see Figure 15 (GHG emissions increase with increasing building volume), including crosswise application of construction element materialisations of an individual building to the other buildings, show that the embodied GHG emissions are primarily located in the internal floor slabs, underground floors, the internal walls, and the thermally insulated slab over the underground floor. The roof may also be a considerable contributor to GHG emissions, in particular for smaller buildings. Such results may provide guidelines where to allocate optimization efforts.

The evaluations reported in (Uboldi *et al.*, 2021; Zwicky, 2023) on generic materialisations of construction elements and their combination into storeys addition on existing buildings can also be regarded as the overground structure of a new building (i.e., neglecting foundation and underground construction). The study compares GHG emissions of different materialisations for the construction of a two-storey addition with a floor plan closely following the existing floor plan (governing span 7.8 m). If solutions using glass-fibre reinforced polymer (GFRP) profiles are excluded, the total GHG emissions vary between relatively close margins (5.1-7.0 kg CO_{2eq}/m^2a of which 11-15% are related to strengthening of the existing building). Timber solutions result in the least GHG emissions, followed by steel or steel-concrete composite options. The use of wall elements made of UHPC (ultra-high-performance concrete), and void slabs or slabs made of prestressed concrete beams and polystyrene “hourdis” can significantly reduce the overall mass of concrete solutions, resulting in favourable effects for the foundation, thereby allowing a partial compensation of increased GHG emissions of the overground structure.

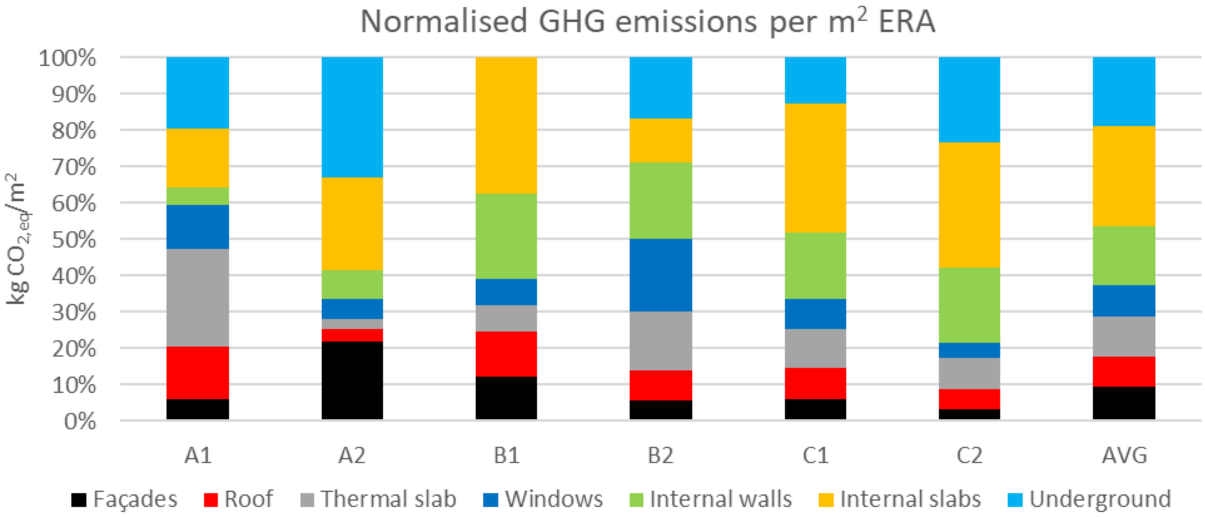


Figure 23: Allocation of normalised GHG emissions to main construction elements (Medziti et al. 2019). A1: wood construction; A2: concrete construction; B1: Brick construction; B2: Wood construction; C1: Mixed construction: C2: Mixed construction.

Materialisation combinations for an open floor plan with a governing span of 11.0 m result in similar conclusions, favouring timber box spans combined with CLT walls. Floor and roof elements contribute similarly and the most to embodied carbon, due to the increased span, followed by the internal walls. If four storeys are constructed, total impacts in embodied carbon and additional weight increase in absolute value. However, as the ERA is also increased, the relatively high impact of the flat roof on embodied carbon decreases, and the floor slabs become the most important contributors, followed by the internal walls. External walls have a contribution lower or comparable to the roof (Zwicky, 2023).

The selected structural material, the applicable structural design method, and its use to optimize material consumption may have a considerable impact on environmental consequences. (Plüss and Zwicky, 2014) compared environmental impacts for different structural materials used to build the floor of a public school. The comparison comprised a reinforced concrete slab, a pure timber slab, and two different types of timber-concrete composite slabs. One has mechanical connectors at the interface between the two construction materials with limited deformation capacity, requiring elastic structural design of the shear interface (“TCC elastic”), while the other uses a connector type with significant deformation capacity, allowing plastic structural design of the interface (“TCC plastic”).

Figure 25a compares normalized environmental impacts (in UBP). The plastic structural design of the interface shear connection results in a division by almost two of the environmental impact of a TCC slab and being only 15% higher than that of a pure timber slab. Compared to a reinforced concrete slab, a reduction in UBP of about 30% can be achieved. Figure 25b compares the GHG emissions of the same structural types. The difference between an elastically designed TCC slab and a concrete slab is negligible (<5%). A reduction of approx. 30% in GHG emissions, compared to the concrete slab, can be obtained if the TCC interface can be designed plastically. However, this TCC slab still results in approx. 20% more GHG emissions than a pure timber slab. The latter, however, may not provide the same performances regarding vibrational behaviour and sound insulation.

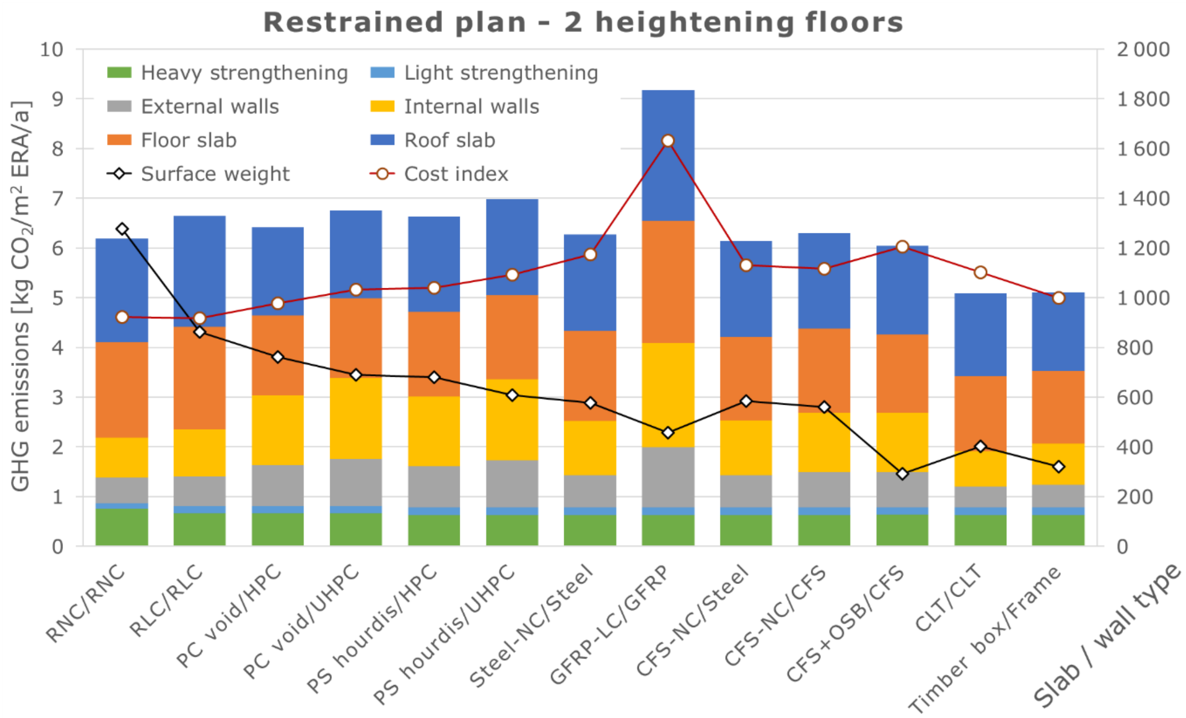


Figure 24: GHG emissions of different combinations of slab and wall materialisations for storey addition of existing buildings (Zwicky, 2023). RNC: reinforced normal-weight concrete; RLC: reinforced light-weight concrete; PC: prestressed concrete (prefabricated); HPC: high-performance concrete; UHPC: Ultra-high performance concrete; PS: polystyrene; GFRP: glass-fibre reinforced polymer; CFS: cold-formed steel; OSB: Oriented strand board; CLT: cross-laminated timber.

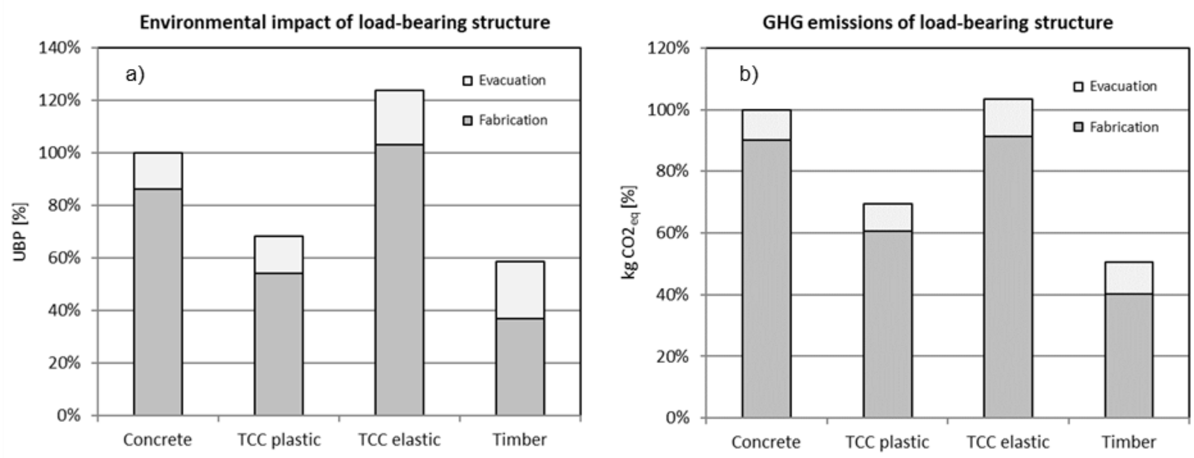


Figure 25: Environmental impact of the load-bearing structure for the floor of a public school (9 m span) – a) normalized UBP and b) relative embodied GHG emissions (Plüss & Zwicky 2014).

3.1.14 Choice and dimensioning of non-structural elements

Relevance of the measure and influencing factors

The selection and dimensions of non-structural elements play a substantial role in shaping a building's environmental impact (also see the example results for finishing and insulation in Figure 20), and this influence becomes even more pronounced in renovation projects where the structural framework typically remains intact to a large extent. Non-structural elements encompass various components, such as the external finishing of facades and roofs (including insulation), windows, internal partition walls, and the internal finishing of walls and floors.

Reducing volumes and weight of non-structural elements can also have the favourable secondary effect of allowing to reduce material quantities in the load-bearing structure.

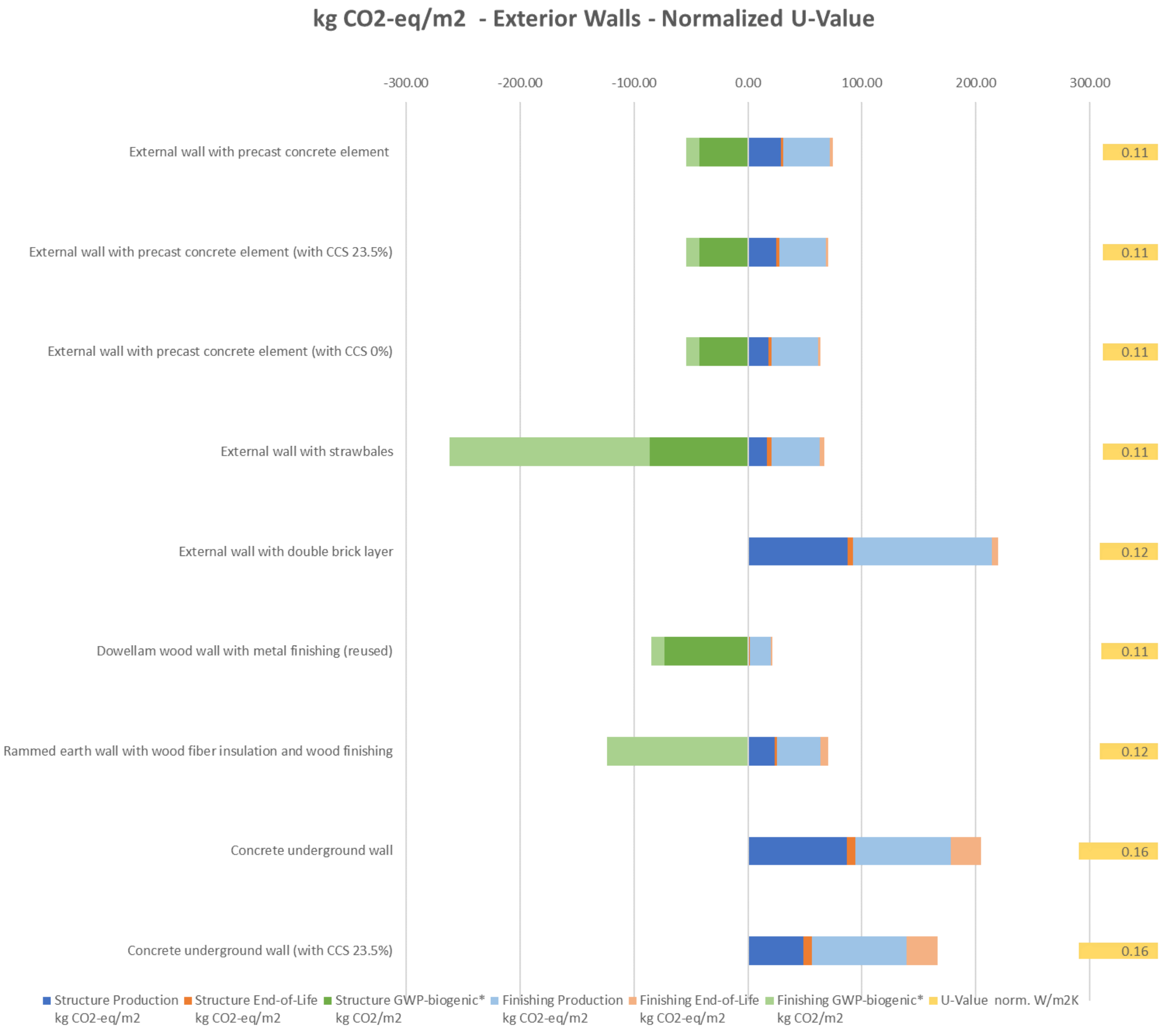


Figure 26: GHG emissions and GWP-biogenic uptake (*negative value to be accounted only in case legally binding permanent storage) of different facades' systems with equivalent thermal function.

Recommendations

- Reduce quantities, for example, by employing flexible design for internal partitions, and optimize the dimensioning of elements, such as the thickness of insulation, or by keeping material quantities required for acoustic insulation to a minimum while still respecting normative requirements.
- Transition towards lightweight, low-carbon, bio-based, or re-used materials as sustainable alternatives.

- Support advancements in the industry, including the production of more environmentally friendly materials.

Limitations

As with structural elements, non-structural elements are also bound to specific design restrictions, regulations (energy performance, fire protection, and acoustic requirements), comfort, and aesthetics requirements. Non-structural elements might also have other technical functions such as urban heat regulation, albedo control, shading, and hygrothermal regulation. Implementing low-carbon and/or alternative materials is often confronted with a lack of knowledge and skills to properly implement it in the design, incurring in extra effort and costs.

Examples

As shown in Figure 26, the GHG embodied emissions of the finishing elements in an exterior wall with comparable U-values can highly vary, ranging from more than 100 $kgCO_{2eq}/m^2$ with brick finishing to lower than 30 $kgCO_{2eq}/m^2$ for a reused metal finishing.

As with structural elements, the choice of materials in non-structural elements holds the potential to increase biogenic carbon storage. Unlike structural elements, non-structural elements tend to have shorter lifespans and therefore potential release of carbon stored could happen faster than with structural materials. Nevertheless, insulation materials based on fast-rotating crop (e.g.: straw, grass, hemp) have the advantage of a faster growth compared to a typical structural wood ensuring a faster recapturing of atmospheric CO_2 and related climate benefits.

Evaluating the total impact of construction elements, that is, considering load-bearing structure and finishings together, may have a considerable impact on the assessment of the solution to be retained. Considering the results presented in Figure 25 regarding the environmental impacts of the load-bearing structure alone, Figure 27 shows the total impacts of the floor slab. The results consider that the finishing is replaced two times, with an environmentally equally performing material, during the service life of 90 years admitted for the load-bearing structure.

The "ranking" for environmental impact entirely changes if the impact of load-bearing structure and finishing is considered. In addition, the admitted service life for a certain layer of the construction element as well as the considered indicator also play relevant roles, considering the differences for the evaluated options in Figure 27a and Figure 27b.

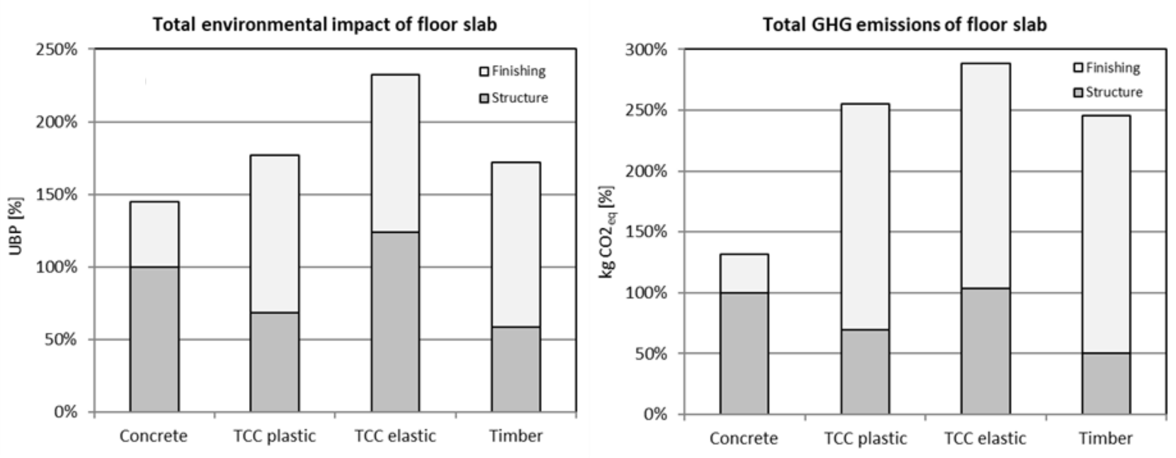


Figure 27: Total impact of floor slab of a public school (9 m span), considering structure and finishing – a) normalized UBP and b) normalized embodied GHG emissions (Plüss and Zwicky, 2014).

Lightweight timber construction often requires adding mass, for acoustic insulation and thermal storage in dynamic heating concepts (also see Figure 27). (Zwicky and Ston, 2024) explored fabrication of lightweight mortars and lightweight aggregates for concrete in a low-energy cold-bonding pelletizing process, using sawdust and ashes from district heating, and alternative binders in combination with or instead of cement. The inclusion of saw dust allows to obtain lightweight materials (900 to 1'700 kg/m^3), while substituting cement with wood ashes, metakaolin and limestone decreases the GHG emissions of the binder.

The mechanical properties of the developed materials cannot compete with commercial lightweight concrete but could do so with structural masonry – while providing a GHG emission reduction of 40% to 60% and a reduced density in the range of 1'390 kg/m^3 to 1'520 kg/m^3, compared to regular masonry with 1'300-2'000 kg/m^3 (thermally insulating to regular heavy-duty masonry).

However, non-structural applications such as screeds with a passive thermal function could be the ideal setting for the developed low-carbon, waste-incorporating materials. Figure 28 shows results for thermal storage capacities of the alternative materials, compared to regular screeds (cement or anhydrite). The latter have a density of 1'850-2'000 kg/m^3 (i.e., principally heavier), 1.6-2.8 MJ/m^3·K specific heat capacity and 180-220 kgCO$_{2,eq}$/m^3 embodied GHG emissions (dashed lines in Figure 28). It shows that there are several developed mixes with thermal storage capacities around 11 MJ/m^3·K while being considerably lighter and providing a reduction in GHG emissions of up to 30%.

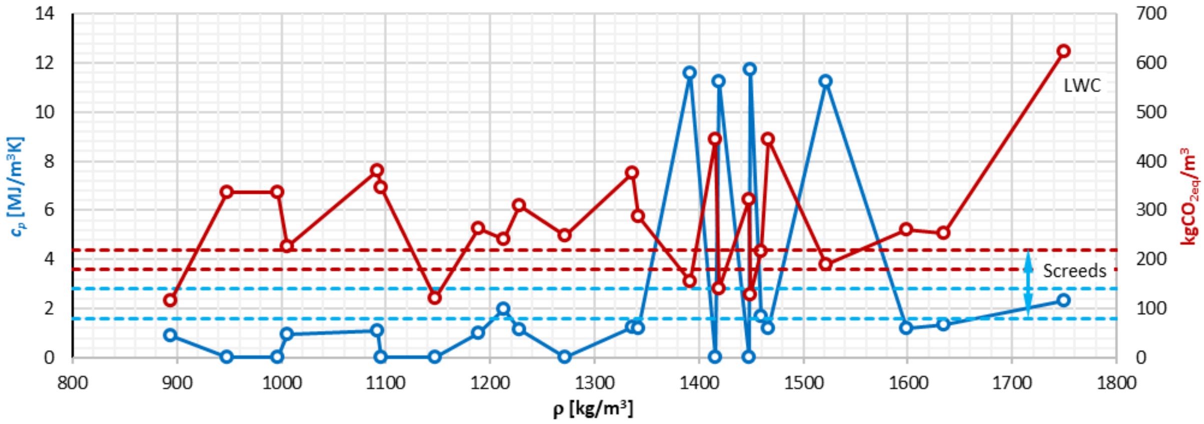


Figure 28: Thermal storage capacity (specific heat c_p) and GHG emissions (in kgCO$_{2eq}$/m^3) of alternative lightweight materials for screeds (Ston & Zwicky 2024). Note: for materials showing zero specific heat capacity, this property was not measured.

The use of such alternative lightweight materials can reduce the embodied GHG emissions of the screed by 60% (Priore and Jusselme, 2023). This results in an overall reduction of a case study building's emissions of around 3%, see Figure 29. Note, however, that the effect of these new materials on acoustic insulation performances needs further investigation.

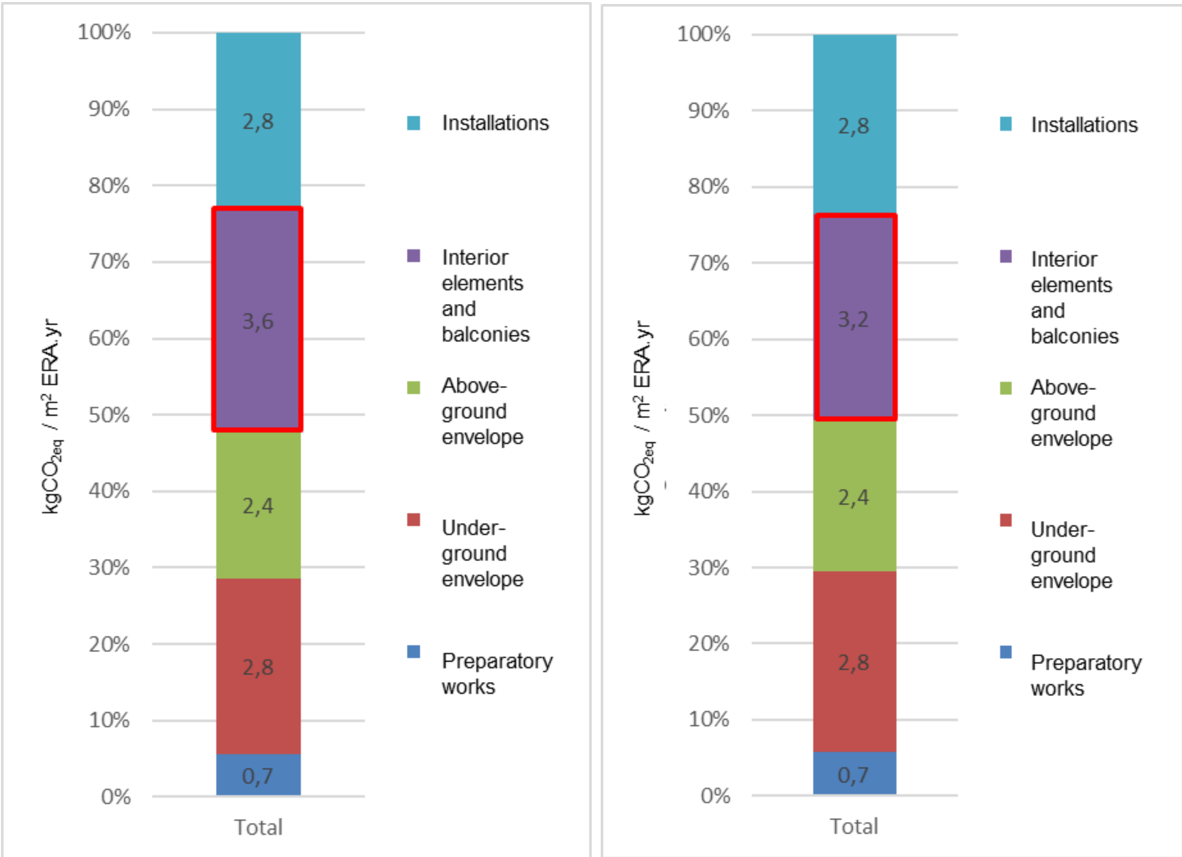


Figure 29: Reduction of GHG emissions thanks to the use of alternative materials in slab screeds.

3.1.15 Choice and dimensioning of preparatory works

Relevance of the measure and influencing factors

It is worth noting that preparatory works are frequently underestimated or even excluded from calculations, despite the fact that they can account for over 30% of the GHG embodied emissions of a building. According to the SIA Energy Efficiency Path (Technical bulletin 2040 of SIA (2017)), which still refers to the old SIA 2032 (2010) standard, only the excavation volume is considered in a building's embodied emissions. Even in Minergie-ECO certifications, excavation supports, and deep foundations are excluded from the calculations. The new version of the SIA2032:2020 includes preparatory works in the system boundaries and the soon to come SIA390/1 will also include these elements. It is recommended to include this impact in all standards and labels as well as budgets and targets.

Recommendations

In 2023, the city of Zurich mandated an extensive analysis to quantify the impact of preparatory works (Kuhn, Knecht and Schultheiss, 2023).. The primary recommendations derived from this analysis are as follows:

- Excavations should be stepped whenever possible. This excavation support method leads to the lowest environmental impact, even for building depths exceeding 10 meters.
- In urban situations, steep angles in excavation support may be necessary due to space constraints. In such cases, shotcrete walls, soldier pile walls, or sheet pile walls have lower environmental impacts compared to other types of sheet pile walls, bored pile walls, or diaphragm walls.

- Piles are significant contributors to GHG emissions. For instance, replacing them with a thinner material layer (e.g., under 1-2 meters) may reduce GHG emissions.
- If good soil conditions exist at shallow depths, it is generally worthwhile to excavate to that depth and place the foundation slab at that level (investigated for a depth of 3.5 meters).
- Challenging soil conditions (e.g., groundwater-bearing soils) often necessitate piles and complex excavation supports, leading to increased GHG emissions. These can potentially be mitigated with shallower foundation depths (i.e., omitting or reducing basements).

Limitations

The type and extent of preparatory works is highly dependent on the site (neighbouring buildings and space), the ground composition, and building depth. Although a certain level of flexibility is possible in the design of these elements, it is often limited by external factors.

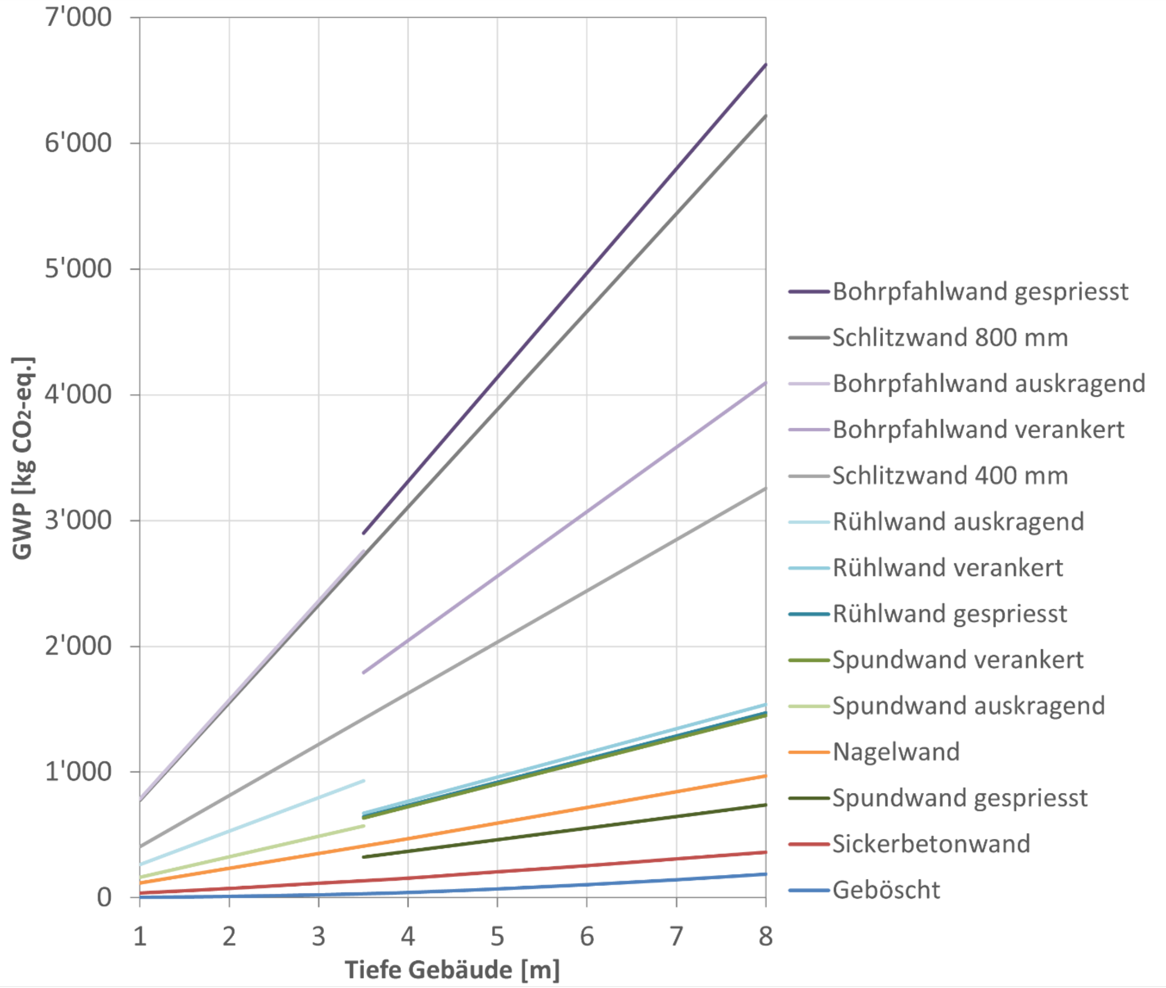


Figure 30: GWP impact in relation to the below ground depth of the building and different types of preparatory works (Kuhn, Knecht and Schultheiss, 2023).

3.1.16 Choice and dimensioning of technical installations

Relevance of the measure and influencing factors

Technical installations represent on average 15% of a new building's embodied emissions (Figure 31) and 30% of a renovation's. In a building's Life Cycle Assessment (LCA), embodied emissions of technical installations is frequently underrepresented (Hoxha *et al.*, 2021), often with only rough estimations, despite their capacity to significantly impact the overall GHG emissions. This is especially pronounced when structural and non-structural elements have already been optimized. Furthermore, operational emissions are still a major contributor, especially in the case of existing buildings, the choice and dimensioning of technical installations during a renovation, the share of renewable energies, and the efficiency of the specific installations determine the level of GHG emissions in this phase.

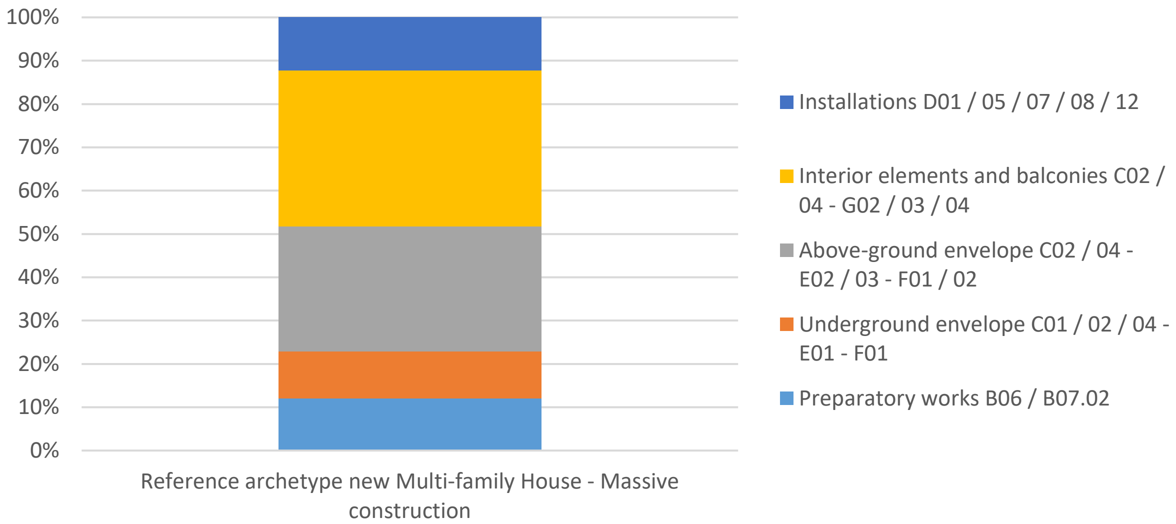


Figure 31: Share of embodied emissions of a reference new multi-family house archetype with standard technical installations. Installations represent ca. 15% of the total embodied emissions.

Recommendations

An innovative approach to simultaneously reduce operational and embodied GHG emissions involves simplifying technical systems within buildings (Voss *et al.*, 2007). This approach underlines the often-overlooked potential of architectural design through a low-tech approach. By purposefully harnessing natural elements like solar gains, natural ventilation, thermal capacity, and other inherent environmental effects, deliberate building design, rather than reliance on complex technical systems, can substantially reduce operational energy demands (Mouton *et al.*, 2023). In their study, Mouton et al. (2023) concluded that further exploration of the low-tech approach, particularly when combined with bio-based and circular building materials, is imperative. This exploration is expected to uncover substantial potential for GHG emissions reduction, offering a viable path to achieving even the most ambitious climate targets.

The adoption of renewable energies is an essential component of GHG emissions reduction in the operation of buildings, as the environmental impact (measured in kg CO_{2eq}) per kWh of energy consumed is significantly lower compared to fossil sources.

Increasing the efficiency of technical installations in buildings holds significant potential for reducing GHG emissions, making it a relevant measure at the building scale. The efficiency of these installations, such as heating, cooling, and ventilation systems, can greatly influence the carbon payback time of the installation in question. By improving efficiency, buildings can significantly lower their energy consumption and, consequently, their GHG emissions.

Limitations

It is important to note that the data available for embodied emissions of technical installations in the KBOB database is largely based on rough estimations derived from average technical installations in specific case studies. Consequently, this database provides limited flexibility for effectively optimizing the systems implemented in a given project. It is recommended to expand the database on technical installations.

Passive measures optimization requires a higher effort in the energy modelling phase during the design to grasp all energy flow dynamics affected by material properties, size and shape of building, and dimensioning of installations. Some shifts between operational reduction and increased embodied are observed when such optimizations are carried out, hence the importance of coupling energy modelling with life cycle assessments.

Extensive implementation of renewable energies on site at building scale is often limited by costs, space (e.g., roof surface for PV installation), and site conditions (e.g., geothermal potential). Similarly, efficiency of such installations might depend on site conditions.

Examples

- In the framework of the LightBudget project (Rezaei Oghazi, Jusselme et Andersen. 2024a) achieving net-zero operational emissions necessitates installing photovoltaic (PV) panels to cover 100% of the roof area.
- The well-known be2226 building case study, built in Lustenau by Baumschlager Eberle Architekten, exemplifies and demonstrates the viability of the low-tech concept by maintaining comfortable temperature levels inside the building without relying on active heating systems. The original building in Lustenau is an office building but the concept is being further developed into residential and mixed-use buildings[9]. This building has been tied to high embodied emissions due to double-layered brick façade, but studies show that applying low-carbon materials is a possible way forward to develop low-carbon and low-tech buildings. In (Mouton *et al.*, 2023), the N11 SolarHouse is also assessed, in comparison to the be2226. This passive house results in one third of the emissions of the be2226 over the life cycle, demonstrating that passive measures do not necessarily come at a higher embodied investment.

3.2 Parametric LCA for net-zero strategies

3.2.1 Strategies applied to a reference multi-family house archetype.

According to the methodology described in section 2.2, a reference multi-family house archetype (see Appendix 7.1) has been used to demonstrate the potential impact of each measure on the embodied and operational emissions as shown in Figure 32. The average reduction potential of each measure is of ca. 15% and no single measure is capable of reducing the impact of more than 30%. An exception to this is the transform instead of building new which by its nature avoids the new construction completely, therefore bringing the impact of new construction to zero. Nonetheless, this measure transfers the impact to the renovation boundaries which are on average lower than a new construction but not zero. Therefore, this measure is treated separately as the impact resulting from the renovation is outside the boundaries of a new construction. The overall highest potential as a single measure is found in considering the linear decarbonization of the industry until 2050 although it carries high uncertainties and methodological issues as described in section 3.1.4. Size and compactness demonstrate a high potential as a single measure, achieving almost 20% reduction compared to the reference case.

[9] https://www.2226.eu/en/implementation/

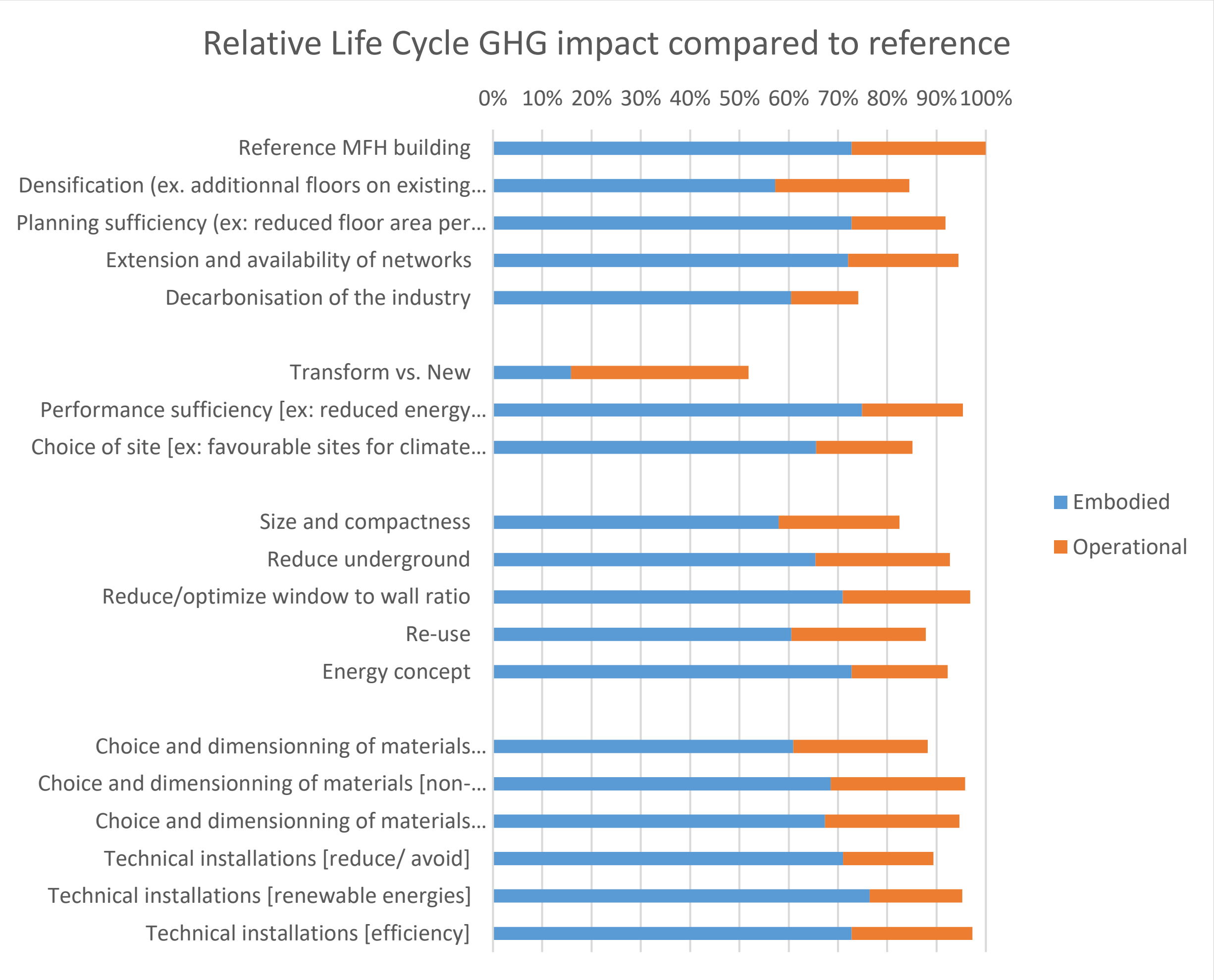


Figure 32: Relative Life cycle GHG emissions of each measure compared to reference MFH archetype (see appendix 7.1).

In a second step, measures are combined into strategies based on the three well-known strategies in the field of sustainable development: “sufficiency”, “consistency”, and “efficiency” (Huber, 2000). In the recent UNEP report on building materials and the climate (UNEP, 2023), the strategies are formulated as “AVOID”, “SHIFT”, and “IMPROVE” but are, in principle, following the same core idea.

Sufficiency – AVOID – strategy

The general direction of this strategy is to avoid/reduce from a quantitative perspective the demand for surfaces, energy, and resources. This is reflected in quantity and/or size of buildings, building parts, and building elements but also materials inside elements and energy requirements for operation and comfort. As shown in Figure 33, the strategy tackles framework condition measures of densification and sufficiency, performance sufficiency in the definition of objectives, size and compactness in the preliminary design, and reduced technical installations in the project phase. The biggest reduction potential lies in the framework conditions, where avoiding construction from the beginning will in fact strongly reduce GHG emissions in the building area.

Consistency – SHIFT – strategy

The general direction of this strategy is to shift to low carbon, bio-based, earth-based building materials, and renewable energies. As shown in Figure 33, the strategy affects measures taken into later design phases (preliminary study and project phase) where materials and energy supply are finally defined, and re-use concepts are established. This strategy is also the only one that triggers an increase in biogenic GWP-uptake in the building (as shown by the negative values in Figure 33), up to ca. 35% of the GHG emissions of the initial reference building if all measures are combined, thanks to the shift to biogenic materials such as wood and straw.

Efficiency – IMPROVE – strategy

The general direction of this strategy is to improve existing practices (processes, materials, networks, and efficiency). As shown in Figure 33, the strategy relies on smaller reductions per single measure.

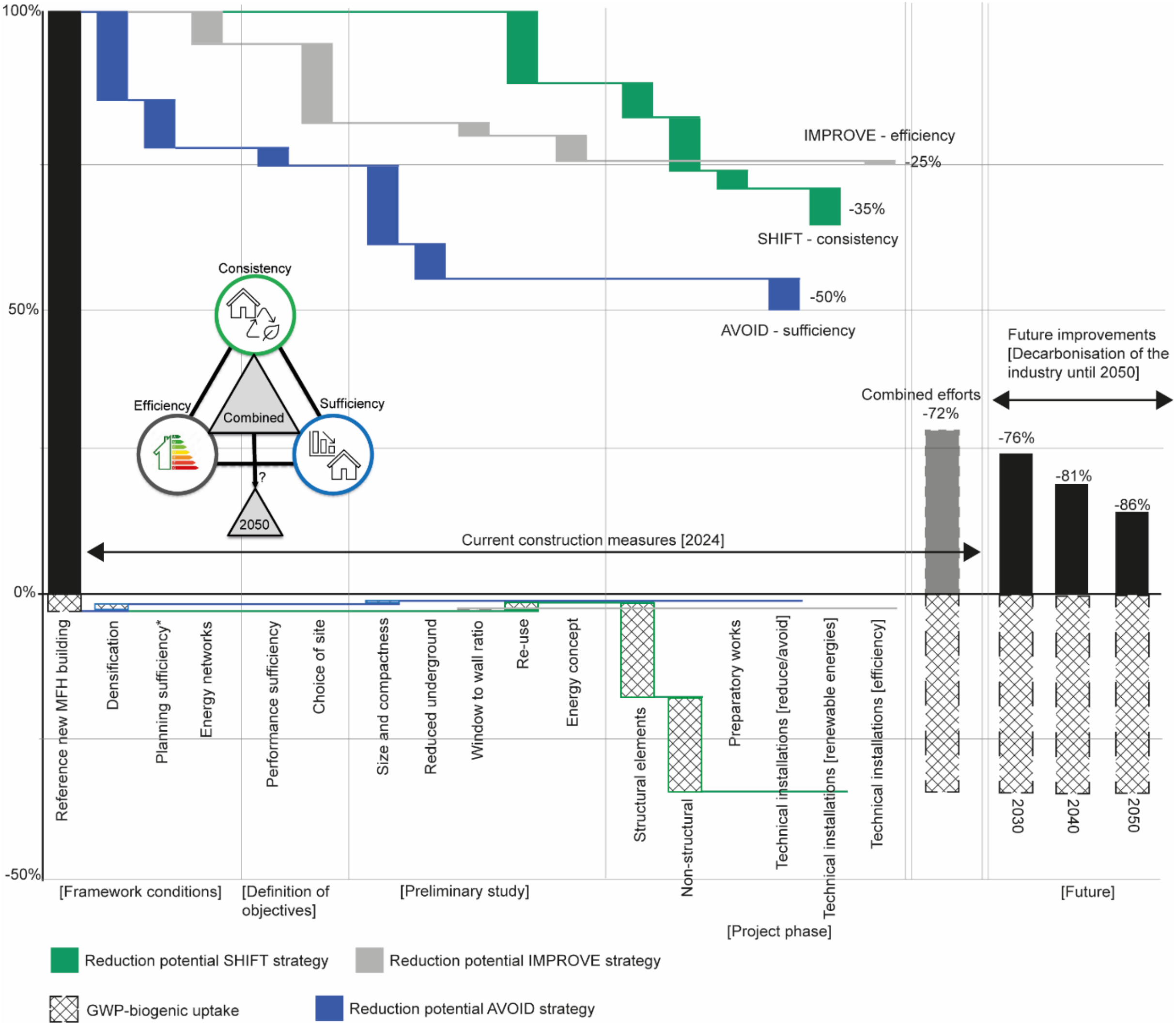


Figure 33: Relative GHG reduction potential and GWP-biogenic uptake (*negative value to be accounted only in case of permanent storage) of the proposed strategies from a reference MFH building per measure.

Eventually, the biggest reduction potential is achieved by combining efforts in all three core strategies, resulting in more than 70% reduction of GHG emissions and 35% increase in GWP-biogenic uptake compared to the initial GHG emissions of the reference MFH.

The proposed strategies and their aggregated potential impact in reducing GHG emissions from a reference case are shown in Figure 33. Considering that the reference archetype (100% in the graph, see appendix 7.1) amounts to ca. 1'200 $kgCO_{2eq}/m^2$ (ca. 20 $kgCO_{2eq}/m^2$.yr.), the strategy "avoid" could potentially bring down the emissions by 50% to ca. 580 $kgCO_{2eq}/m^2$ (ca. 10 $kgCO_{2eq}/m^2$.yr.). Combining all measures using the methodology described in section 2.2, the emissions could be reduced to ca. 260 $kgCO_{2eq}/m^2$ (ca. 4.4 $kgCO_{2eq}/m^2$.yr.) corresponding to a 72% reduction in GHG emissions (operation and embodied). Finally, a further expected reduction in supply chain emissions in 2050 could further reduce emissions by ca. 50% with potentially a linear reduction until then.

3.2.2 Strategies applied to a reference single-family house archetype.

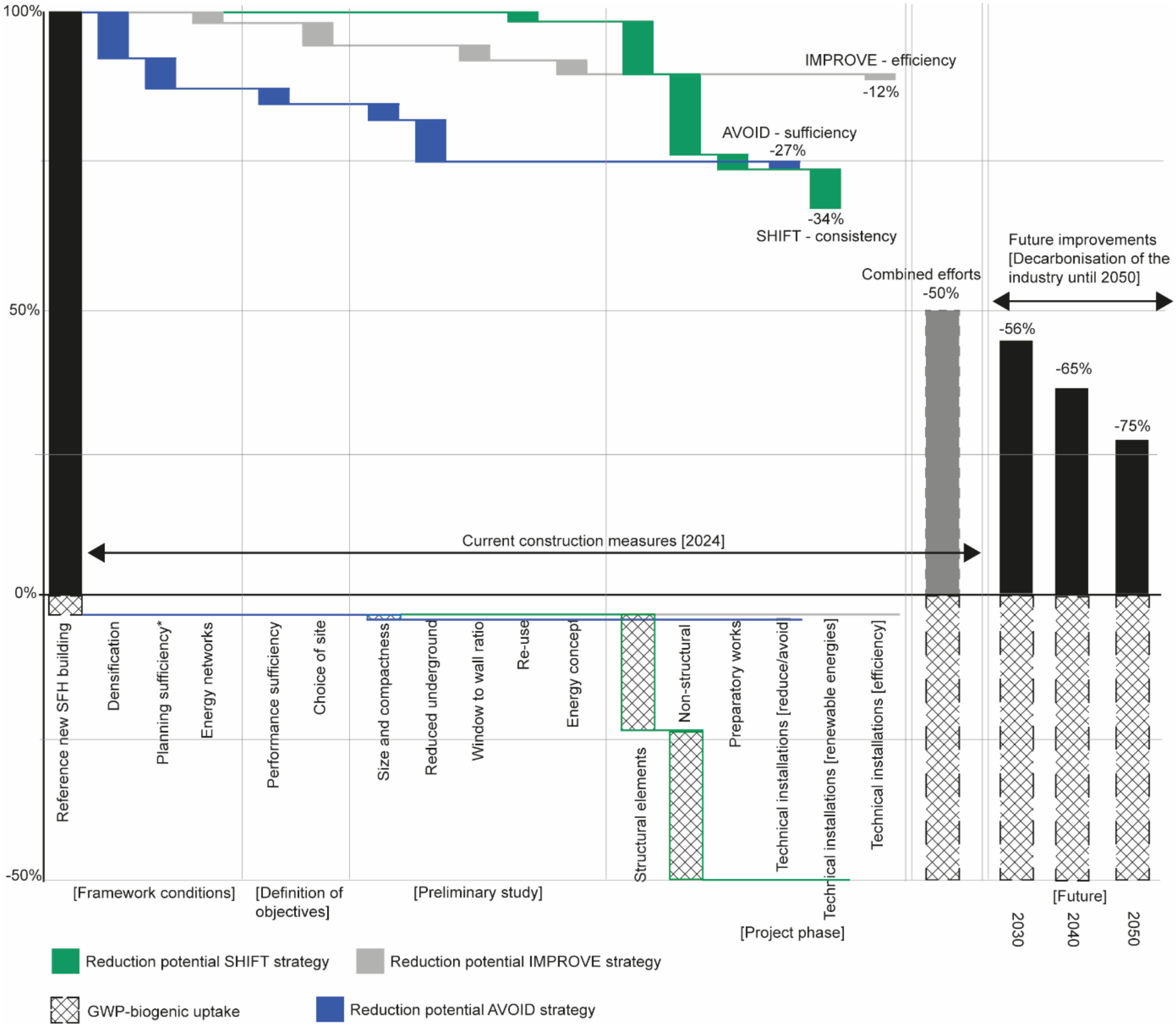


Figure 34: Relative GHG reduction potential and GWP-biogenic uptake (*negative value to be accounted only in case of permanent storage) of the proposed strategies from a reference SFH building per measure.

Following the same methodology as the previous section, measures and strategies are applied to a reference single-family house archetype as shown in Figure 34. The potential reductions are lower than in the case of a multi-family house partially due to the difference in configuration of the initial archetype (e.g.: less underground volume / better initial compactness) and partially due to the relative higher emissions per square meter of energy reference area of single components in single-family houses. A relevant parameter in the comparison between MFH and SFH is the envelope factor. Intrinsically SFH have a higher envelope factor (i.e. relatively higher envelope surface per energy reference area), this measure can’t be improved drastically while remaining in the size boundaries of a SFH. This also means that per square meter of energy reference area, façade elements and roof are bigger in a SFH, resulting in a higher potential reduction and higher increase of GWP-biogenic uptake when switching to bio-based materials in structural and non-structural elements.

Considering that the reference archetype (100% in the graph) amounts to ca. 1'230 $kgCO_{2eq}/m^2$ (ca. 20 $kgCO_{2eq}/m^2.yr.$), strategy "shift" could potentially bring down the emissions by 35% to ca. 800 $kgCO_{2eq}/m^2$ (ca. 14 $kgCO_{2eq}/m^2.yr.$). Combining all measures together, the emissions could be reduced to ca. 620 $kgCO_{2eq}/m^2$ (ca. 10 $kgCO_{2eq}/m^2.yr.$) corresponding to a 50% reduction in GHG emissions (operation and embodied). Finally, a further expected reduction in supply chain emissions in 2050 could further reduce emissions by ca. 50%.

3.2.3 Sensitivity analysis

Figure 35 presents the best- and worst-case scenarios and individual impact of measures stemming from the sensitivity analysis described in 2.2.1. In the best-case scenario, the building meets the lower GHG emission target, demonstrating that it is feasible to achieve ambitious goals by making optimal design choices throughout the planning process. This scenario integrates all studied measures, nevertheless some additional measures would also be available but were not included in this study for different reasons (see2.2.1). In contrast, the worst-case scenario highlights how far GHG emissions can deviate from targets when high-impact, carbon-intensive measures are selected. In the best-case scenario the measures with the highest sensitivity are size and compactness, material choices (structural and non-structural), as well as energy supply and technical installations. These results emphasize the importance of a holistic approach to design and planning, where both individual and combined choices must be made carefully to stay within acceptable GHG emission ranges. Further detailed results from the sensitivity analysis are presented in Appendix II.

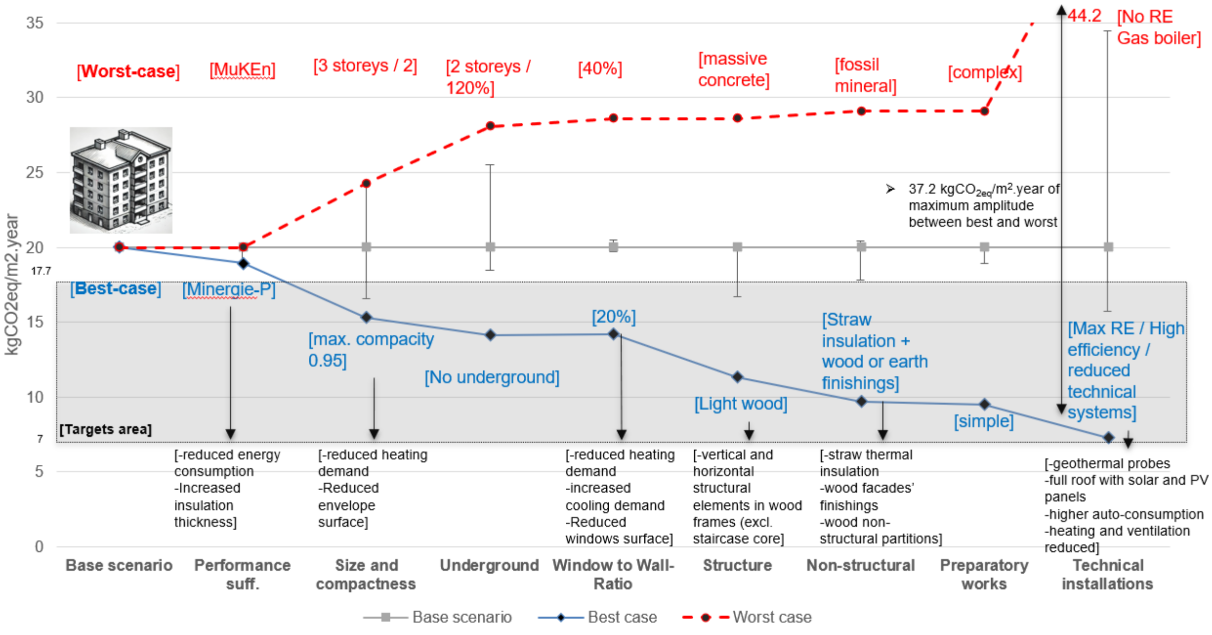


Figure 35: Best- and worst-case scenarios with combined measures applied to the base model of a MFH.

3.3 Evaluation of measures and strategies according to feasibility criteria

The measures presented in 3.1 are evaluated internally according to the methodology presented in 2.4, and final results are aggregated in a summary evaluation grid (Figure 36) graded as easy, moderate-easy, moderate, moderate-difficult, and difficult.

Feasibility dimension	Economic		Social		Technical				Evaluation	Summary ranking per measure
Evaluation indicator	Costs now, in 2030 and in the long term	Employment effects and economic growth	Social co-benefits	Public acceptance: extent to which the public supports the option and changes behavior accordingly	Technical scalability: can the option be scaled up quickly	Maturity: R&D and time needed to implement the option	Simplicity: is the option technically simple to build, operate, and maintain	Absence of risk	Critical	
Framework condtions										
Densification (ex. additionnal floors on existing buildings)	EASY		MOD.	MOD.	MOD.	EASY	MOD.	MOD.	MOD.	
Planning sufficiency (ex: reduced floor area per inhabitant)	EASY	MOD.	EASY	DIFF.	MOD.	EASY	MOD.	EASY	DIFF.	
Extension and availability of networks	DIFF.	EASY	MOD.	MOD.	MOD.	MOD.	MOD.	MOD.	DIFF.	
Decarbonisation of the industry	DIFF.	MOD.	MOD.	EASY	MOD.	MOD.	DIFF.	MOD.	DIFF.	
Definition of objectives										
Transform vs. New	MOD.	MOD.	EASY	MOD.	EASY	EASY	MOD.	EASY	MOD.	
Performance sufficiency [ex: reduced energy demand]	MOD.	MOD.	EASY	MOD.	MOD.	MOD.	EASY	EASY	MOD.	
Choice of site [ex: favourable sites for climate conditions]	MOD.	MOD.	MOD.	MOD.	MOD.	EASY	EASY	EASY	MOD.	
Preliminary study										
Size and compactness	EASY	MOD.	MOD.	MOD.	EASY	EASY	EASY	EASY	MOD.	
Reduce underground	EASY	MOD.	MOD.	MOD.	EASY	EASY	EASY	EASY	MOD.	
Reduce/optimize window to wall ratio	EASY	MOD.		MOD.	EASY	EASY	EASY	EASY	MOD.	
Re-use	MOD.	EASY	EASY	MOD.	MOD.	MOD.	MOD.	MOD.	MOD.	
Energy concept	MOD.	EASY	EASY	EASY	MOD.	EASY	MOD.	EASY	MOD.	
Project phase										
Choice and dimensionning of materials [structural elements]	MOD.	MOD.	MOD.	MOD.	EASY	MOD.	MOD.	EASY	MOD.	
Choice and dimensionning of materials [non-structural]	MOD.	MOD.	MOD.	EASY	EASY	EASY	MOD.	EASY	MOD.	
Choice and dimensionning of materials [preparatory works]	MOD.	MOD.	MOD.	MOD.	MOD.	EASY	MOD.	MOD.	MOD.	
Technical installations [reduce/ avoid]	EASY	MOD.	EASY	MOD.	MOD.	EASY	MOD.	MOD.	MOD.	
Technical installations [renewable energies]	MOD.	EASY	MOD.	MOD.	MOD.	MOD.	MOD.	MOD.	MOD.	
Technical installations [efficiency]	MOD.	EASY	EASY	EASY	MOD.	EASY	MOD.	MOD.	MOD.	
Tendering										
Suppliers [environmental performance and reduce distances]	MOD.	MOD.	EASY	EASY	MOD.	MOD.	MOD.	MOD.	MOD.	
Ranking per indicator										

Figure 36: Evaluation grid of the selected measures. Single indicators per single measures are evaluated as easy (dark green), moderate-easy (light green), moderate (yellow), moderate-difficult (light red), and difficult (red). A "critical" column is added to pinpoint the most critical indicator for each measure. Additionally, ranking per measure (on the right) and per indicator (below) is added, indicating the difficulty level across all indicators for each measure and across all measures for each indicator and ranked from most difficult (dark red) and easiest (dark green). Finally, the design phases are also color coded based on difficulty level of the measures included in each phase.

Clearly, very few indicators result in strong agreement and/or evidence as barrier to measures (red in Figure 36). These are only found in measures at the "framework conditions" phase such as costs for extending energy networks and decarbonizing the industry, public acceptance of planning sufficiency, and technical simplicity of decarbonizing the industry. In general, measures in the framework conditions are the ones faced with the highest level of barriers on all dimensions.

Early design phase measures (definition of objectives and preliminary design) are faced, generally, with less barriers and more enabling conditions especially from a technical front (except for the re-use measure). The re-use measure is an exception to the general trend in this phase as it would find a better fit in the project phase in current practices. Although the measure should, optimally, be defined in early design stages, the technical barriers and higher costs are more related to its implementation later in the project.

Project and tendering phases' measures are generally faced with a medium-easy feasibility (moderate-difficult for tendering). Technical simplicity and absence of risk tend to appear more as barriers with a strong correlation of increased costs as well.

The measure faced with the most barriers over all indicators is the decarbonisation of the industry which is consistent with the enormous challenges connected with such a revolutionary change. Not surprisingly, this measure is presented with enabling conditions only from a social perspective with society most likely embracing such a change and finding co-benefits on many fronts.

The measure with the least barriers over all indicators is the implementation of an energy concept in the early design phases which is again consistent with the low costs and technical skills associated with it.

Reading Figure 36 in a “vertical” direction indicates that both economic indicators pose the most barriers throughout the measures followed by technical simplicity and public acceptance which is consistent with the usual challenges of implementing changes in an established sector. Technical maturity is, instead, the indicator posing the least barriers, indicating that the majority of the measures are available and ready to be implemented fast.

The three strategies introduced in previous section are also evaluated in the feasibility assessment by aggregating the results of the single measures they include. Figure 37 presents the aggregated results of the feasibility of the AVOID strategy. Critical measures are here found in the framework condition phase (densification and sufficiency) and the two main critical indicators, across all measures, are identified in the economic dimension (employment effects and economic growth) and social dimension (public acceptance).

AVOID	Economic		Social		Technical				Evaluation	
Evaluation indicator	Costs now, in 2030 and in the long term	Employment effects and economic growth	Social co-benefits	Public acceptance: extent to which the public supports the option and changes behavior accordingly	Technical scalability: can the option be scaled up quickly	Maturity: R&D and time needed to implement the option	Simplicity: is the option technically simple to build, operate, and maintain	Absence of risk	Critical	Ranking per measure
Frame condtions										
Densification (ex. additionnal floors on existing buildings)	EASY		MOD.	MOD.	MOD.	EASY	MOD.	MOD.	MOD.	
Planning sufficiency (ex: reduced floor area per inhabitant)	EASY	MOD.	EASY	DIFF.	MOD.	EASY	MOD.	EASY	DIFF.	
Definition of objectives										
Performance sufficiency [ex: reduced energy demand]	MOD.	MOD.	EASY	MOD.	MOD.	MOD.	EASY	EASY	MOD.	
Preliminary study										
Size and compactness	EASY	MOD.	MOD.	MOD.	EASY	EASY	EASY	EASY	MOD.	
Reduce underground	EASY	MOD.	MOD.	MOD.	EASY	EASY	EASY	EASY	MOD.	
Project phase										
Technical installations [reduce/ avoid]	EASY	MOD.	EASY	MOD.	MOD.	EASY	MOD.	MOD.	MOD.	
Ranking per indicator										

Figure 37: Evaluation grid of the AVOID strategy. Single indicators per single measures are evaluated as easy (dark green), moderate-easy (light green), moderate (yellow), moderate-difficult (light red), and difficult (red). A “critical” column is added to pinpoint the critical indicator for each measure. Additionally, ranking per measure (on the right) and per indicator (below) is added, indicating the difficulty level across all indicators for each measure and across all measures for each indicator and ranked from most difficult (dark red) and easiest (dark green). Finally, the design phases are also color coded based on difficulty level of the measures included in each phase.

Figure 38 presents the aggregated results of the feasibility of the SHIFT strategy. Critical measure is here found in the preliminary study phase (re-use) and the two main critical indicators, across all measures, are identified in the economic dimension (costs) and technical dimension (simplicity).

SHIFT	Economic		Social		Technical				Evaluation	
Evaluation indicator	Costs now, in 2030 and in the long term	Employment effects and economic growth	Social co-benefits	Public acceptance: extent to which the public supports the option and changes behavior accordingly	Technical scalability: can the option be scaled up quickly	Maturity: R&D and time needed to implement the option	Simplicity: is the option technically simple to build, operate, and maintain	Absence of risk	Critical	Ranking per measure
Preliminary study										
Re-use	MOD.	EASY	EASY	MOD.	MOD.	MOD.	MOD.	MOD.	MOD.	
Project phase										
Choice and dimensionning of materials [structural elements]	MOD.	MOD.	MOD.	MOD.	EASY	MOD.	MOD.	EASY	MOD.	
Choice and dimensionning of materials [non-structural]	MOD.	MOD.	MOD.	EASY	EASY	EASY	MOD.	EASY	MOD.	
Choice and dimensionning of materials [preparatory works]	MOD.	MOD.	MOD.	MOD.	MOD.	EASY	MOD.	MOD.	MOD.	
Technical installations [renewable energies]	MOD.	EASY	MOD.	MOD.	MOD.	MOD.	MOD.	MOD.	MOD.	
Ranking per indicator										

Figure 38: Evaluation grid of the SHIFT strategy. Single indicators per single measures are evaluated as easy (dark green), moderate-easy (light green), moderate (yellow), moderate-difficult (light red), and difficult (red). A “critical” column is added to pinpoint the critical indicator for each measure. Additionally, ranking per measure (on the right) and per indicator (below) is added, indicating the difficulty level across all indicators for each measure and across all measures for each indicator and ranked from most difficult (dark red) and easiest (dark green). Finally, the design phases are also color coded based on difficulty level of the measures included in each phase.

Figure 39 presents the aggregated results of the feasibility of the IMPROVE strategy. Critical measures are here found again in the framework condition phase (i.e.: extension of networks) and the main critical indicator, across all measures, is identified in the economic dimension (costs).

IMPROVE	Economic		Social		Technical				Evaluation	
Evaluation indicator	Costs now, in 2030 and in the long term	Employment effects and economic growth	Social co-benefits	Public acceptance: extent to which the public supports the option and changes behavior accordingly	Technical scalability: can the option be scaled up quickly	Maturity: R&D and time needed to implement the option	Simplicity: is the option technically simple to build, operate, and maintain	Absence of risk	Critical	Ranking per measure
Frame condtions										
Extension and availability of networks	DIFF.	EASY	MOD.	MOD.	MOD.	MOD.	MOD.	MOD.	DIFF.	
Definition of objectives										
Choice of site [ex: favourable sites for climate conditions]	MOD.	MOD.	MOD.	MOD.	MOD.	EASY	EASY	EASY	MOD.	
Preliminary study										
Reduce/optimize window to wall ratio	EASY	MOD.		MOD.	EASY	EASY	EASY	EASY	MOD.	
Energy concept	MOD.	EASY	EASY	EASY	MOD.	EASY	MOD.	EASY	MOD.	
Project phase										
Technical installations [efficiency]	MOD.	EASY	EASY	EASY	MOD.	EASY	MOD.	MOD.	MOD.	
Ranking per indicator										

Figure 39: Evaluation grid of the IMPROVE strategy. Single indicators per single measures are evaluated as easy (dark green), moderate-easy (light green), moderate (yellow), moderate-difficult (light red), and difficult (red). A "critical" column is added to pinpoint the critical indicator for each measure. Additionally, ranking per measure (on the right) and per indicator (below) is added, indicating the difficulty level across all indicators for each measure and across all measures for each indicator and ranked from most difficult (dark red) and easiest (dark green). Finally, the design phases are also color coded based on difficulty level of the measures included in each phase.

To ensure a successful shift to net-zero practices, the scalability of the proposed strategies is critical. The AVOID strategy finds barriers in economic and social aspects, necessitating strong regulatory frameworks, public awareness campaigns, and financial incentives to enable its deployment. The SHIFT strategy is, instead, limited by costs and technical complexity. This strategy would highly benefit from advanced education and training of professionals to reduce initial costs of labour and reduce complexity of implementation. Financial incentives and regulatory frameworks would also enable this strategy by reducing costs and risks of such measures. Finally, the IMPROVE strategy is mainly hindered by costs, similarly to the previous strategies, financial incentives and regulatory frameworks are essential to enable a scalable deployment of the strategy.

For all measures and strategies, scalability depends on all three dimensions analysed in this section. Measures that demonstrate moderate to high economic feasibility include those that have lower upfront costs and higher potential for long-term savings, such as energy-efficient installations and the use of bio-based materials. Social scalability, on the other hand, depends on public acceptance and the co-benefits that these measures bring to communities. Strategies that enhance public acceptance, such as those promoting the use of renewable energy and improving building performance, are more likely to be scalable on a larger scale.

3.4 Building standards and labels assessment and comparison

The Excel sheet containing the comparison of standards and labels is provided in appendix 7.4 It contains detailed information on choice, calculation rules on both direct building energy (useful, final) and whole life cycle building calculations (scope, indicators, data), limit values, and required or encouraged measures towards reduced GHG emissions and net-zero perspective for the two groups of available documents: the standards and technical bulletins/others (e.g., MoPEC/MuKEn), as well as the labels.

Below are summarized the main aspects of the comparison of the main standards (SIA 2032:2020, SIA 2040:2017 and prSIA 390/1:2023) and labels (Minergie, CECB/GEAK, SNBS) "towards net-zero GHG emissions", while the Excel grid provides the full list of all documents analysed and the full details for each document according to the assessed criteria and measures (as presented in section 2.4).

Standards and technical bulletins

In a view of a net-zero GHG emissions' perspective, the prSIA 390/1 standard stands out as the only analysed document which provides a first basis towards LCA-based requirements compatible with a net-zero target. However, this standard in its final form is currently under preparation as of beginning of 2024.

Both the prSIA 390/1 draft version (February 2024) and its former SIA 2040 technical bulletin, indicative values are given for GHG emissions for both construction and operation (as well as mobility), addressing new buildings and transformations for different typologies (residential, offices, schools etc.). These indicative values are different for new or transformation projects and can be exceeded in one of the domains as what really matters in the overall limit and target values (see the tables below for an illustration for residential buildings). So, each building must comply with a typology-specific target value for the total of construction and operation.

Table 3: SIA 2040 target and limit values of GHG emissions for residential buildings both new and transformation.

	Valeurs limites		Valeurs cibles	
	Émissions de gaz à effet de serre kg/m^2		Émissions de gaz à effet de serre kg/m^2	
Habitation	Construction nouvelle	Transformation	Construction nouvelle	Transformation
Valeur indicative construction	9,0	5,0	7,0	5,0
Valeur indicative exploitation	2,0	4,0	0,0	2,0
Valeur indicative mobilité	4,0	4,0	3,0	3,0
Valeur limite I Valeur cible	**15,0**	**13,0**	**10,0**	
Exigences $_{\text{construction+ exploitation}}$	**11,0**	**9,0**	**7,0**	

Table 4: prSIA 390/1 target and limit values of GHG emissions for residential buildings both new and transformation.

Residential	**GHG emissions [kgCO2eq/m2.yr]**			
	Limit value		**Target value**	
	New building	Transformation	New building	Transformation
Construction	9.0	5.0	6.0	4.0
Operation	2.0	4.0	1.0	3.0
Construction + Operation	11.0	9.0	7.0	7.0

In alignment with the measures outlined in F2 project, the SIA standards and technical bulletins (SIA 2032, SIA 2040 and prSIA 390/1) recommend several incentives to support a net-zero target in the framework conditions, the definition of objectives, preliminary study and project phases. Generally speaking, the three documents have similar incentives reported in appendixes or in separate documentation with a list of influencing factors that match the identified measures in this project e.g., for SIA 2040:2017 in D0258 with the choice of site, the strategic choice between transform vs. new, the compactness factor, the construction type (structural and non-structural), the presence of underground levels, the heat production and energy carrier for electricity choice, etc. Some new measures are introduced in prSIA 390/1 such as Re-use while this is not explicitly described in SIA 2040:2017.

The prSIA 390/1 also includes two informative appendixes aligning with a net-zero GHG emissions perspective for buildings until 2050: 1) reduction trajectories until 2050 with/without negative emissions accounted for; and 2) a contribution to climate neutrality in buildings with definitions provided for the "net zero building" term and "negative emissions".

Labels

Until september 2023 (when this SFOE project was already running) labels and standards exhibited variations in their philosophies, system boundaries, requirements, indicators, and reporting methods. In September 2023, Swiss building labels CECB/GEAK, Minergie and SNBS announced a harmonization of their methodologies and provided clearer distinctions in their area of application and intended objectives. The following analysis thus includes the most recent versions of these labels namely CECB/GEAK 2.1, Minergie -/A/P/-ECO 2023 and SNBS 2023.

CECB/GEAK promotes the renovation of existing buildings through an energy audit and labelling. It focuses on energy consumption, direct CO_2 emissions and GHG emissions during operation with dedicated indices. Operational GHG emissions are calculated for information purpose without limit value or another requirement. Its philosophy is focused on global energy performance of existing buildings and its calculation method encourages performance sufficiency, energy concept, efficient technical installations, and urban or domestic renewable energies.

Minergie -/A/P aims at improving energy efficiency, comfort, and limiting GHG emissions. Notably, there is no requirement specified for operational GHG emissions. While it establishes GHG emissions limit values for construction in the case of new buildings, no such limits are defined for transformation projects. This limit value for new buildings is higher than the indicative values in SIA 2040 and prSIA 390/1. For example, for new residential buildings, the limit is set at 12.4 $kgCO_{2eq}/m^2.yr$ for the heated floor area, surpassing the indicative value of 9 $kgCO_{2eq}/m^2.yr$ in both SIA 2040 and prSIA 390/1. There is also a limit value for the non-heated floor area as presented in the table below. However, for the Minergie developers, it is driven to have higher limit value for the GHG emissions in these energy-related labels compared to the ECO one that should keep lower limit value for GHG emissions (see below the presentation of ECO).

Table 5: Minergie -/A/P labels (2023 version) limit value of GHG emissions for new residential construction.

	Limit values (Minergie -/-A/-P)	
	Limit value [kg CO_{2eq}/m2*a]	Limit value [kg CO_{2eq}/m2*a]
Reference unit	Per heated surface area (AE)	Per non-heated area (SP-AE)
Multi-family building	12.4	5.5

In all Minergie labels, the contributions of solar installations (solar or photovoltaic) and geothermal probes are included in the limit value, reason why those are “dynamic values”, categorizing them as “burden free” with respect to the compliance to the limit value. Conversely, the embodied GHG emissions of PV panels attributed to the building include 100% of the share of auto-consumption and 40% of the share of electricity exported to the grid. This allocation contradicts the proposed methods in research question F0.4.C, which advocates for the total exclusion of exported electricity from attributions to the building (i.e., assigning 0% of the share associated with exported electricity to the building). Minergie -/A/P’s philosophy incentivizes performance sufficiency, energy concept, efficient technical installations, and a high share of renewable energy (including domestic production). The requirements in detail are:

- the connection to an urban heat network with less than 50% fossil source (measure of “extension and availability of networks”).
- the valorisation of waste heat, classified (measure of “decarbonisation of industry”).
- between 60% to 100% of roof area covered with PV or thermal solar panels (measure of “technical installations”).

- No domestic fossil fuel heat generation, except a cogeneration with electrical efficiency of 35% (measure of "technical installations").

The Minergie-ECO add-on to Minergie -/A/P aims to enhance ecological, human health, and circularity qualities. Regarding GHG emissions from construction, it established more ambitious limit values for both new construction and transformation projects. Specifically, it sets upper and lower limit values for residential new construction at 8 and 10 $kgCO_{2eq}/m^2.yr$ of heated area, the requirement being to be at least below 10 $kgCO_{2eq}/m^2.yr$ ("good enough"), and for best practices below 8 $kgCO_{2eq}/m^2.yr$ ("good to best projects").

Table 6: Minergie-ECO label (2023 version) limit values of GHG emissions for new construction of residential building.

	Target and Limit values (ECO)			
	target value [kg CO_{2eq}/m2*a]	limit value [kg CO_{2eq}/m2*a]	target value [kg CO_{2eq}/m2*a]	limit value [kg CO_{2eq}/m2*a]
Reference unit	Per heated surface area (AE)		Per non-heated area (SP-AE)	
Multi-family building	8.0	10.0	2.8	4.5

For transformation, GHG emissions limit values are specified by the area of renovated or new-built construction elements (e.g., roof, external walls) and technical installation (e.g., sanitary, heat distribution). In terms of measures towards a net zero target, non-european wood-based products must be certified (e.g., PEFC, FSC) if used in the building. Numerous incentives are in line with the listed measures in this report:

In alignment with the measures outlined in this report, Minergie-ECO encourages several incentives to support a net-zero target:

- Encourages the vertical extension of more than 20% m² ERA for building undergoing transformation (measure "Densification").
- Promotes the flexibility and adaptability of building, potentially contributing to the measure "planning sufficiency".
- Encourages transformation by imposing a penalty on new buildings if they entail the deconstruction of existing structures under 60 years old, based on their residual construction GHG emissions (measure "Transform vs New").
- Encourages a reclamation audit and the use 75% volume of reclaimed building elements during deconstruction. Encourages 10 to 20% volume of reused elements in both new construction and transformation. Reused elements are considered "burden-free" regarding GHG emissions in production. Encourages design for disassembly (measure "Reuse").
- Encourages the use of local resources, specifying distances of under 25 km for sand, gravel, stone and earth, and under 100 km for other building products (measure "Suppliers").

Minergie-ECO's philosophy contributes to a more comprehensive approach to reaching a net-zero target compared to Minergie -/A/P. It introduces a more ambitious GHG emissions limit value for construction, and more practical incentives that aid in emission reduction. However, Minergie labels are more permissive than SIA 2040 and prSIA 390/1 on the construction's emissions because the base limit values are higher and don't include solar panels and geothermal probes. Furthermore, there is no defined limit value for GHG emissions during the operational phase. A building that respects the Minergie ECO target value can be in line with SIA 2040 and prSIA 390/1 limit values if the solar panels and geothermal probes have less than 1 $kgCO_{2eq}/m^2.yr$ embodied emissions.

The SNBS label broadens the scope of previous labels by adding economic and social specifications, along with urban planning aspects. Benefiting from the harmonization of Swiss building labels, it seamlessly integrates with MoPEC/MuKEN, CECB/GEAK, Minergie -/A/P and Minergie-ECO. To achieve a minimum grade of 4/6, construction emissions should be lower than the limit value defined by

Minergie-ECO. A grade of 6/6 corresponds to meeting the Minergie-ECO target value for embodied emissions. Unlike other labels, SNBS explicitly encourages low GHG emissions during the operational phase. A grade of 4/6 is achieved with emissions under 7.5 $kgCO_{2eq}/m^2.yr$ for both new construction and transformation, while a maximum grade of 6/6 is obtained with emissions under 2.5 $kgCO_{2eq}/m^2.yr$. For comparison, prSIA 390/1 (revised draft dated 12.02.2024) sets limit values at 2.0 and 4.0 $kgCO_{2eq}/m^2.yr$ for new construction and transformation, with target values of 1.0 and 3.0 $kgCO_{2eq}/m^2.yr$ respectively. Practical incentives within SNBS that participate in achieving net-zero target include:

- Encourages new construction with high land density, contributing to inward urban development. Encourages transformation that increases density with elevation (measure “Densification”).
- Encourages reducing energy reference (heated) area per occupant (measure “Planning sufficiency”).
- Encourages transformation of existing buildings by imposing a penalty on new construction if they are about to deconstruct existing structures based on their residual embodied GHG. This involves a simplified calculation with 8 $kgCO_{2eq}/m^2$ for existing and 10 $kgCO_{2eq}/m^2$ for new construction (measure “Transform vs New”).
- Encourages the compliance with performance sufficiency at least meeting MoPEC/MuKEN 2014 requirements, with Minergie P/A requirements receiving the highest grades (measures “Performance sufficiency” and “Energy concept”).
- Providing similar incentives for reused elements as in Minergie-ECO, except that there is no encouragement to attain a specific volume of reused elements (measure “Reuse”).
- Encourages the regulation and optimisation of operation immediately after commissioning (measure “Technical installations”).

Additionally, the inclusion of social criteria such as “accessibility and facilities” and “participation” can aid in public acceptance and well-being, crucial factors for effective implementation of sufficiency measures that may face social resistance (see section 3.3). It's interesting to observe that in the SNBS documentation, the criteria 222 "Density of occupancy" is not explicitly linked to SDG 13 "Climate Action," although it should be considered in that context.

The SNBS incorporates a broad sustainability perspective and assessing its “climate friendly” or net-zero criteria reveals their weight in obtaining certification. The SNBS 2023 documentation outlines 13 criteria-related criteria under the “Climate protection” (Klimaschutz) transversal theme and 2 more within the “Sobriety and suffiency” transversal theme, totalling 15 criteria aligned with net-zero targets out of a total of 35 SNBS criteria. The certification process involves assigning scores from 0 to 6 to each criterion and calculating a global score (arithmetic mean), with the certification achieved at different ranks:

- “Silver”: a global score of at least 4 and at most 3 insufficient grades (< 4).
- “Gold”: a global score of at least 5 and at most 2 insufficient grades.
- “Platinum”: a global score of at least 5.5 and 0 insufficient grade.

Based on these rules, the weight of climate criteria in obtaining SNBS certification was estimated for worst and best-case scenarios and for each rank. In the worst-case scenario, the authorized number of insufficient grades and minimal grades of 4 are attributed to climate criteria. In the best-case scenario, the maximal grade of 6 is given to all climate-related criteria. In both scenarios, the other criteria are given the lowest possible grade to achieve a given rank. The summarized results are presented in the table below, and detailed data is available in the annex. SNBS Silver and Gold certifications can be achieved with 63% of the possible points over climate criteria, equivalent average climate score of 3.8/6 generally considered insufficient. A Platinum certification can be achieved with 80% of the climate criteria points. Across all scenarios and ranks, climate criteria contribute to 33% to 54% of the tested certifications.

Table 7: SNBS certification scenarios with varying climate criteria score for the Silver, Gold and Platine ranks.

SNBS certification scenarios	Worst-case			Best-case			Max.
	Silver	Gold	Platinum	Silver	Gold	Platinum	
Total score of 15 climate criteria	57	58	72	90	90	90	90
Percentage of max. possible score for climate criteria	63%	63%	80%	100%	100%	100%	100%
Total score of all 35 criteria (max. 210)	139	174	192	167	176	192	210
Weight of climate criteria in the total	41%	33%	38%	54%	51%	47%	43%
Global score (/6)	4.0	5.0	5.5	4.8	5.0	5.5	6.0

Finally, in line with the above-mentioned Minergie-ECO and SNBS labels, the ecobau association supports the sector with a clear methodology and pathway to net-zero for evaluating building materials based on their environmental and health-related properties (ecobau, 2024). The evaluation considers the entire lifecycle of materials, including production, on-site processing, usage, and disposal. Key metrics for assessment include embodied energy and GHG emissions, which are set to follow a linear reduction path from 2026 to achieve net-zero targets as per the “Climate and Innovation Act”.

4 Conclusions

4.1 Measures for GHG reduction

The identification and assessment of measures for GHG reduction at building scale highlighted the high diversity of possibilities that are available to the stakeholders involved in the construction and renovation of buildings to reduce GHG emissions. Construction works are always very much tight to specific site conditions, regulatory frameworks, specific owner and user preferences, building typology, and context conditions of where and when they take place. These are the recurrent limitations of achieving the full potential of the identified measures. Nonetheless, each measure has multiple levers to tackle emissions reduction while complying with the specific limitations and it is essential to make these levers a priority for all stakeholders involved in the design of buildings and in setting the necessary enabling framework conditions.

Table 8 summarizes the identified measures for GHG reduction at building scale described in the frame of this report. The potential reduction values refer to the application of the measure to a reference multi-family house (MFH), specific conditions and requirements might differ from this average potential value. Recommendations and limitations are based on the case studies and examples presented in this report.

Table 8: Summary of identified measures for GHG reduction at building scale, potential reduction quantified on a reference new multi-family house archetype.

List of measures	Potential reduction	Description	Recommendations	Limitations
Framework conditions				
Densification (e.g. additional floors on existing buildings)	15%	Extension of existing buildings by adding storeys or repurposing unutilized surfaces	Planning of new surfaces on already built areas and prioritize light construction (i.e. timber) and follow existing structural concept for additional storeys	Strengthening of existing structure is usually necessary (10-15% of total GHG embodied emissions)
Planning sufficiency (e.g. reduced floor area per inhabitant)	8% with current indicators 50% for $kgCO_{2eq}$/inhabitant	Reduce demand of surface per inhabitant Occupancy regulations	Design of buildings with lower surfaces per inhabitant. Implement limits and incentives in reduced surface per inhabitant. Include number of inhabitants in the GHG indicators of buildings.	Reduced leverage on users' preferences
Extension and availability of networks	6% (in case of existing fossil-fuel supply, higher reduction possible)	Increasing availability of renewable energy networks	Design of buildings should consider current and future development of energy networks on site	Limited technical feasibility of extension. Design of buildings is limited to specific site supply.
Decarbonisation of the industry	50% in 2050	Future developments in emissions' reduction of supply chain of energy and materials	This measure is informative on the potential future of the supply but can't be implemented today	High uncertainties in future developments. Waiting for this measure to happen will hinder the capability to meet GHG reduction pathways.

List of measures	Potential reduction	Description	Recommendations	Limitations
Definition of objectives				
Transform vs. New	48%	Opting for the renovation of the existing building instead of demolishing and building new	Always consider the preservation of the existing buildings Low-carbon materials and renewable energies are to be prioritized for the renovation	Structural conditions might hinder the fulfilment of current regulations
Performance sufficiency [e.g. reduced energy demand]	5% (50% reduction in heating consumptio n – in case of fossil supply higher reduction potential)	Defining additional goals for reduced energy demand in operation (e.g.: Minergie-P/-A)	Early definition of operational performance goals. Fulfil higher requirements (e.g. insulation) with low carbon materials.	Standard requirements might hinder the full potential of this measure. Higher performance in operation comes at a cost in embodied emissions
Choice of site [e.g. favourable sites for climate conditions]	15%	Opting for favourable sites for energy networks availability, soil conditions, and renewable energy implementation	If choice of site is not an option, adapt planning of buildings based on site conditions	Site is usually given and not a choice
Preliminary study				
Size and compactness	18%	Reduce ratio of envelope surface to energy reference area	Implement a target/limit in envelope factor to incentivize compact buildings	Natural lighting and ventilation might be affected by an increased compactness
Reduce underground	7%	Avoid or reduce underground construction	Evaluate the construction of overground alternatives to meet the necessary function requirements. If underground construction can't	Minimum requirements of parking space Limited overground space availability

List of measures	Potential reduction	Description	Recommendations	Limitations
			be avoided, it must be limited to below the overground building's footprint	
Reduce/optimize window to wall ratio	3%	Optimize ratio to reduce amount of glass while optimizing heat gains and heat losses and natural lighting	Include embodied, operational, and lighting criteria in the design. Design optimal ratio for reduction of GHG emissions	Existing buildings have limited flexibility in the aperture proportion Site specific conditions can limit the optimal ratio
Re-use	12% (highly depends on the share and type of reused elements)	Include and increase the ratio of reused elements in the design of buildings	Prioritize elements with high mass and high manufacturing emissions to be reused	Compatibility with current standards and norms Logistic obstacles in the scalability of this measure Limited availability of reused elements in the current context
Energy concept	8%	Early definition of an energy concept including site specific conditions, energy networks availability, and potential synergies with neighbouring buildings	Identify potential and synergies of the site Include energy provider constraints	Integrated design in subsequent design phases and in operation

List of measures	Potential reduction	Description	Recommendations	Limitations
Project phase				
Choice and dimensioning of materials [structural elements]	7%	Shift to low carbon materials for the structural elements of the buildings Reduce complexity and opt for low spans	Prioritize low carbon and/or biobased materials Simple and linear structural concept	User requirements, owner preference, regulations, and costs
Choice and dimensioning of materials [non-structural]	12%	Shift to low carbon materials for the insulation and finishings	Prioritize low carbon and/or biobased materials	Comfort requirements, owner preference, regulations, and costs
Choice and dimensioning of materials [preparatory works]	5%	Reduce complexity of excavation and shielding works	Simple stepped excavations are prioritized whenever possible	Site specific conditions might not allow simple preparatory works
Technical installations [reduce/ avoid]	11%	Technical installations are usually carbon intensive, reducing the complexity of the systems and/or avoiding specific installations	Prioritize passive design measures to reduce and avoid complex technical installations	Comfort requirements, owner preference, regulations, and costs
Technical installations [renewable energies]	5% (in case of existing fossil supply, higher reduction possible)	Implementation of renewable energies-based installations	Prioritize renewable energy on site and off site for the supply of energy of buildings	Site specific conditions
Technical installations [efficiency]	3%	Select high efficiency installations	Efficiency of installations must be maximised to increase the carbon payback time	Costs

4.2 Strategies for net-zero individual buildings

Strategies for net-zero individual buildings are identified, in the frame of this project, using a parametric model of a reference archetype. The reference archetype is necessary to allow a fair comparison of resulting emissions reductions when applying measures to the building and when combining measures into strategies. The reference archetypes are identified with building characteristics of case studies and statistical information on average building size and construction to best represent an average multi-family house and an average single-family house. Single measures are combined along three main strategies, reflecting the three commonly used pillars in sustainable development literature. The first strategy tackles sufficiency principles or “avoid” concept by combining measures that reduce the demand for surface, elements, materials, or energy. Overall, this strategy can potentially reduce the GHG emissions of a reference multi-family house by 50% and 27% in a reference single-family house. The second strategy is based on the consistency principle or “shift” concept by combining measures that make a consistent use of low carbon and fossil-free options such as extensive use of biobased materials and increase share of renewable energies. This strategy achieves a 35% reduction of GHG emissions from both reference cases and potentially increases GWP-biogenic uptake by up to 32% of the reference multi-family house initial GHG emissions and 50% of the reference single-family house initial emissions. The third strategy focuses on efficiency principles or “improve” concept by combining measures that improve existing practices and increase efficiency of implemented systems. This strategy achieves a 25% decrease in GHG emissions in a reference MFH and 12% in a reference SFH with current technologies (excluding the future decarbonisation of the industry).

If all measures are combined, a 72% reduction in GHG emissions from the reference MFH and 50% in a SFH can be achieved with GWP-biogenic uptake matching the level of emissions if considered permanent with legally binding settlements. The same reference building with combined measures built in 2050 (assuming a decrease in supply chain emissions) could further decrease its emissions by ca. 50%.

4.3 Feasibility

The feasibility assessment conducted in the frame of this project is based on quantitative and qualitative data of the studied references for GHG reduction measures at building scale and experience in the sector of the project partners. Three dimensions are evaluated: economic, social, and technical. For each dimension, indicators have been chosen to represent the specific levers and obstacles characterizing the Swiss building sector. From an economic perspective, costs (now, mid-term, and long-term) and employment effects and economic growth are used. In the social dimension, co-benefits, and public acceptance and in the technical dimension four indicators are used: scalability, maturity, simplicity, and absence of risk. The assessment, based on a grading system and a standard weighted sum method, highlighted both levels of enabling and barriers conditions of each indicator for every measure. Results show that strong agreement on barriers are found in the framework conditions of a project for costs of extending energy networks and decarbonizing the industry, public acceptance of planning sufficiency, and technical simplicity of decarbonizing the industry. Technical indicators suggest enabling conditions to scale up measures quickly and simply in early design phases (e.g., compactness, window to wall ratio, reduce underground floors). Project phase measures (choice and dimensioning of building elements and technical installations) score high in the maturity level but medium-low in the simplicity of implementations and are generally associated with higher costs. In general, the feasibility assessment highlighted that the majority of the measures are ready to be implemented with early design phases measures presented with more enabling conditions overall while framework conditions measures facing more barriers across all indicators.

The three strategies are also evaluated from a feasibility perspective based on the results of the single measures they include. The “avoid” strategy is faced with implementation barriers from an economic (employment effect and economic growth) and social (public acceptance) perspective but enabling conditions from the technical side. The “shift” strategy finds barriers in the costs of the measures it includes as well as in the simplicity of implementation but high social acceptance and co-benefits. Finally, the “improve” strategy find strong difficulties in the deployment of framework condition measures (extension of energy networks) from an economic and technical perspective.

4.4 Building standards and labels assessment and comparison

In terms of scope, indicators and data and limit values for GHG emissions, SIA 2032, 2040 and prSIA 390/1 standards and technical bulletins are consistent together to assess a building in a full life cycle-based approach with limit and target values to comply with in terms of GHG emissions.

The analysed other standards and labels do not follow a full life cycle approach, and the requirements differ from one to another. This can be explained by the context of use of each label or standard, e.g., a GEAK/CECB is not intended to report a full LCA, as of to date, but rather inform the building owner about its building energy performance and associated GHG emissions. For better comparability, harmonisation should be done between LCA-based standards/bulletins (SIA standards) and the labels (e.g., Minergie) for specific rules like the allocation of PV electricity between the building and the grid.

Concerning the measures, labels require or encourage practical, specific measures — from urban planning and objective definition to supplier selection in tenders. Some measures that are listed in the SIA standards and technical bulletins, although indirectly needed for meeting requirements, are not explicitly promoted in the labels. These include optimizing size and compactness, minimizing underground constructions, ensuring optimal window-to-wall ratios, and implementing a simple load-bearing structure with adapted spans (i.e. optimal dimensioning of the structure). Notably no measures related to carbon storage or NET are required nor recommended.

Only the prSIA 390/1:2023 starts addressing net-zero target-aligned quantitative objectives but only with informative appendixes. Existing labels, particularly more environmentally focused Minergie-ECO and SNBS, could better align with net-zero targets by adopting consistent life cycle GHG emissions limit values based on the national carbon budget for buildings in the coming years. In the case of SNBS, the broader sustainability scope lessens the weight of net-zero aligned measures. Certification rules should be more stringent in this regard to align the label with net-zero targets. Incorporating criteria that explicitly promote the four missing measures listed earlier could raise awareness among practitioners about these key emissions reduction levers, facilitating the implementation of low carbon buildings and eventually build towards net-zero targets. Overall, the combination of a lack of sufficient requirement regarding GHG emissions reductions at construction and operation, and the lack of measures of carbon storage or NET outline a non-alignment of the studied labels with net-zero targets.

5 Outlook and next steps

The results presented in this report and the ongoing efforts of the team members aim to contribute to a comprehensive understanding of the strategies employed for reducing GHG emissions, with a particular emphasis on achieving a net-zero outcome in the Swiss building area. Nevertheless, further work is needed to increase robustness of the results, be able to better generalize results, and include more innovative and alternative measures and solutions.

Material level and data availability

The data used to quantify life cycle GHG emissions in this work are limited to the latest version of the KBOB 2009/1:2022. The availability, comprehensiveness, and financing of data at material level was not questioned further in the frame of this report but it is integral part of the robustness of the results presented. The ecobau standards[10] aim to standardize the evaluation of construction materials also from the emissions' perspective and to involve material manufacturers in the process, which is critical to achieve the net-zero goals.

[10] https://www.ecobau.ch/de/home

Results and building case studies

As mentioned throughout the report, and as well-known from practitioners in the sector, every building is different, and no construction site is identical to another. For this reason, generalizing results calculated on specific building types and case studies is a hard task. To improve the robustness and generalization of the results presented in this report, more data and case studies need to be assessed. Currently, the lack of available GHG emissions calculations of real buildings (especially non-residential buildings) conducted with comparable approaches and databases is an important limitation. The implementation of a standardized template for reporting of emissions of buildings coupled with a mandatory requirement to report such emissions would strongly improve the availability and robustness of data to further exemplify and conduct generalized assessments of impact of measures at building scale.

Feasibility Assessment and scalability

The results of the feasibility assessment in this report are strongly based on the expertise and projects available of the team members of F2. As the implementation of such measures is a complex and long process, it is recommended to expand the feasibility assessment to the whole range of stakeholders involved in the process. This would increase the robustness of the results.

To create the right environment for the measures and strategies to be quickly scaled-up, establishing a solid foundation is essential. This includes creating comprehensive regulations and standards to enforce and guide the implementation of measures and strategies. Additionally, education and training programs for building industry professionals are critical. Continuous professional development programs can ensure that architects, engineers, and builders are equipped with the necessary knowledge and skills in the net-zero practices. Public awareness and engagement are also crucial. Raising public awareness about the needs, challenges, and opportunities of measures and strategies and engaging communities through information campaigns and participatory planning processes can enhance public acceptance and support for net-zero initiatives.

Furthermore, high-quality and comprehensive data is critical for the scalability of net-zero strategies. Detailed lifecycle inventories for building materials and processes is necessary to accurately evaluate the environmental impact of building projects. This data should be regularly updated to reflect advancements in materials and technologies. Collecting and analysing data on building performance, including energy consumption, emissions, and indoor environmental quality, can help identify areas of improvement and validate the effectiveness of implemented measures. Establishing benchmarks based on successful projects can provide valuable reference points, while sharing best practices and case studies can help stakeholders understand the practical applications and benefits of various measures and strategies. Finally, tools are needed to support the planning, implementation, and monitoring of net-zero practices. Decision support systems can assist stakeholders in evaluating different strategies and making informed decisions based on comprehensive data analysis and scenario planning. Robust monitoring and reporting systems can ensure transparency and accountability in the implementation of net-zero strategies.

To scale up net-zero strategies, several resources are necessary. Governments and financial institutions should provide financial incentives such as grants, subsidies, and low-interest loans to encourage the adoption of net-zero strategies. These incentives can help offset the higher upfront costs associated with some measures. Providing technical assistance to building professionals and developers can help overcome barriers to the adoption of new technologies and practices. This support can include consultancy services, technical guidelines, and access to expert networks. Creating platforms for collaboration among stakeholders, including government agencies, industry associations, research institutions, and civil society, can facilitate knowledge exchange, innovation, and coordinated efforts towards net-zero goals.

Strategies for net-zero buildings

As highlighted throughout this report, no single measure is able to bring current building practices to net-zero buildings, unless the material and energy supply chain is completely decarbonized. In the same lines, multiple combinations of measures are possible to reduce GHG emissions resulting in multiple possible strategies. While the best result would be achieved by combining all measures and implementing the maximum efforts over all phases and from all stakeholders, it is clear that priorities have to be set from a political, societal, and economic perspective to define viable strategies for net-zero buildings. The strategies presented in this report reflect the point of view of the project partners in the possible pathways and priorities the industry should/could take. A common understanding of strategies could be achieved by conducting workshops with all representative stakeholders involved in the building sector.

A net-zero outcome at building scale can be achieved with combined efforts for GHG reduction and by accounting for GWP-biogenic uptake as seen in Figure 33 and Figure 34. The potential and implications of GWP-biogenic uptake on the climate is discussed in F0, considering its potential until 2050 and uncertainties of subsequent release beyond 2050 in a whole life-cycle perspective. At building scale, the primary benefit of biogenic materials is in their substitution effect of replacing carbon-intensive materials with low carbon alternatives. From an overall perspective, maximizing biogenic uptake should remain a goal for attaining the climate targets per 2050 and beyond.

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7 Appendix

7.1 Building types

In Switzerland, 75% of the building stock is residential, of which 52% are single-family houses (Ostermeyer *et al.*, 2017), though recent trends show a substantial increase in flow of investments in multi-family houses. According to (Pongelli *et al.*, 2023), based on data from the GEAK certification schemes, the median ERA of MFH of the last decade is circa 1000m^2 with an envelope factor of 1.3, 3 floors above ground, heavy construction type, and a heat pump as primary energy source. It must be noted, that depending on the location (dense urban area or rural) these median values can vary, generally with higher, bigger, and more compact buildings in dense urban areas and smaller and less compact buildings in less dense areas.

The following exemplary building types have been collected and evaluated by the partners of this project. They represent case studies, built or in the planning phase, with common practices or innovative characteristics. The buildings have been anonymised.

Residential multi-family house [new construction – reference archetype]

Energy reference area	2550
Number of units	25
Envelope factor	1.5
Window-to-wall ratio	30%
Number of floors above ground	5
Number of floors below ground – not heated	1 (510m2)
Installations	Heat pump - Photovoltaics
Main structural material	Concrete
Type of preparatory works	Pilling and excavation shielding

Standard	*Size and description*	*Emissions kg CO_{2eq}/m2SRE*	*GWP-biogenic kg CO_{2eq}/m2SRE*
Preparatory works	Excavation shielding (berlin walls) / pilling foundation	63	/
Underground elements	20cm concrete floor / 25cm concrete walls with XPS	83.8	/
Envelope elements	20cm concrete walls + EPS	273.6	/

	Wood-metal and triple glazing 25cm concrete roof + EPS		
Interior elements and balconies	15cm brick load-bearing walls 25cm concrete slabs	311.4	/
Installations	Heat Pump, floor heating distribution + general equipment	116.6	/
Total		**848.5**	**/**
Operational emissions (60 years)		**318**	

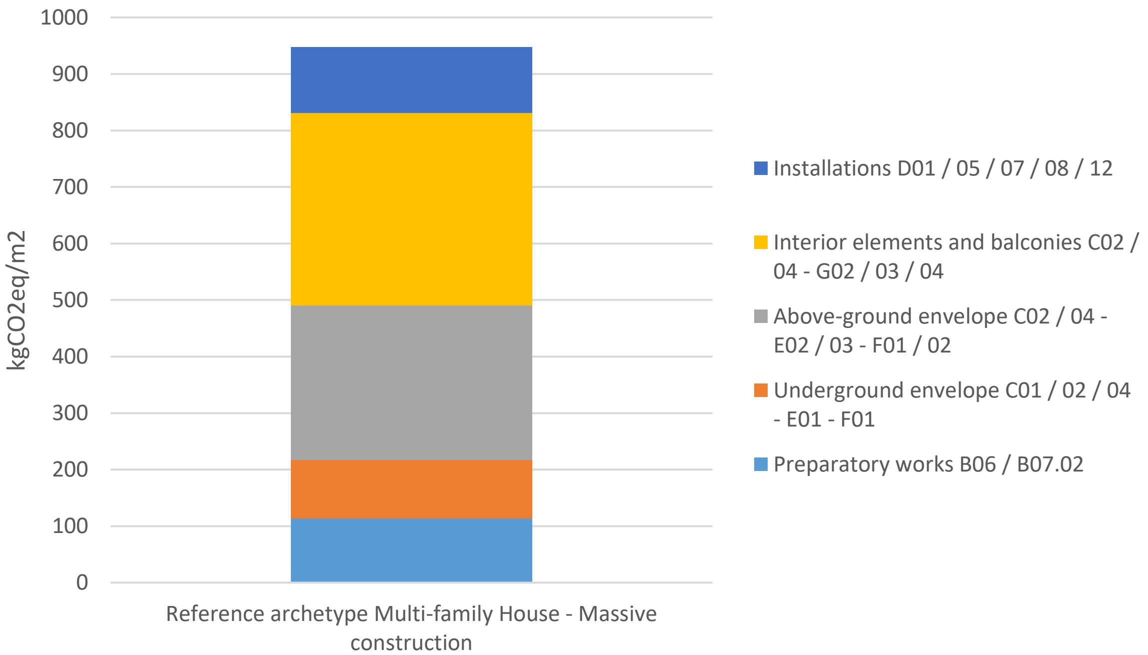

Figure 40: GHG embodied emissions of a residential multi-family house building type (reference archetype used throughout the report)

Residential multi-family house [new construction – bio-based]

Energy reference area	890
Number of units	6
Envelope factor	1.4
Window-to-wall ratio	25%
Number of floors above ground	3
Number of floors below ground – not heated	1 (500m2)
Installations	Heat pump - geothermal / Photovoltaics

Main structural material		Straw-wood	
Type of preparatory works		Pilling and stepped excavation	
Advanced	*Size and description*	*Emissions kg CO_{2eq}/m2SRE*	*GWP-biogenic kg CO_{2eq}/m2SRE*
Preparatory works	Simple excavation / pilling foundation	1.10	/
Underground elements	20cm concrete floor / 25cm concrete walls with rockwool	154.11	/
Envelope elements	Straw walls Wood triple glazing Wood roof frame with straw/gramitherm insulation	151.21	302.17
Interior elements and balconies	Wood frames load-bearing walls 18cm timber slabs	215.47	225.87
Installations	Heat Pump, floor heating distribution + general equipment	173.77	/
Total		**695.66**	**528.04**

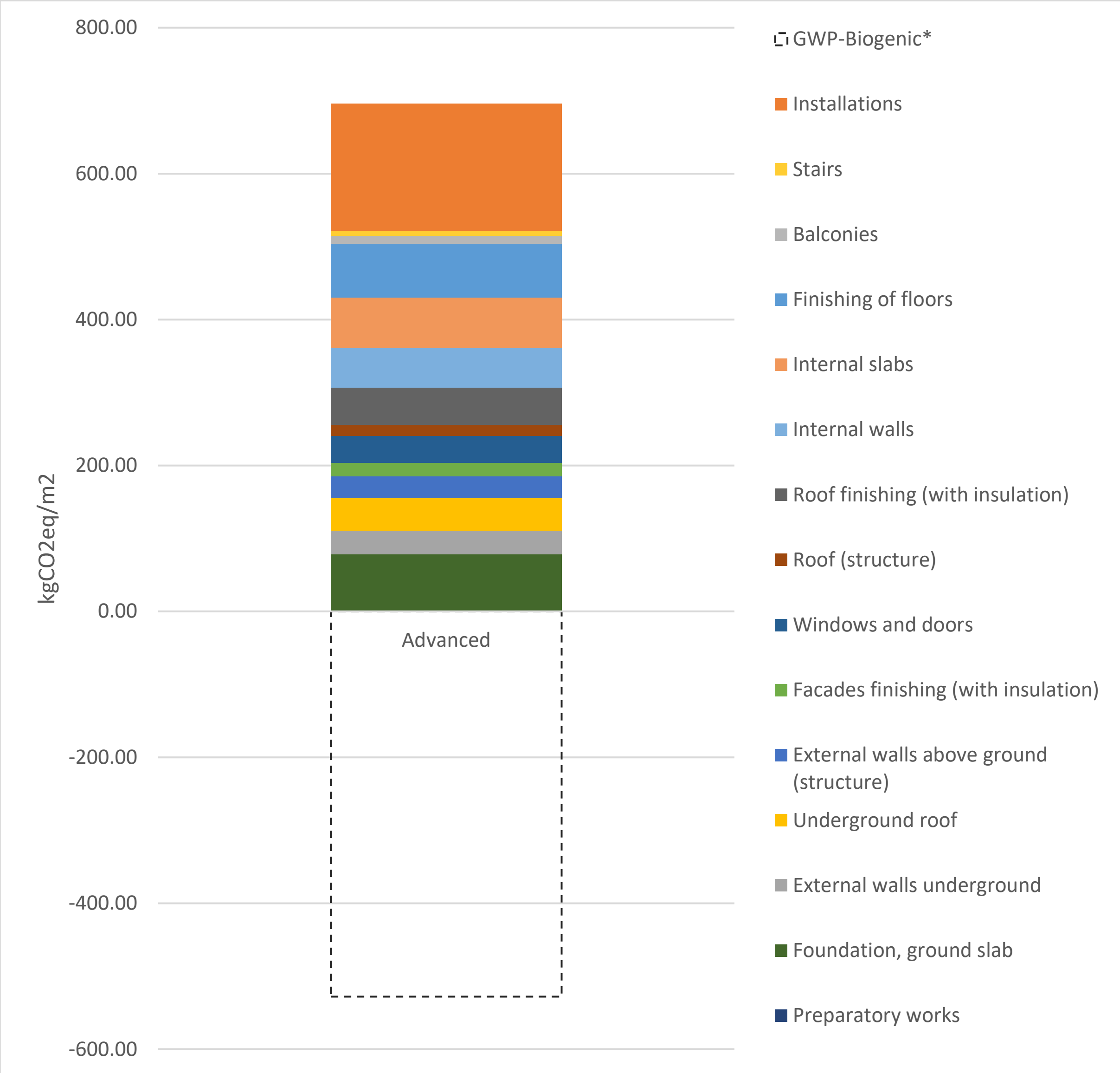

Figure 41: GHG embodied emissions of a residential multi-family house building type with high share of bio-based materials. * GWP-biogenic uptake can be considered negative only if permanent storage is legally binding.

Residential single-family house [new construction - standard]

Energy reference area	373
Number of units	3 (still considered a single-family house in the current context)
Envelope factor	1.9
Window-to-wall ratio	16%
Number of floors above ground	2
Number of floors below ground – not heated	1 (122m2)
Installations	Heat pump - geothermal / Photovoltaics

Main structural material		Concrete	
Type of preparatory works		Pilling and stepped excavation	
Standard	*Size and description*	*Emissions kg CO_{2eq}/m2SRE*	*GWP-biogenic kg CO_{2eq}/m2SRE*
Preparatory works	Simple excavation / pilling foundation	6.85	/
Underground elements	20cm concrete floor / 25cm concrete walls with XPS	90.65	/
Envelope elements	20cm concrete walls + EPS PVC triple glazing 25cm concrete roof + EPS	317.98	5.92
Interior elements and balconies	20cm concrete load-bearing walls 25cm concrete slabs	239.27	5.84
Installations	Heat Pump, floor heating distribution + general equipment	114.02	/
Total		**768.77**	**11.75**

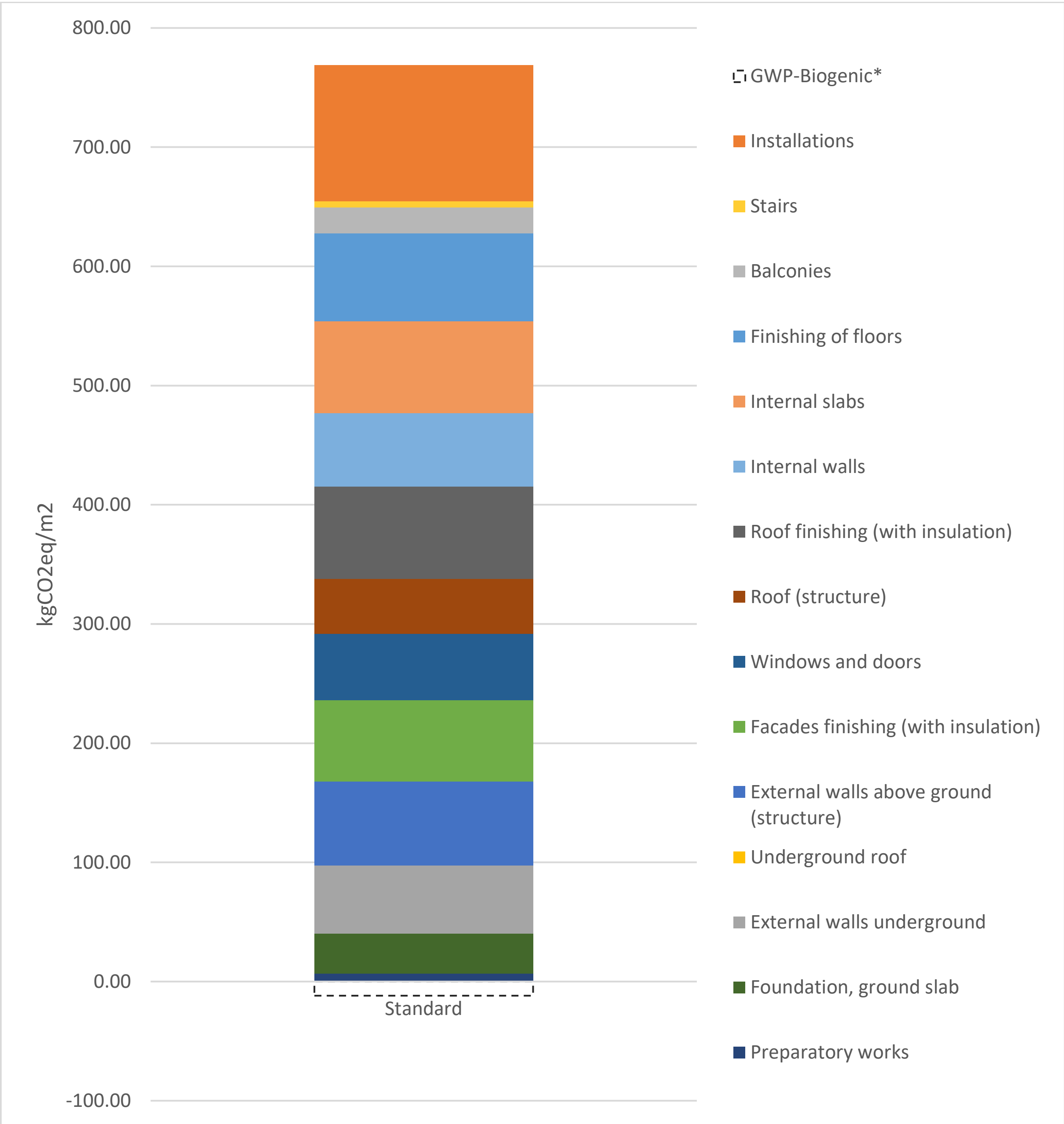

Figure 42: GHG embodied emissions of a residential single-family house building type. * GWP-biogenic uptake can be considered negative only if permanent storage is legally binding.

Residential single-family house [new construction – bio-based]

Energy reference area		409	
Number of units		3	
Envelope factor		1.9	
Window-to-wall ratio		16%	
Number of floors above ground		2	
Number of floors below ground – not heated		1 (122m2)	
Installations		Heat pump - geothermal / Photovoltaics	
Main structural material		Straw-wood	
Type of preparatory works		Pilling and stepped excavation	
Advanced	*Size and description*	*Emissions kg CO_{2eq}/m2SRE*	*GWP-biogenic kg CO_{2eq}/m2SRE*
Preparatory works	Simple excavation / pilling foundation	5.26	/
Underground elements	20cm concrete floor / 25cm concrete walls with rockwool	68.88	5.99
Envelope elements	Straw walls Wood triple glazing Wood roof frame with straw/gramitherm insulation	114.61	234.92
Interior elements and balconies	Wood frames load-bearing walls 18cm timber slabs	77.16	132.90
Installations	Heat Pump, floor heating distribution + general equipment	98.62	/
Total		**368.51**	**374.39**

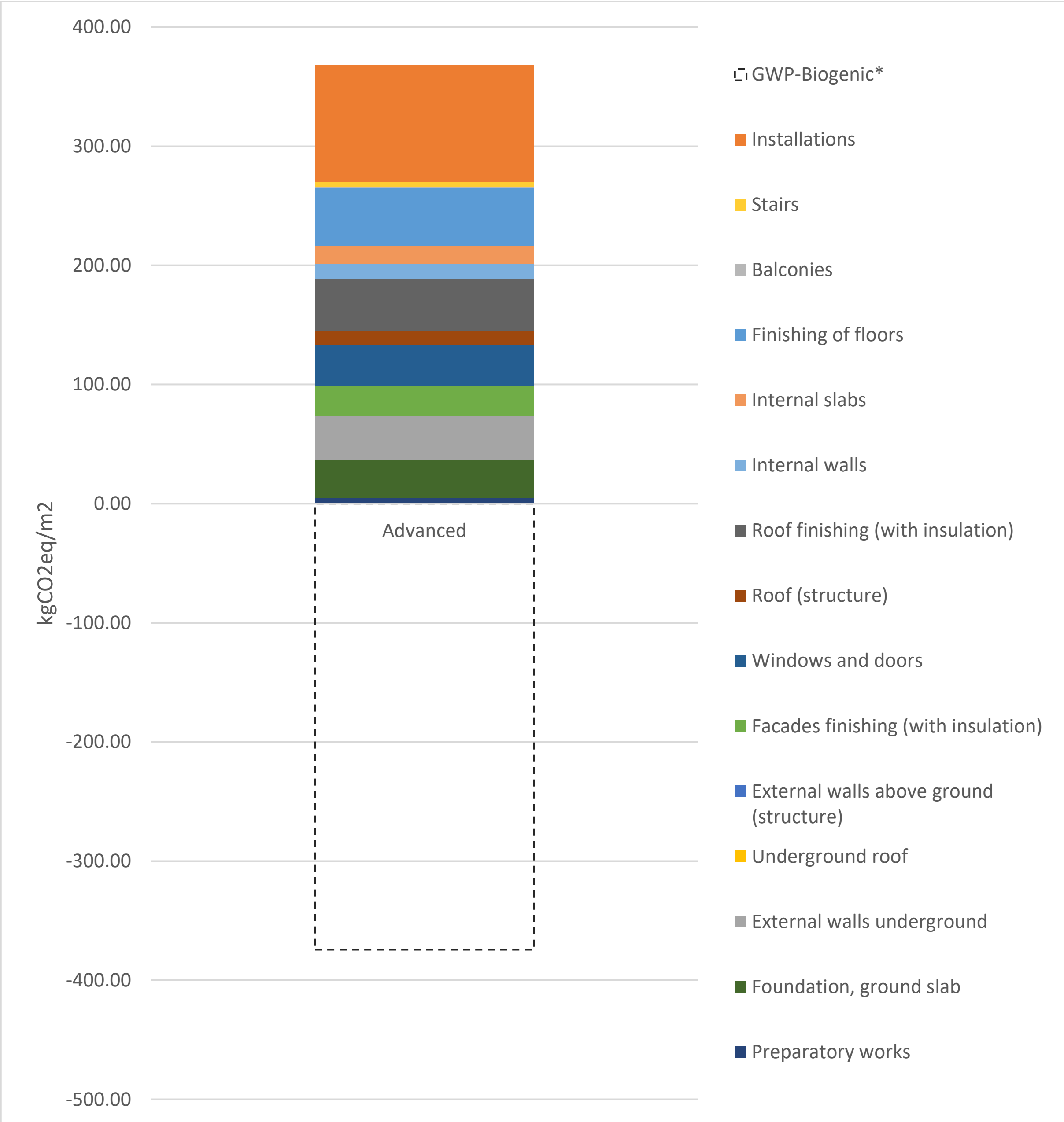

Figure 43: GHG embodied emissions of a residential single-family house building type with high share of bio-based materials. * GWP-biogenic uptake can be considered negative only if permanent storage is legally binding.

Residential multi-family house [renovation - standard]

Energy reference area		1238 Standard / 1243 Realistic / 1267 Advanced	
Construction year		1976	
Envelope factor		1.1	
Window-to-wall ratio		30%	
Number of floors above ground		4	
Number of floors below ground – not heated		1 (122m2)	
Installations		Oil boiler replacement	
Main structural material		Concrete	
Type of preparatory works		/	
Standard	*Size and description*	*Emissions kg CO_{2eq}/m2SRE*	*GWP-biogenic kg CO_{2eq}/m2SRE*
Preparatory works	Simple excavation	0.03	/
Underground elements	18cm XPS	11.08	/
Envelope elements	EPS 14cm PVC triple glazing EPS 16cm	71.28	/
Interior elements and balconies	Plaster boards ceilings with rockwool EPS in the balconies	18.53	0.17
Installations	Boiler, floor heating distribution + general equipment	83.94	/
Total		**184.86**	**0.17**

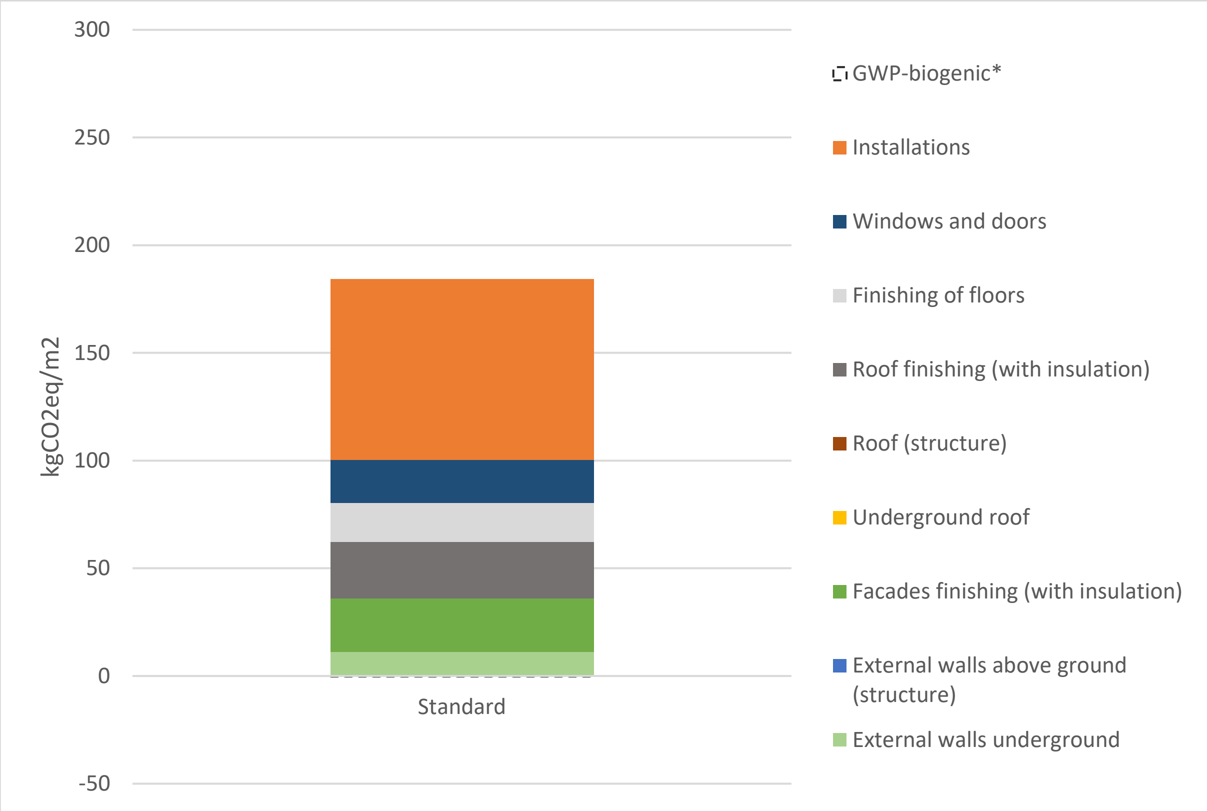

Figure 44: GHG embodied emissions of a renovation of residential multi-family house building type. * GWP-biogenic uptake can be considered negative only if permanent storage is legally binding.

Residential multi-family house [renovation – bio-based]

Energy reference area		1267	
Construction year		1976	
Envelope factor		1.1	
Window-to-wall ratio		30%	
Number of floors above ground		4	
Number of floors below ground – not heated		1 (122m2)	
Installations		Oil boiler replacement	
Main structural material		Concrete	
Type of preparatory works		/	
Advanced	*Size and description*	*Emissions kg CO_{2eq}/m2SRE*	*GWP-biogenic kg CO_{2eq}/m2SRE*
Preparatory works	Simple excavation	0.03	/
Underground elements	18cm XPS	10.83	/
Envelope elements	Gramitherm 8cm Wood triple glazing	48.66	44.27

	Wood fibres 8cm +Thermohanf 16cm		
Interior elements and balconies	wood ceilings with rockwool	18.01	11.22
	Thermohanf in the balconies		
Installations	Heat Pump, floor heating distribution + general equipment	83.94	/
Total		**161.46**	**55.49**

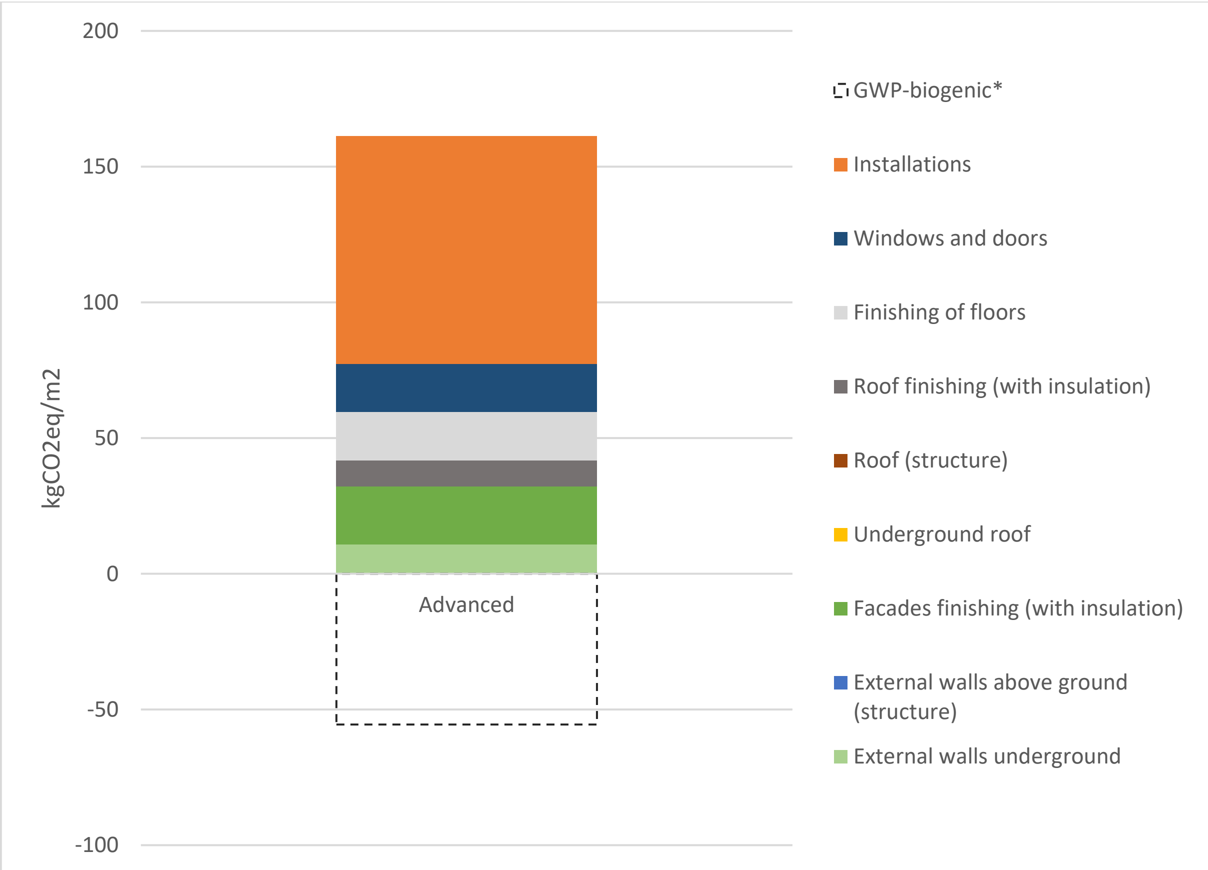

Figure 45: GHG embodied emissions of a renovation of residential multi-family house building type with high share of bio-based materials.
* GWP-biogenic uptake can be considered negative only if permanent storage is legally binding.

Residential single-family house [renovation - standard]

Energy reference area		170	
Construction year		1974	
Envelope factor		2.58	
Window-to-wall ratio		20 %	
Number of floors above ground		2	
Number of floors below ground – not heated		1 (technical)	
Installations		Wood heater	
Main structural material		Concrete	
Type of preparatory works		/	
Standard	*Size and description*	*Emissions kg CO_{2eq}/m2SRE*	*GWP-biogenic kg CO_{2eq}/m2SRE*
Preparatory works	Simple excavation	0.23	/
Underground elements	15cm XPS	34.86	/
Envelope elements	EPS 10cm PVC triple glazing Glass wool on roof 12 cm	134.65	18.09
Interior elements and balconies	Plaster boards ceilings with rockwool	15.96	0.22
Installations	Boiler + general equipment	83.94	/
Total		**269.64**	**18.31**

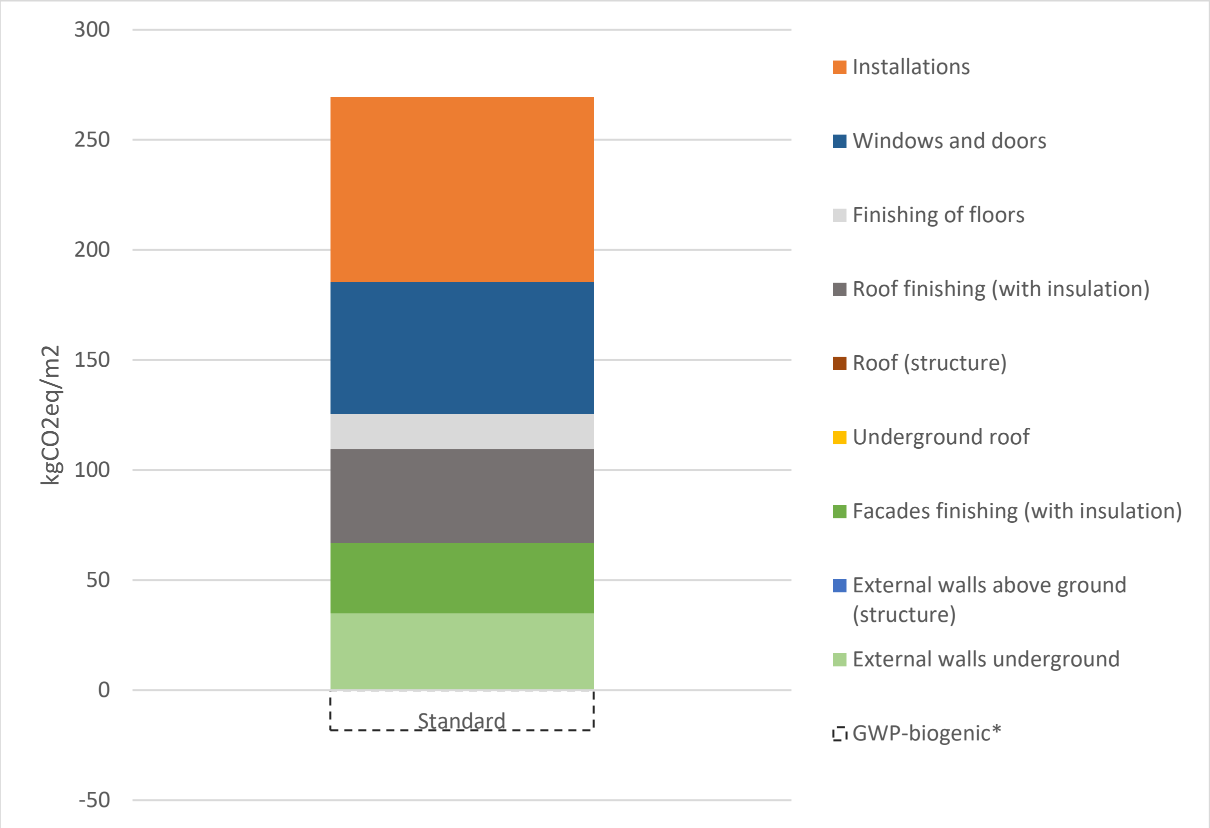

Figure 46: GHG embodied emissions of a renovation of residential single-family house building type. * GWP-biogenic uptake can be considered negative only if permanent storage is legally binding.

Residential single-family house [renovation – bio-based]

Energy reference area	176
Construction year	1974
Envelope factor	2.58
Window-to-wall ratio	20 %
Number of floors above ground	2
Number of floors below ground – not heated	1 (technical)
Installations	Wood heater
Main structural material	Concrete
Type of preparatory works	/

Advanced	*Size and description*	*Emissions kg CO_{2eq}/m2SRE*	*GWP-biogenic kg CO_{2eq}/m2SRE*
Preparatory works	Simple excavation	0.22	/
Underground elements	15cm XPS	34.27	/

Envelope elements	Wood frame with gramitherm and woodwool Wood triple glazing Thermohanf on roof	64.59	89.41
Interior elements and balconies	Wood boards ceilings with Gramitherm	2.96	11.62
Installations	Boiler + general equipment	83.94	/
Total		**185.98**	**106.71**

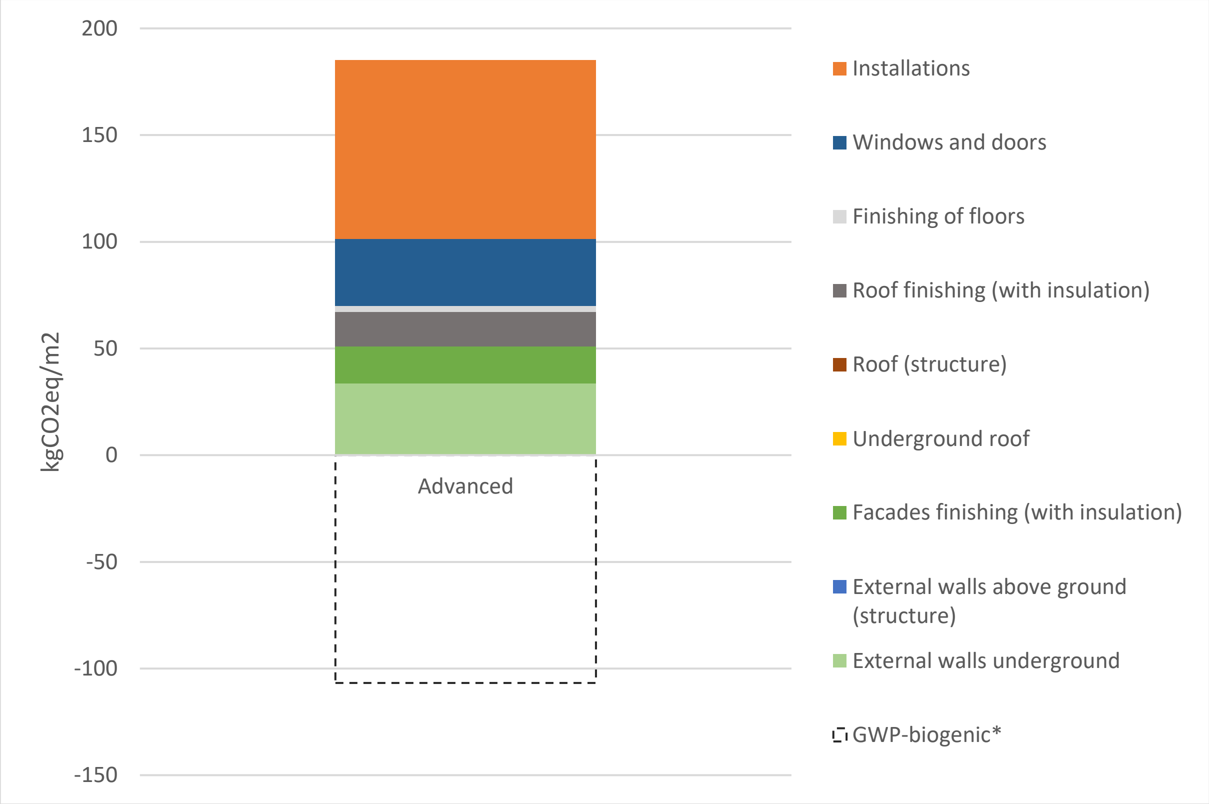

Figure 47: GHG embodied emissions of a renovation of residential single-family house building type with high share of bio-based materials.
* GWP-biogenic uptake can be considered negative only if permanent storage is legally binding.

Primeo Energy Cosmos [Reuse-LCA]

The Primeo Energy Cosmos case study is shown in the section 3.1.11 about Reuse.

Energy reference area	724
Construction year	2022
Envelope factor	1.48
Window-to-wall ratio	35 %
Number of floors above ground	3
Number of floors below ground – not heated	0
Installations	Urban heat
Main structural material	Wood
Type of preparatory works	/

Reuse elements	*Size and description*	*Emissions kg CO_{2eq}/m2SRE*	*GWP-biogenic kg CO_{2eq}/m2SRE*
Preparatory works	Simple excavation	0.03	/
Underground elements	12cm PIR	38.09	/
Envelope elements	Rockwool panel 20cm in exterior wall PVC triple glazing Rockwool panel 20cm in roof External steel structure and cladding	404.08	123.31
Interior elements and balconies	Plaster panels Wood wool Wood cladding	17.80	24.55
Installations	Boiler, floor heating distribution + general equipment	122.20	/
Total		**582.20**	**147.86**
Variant "All New"	Size and description	Emissions kg CO_{2eq}/m2SRE	GWP-biogenic kg CO_{2eq}/m2SRE
Preparatory works	Simple excavation	0.03	/
Underground elements	12cm PIR	38.12	/
Envelope elements	Rockwool panel 20cm in exterior wall PVC triple glazing	443.13	123.31

	Rockwool panel 20cm in roof External steel structure and cladding		
Interior elements and balconies	Plaster panels Wood wool Wood cladding	24.79	24.55
Installations	Boiler, floor heating distribution + general equipment	128.88	/
Total		**634.93**	**147.86**

Reused component	Dismantling	Storage	Losses	Modification	Transport (km)		GHG emissions (kg CO_{2eq}/kg)		
	A1	A3	A3	A3	A2	A4	Reuse A1-A4	New eq. A1-A4	EoL C1-C4
Steel bars	Diesel	**Ext.**	**74%**	**Preparation**	**60**	**5**	0.263	0.740	0.007
Stone cladding	**No, surplus**	**No storage**	**48%**	**No**	**10**	**20**	0.248	0.792	0.231
HPL panels	Electric	Int., 5.5 m^3, 1.2 year	10%	**No**	**87**	**129**	0.174	2.888	1.086
Wood cladding	Electric	Int., 0.5 m^3, 1.2 year	10%	**Oiling,** 22kg/m²	**14**	**2**	0.056	0.093	0.039
Toilet doors	**By hand**	Int., 2.1 m^3, 1.2 year	0%	*Grinding, painting, handles assembling (not accounted)*	**11**	**8**	0.045	1.089	0.216
OSB panels	Electric	No data	10%	*Cutting (not accounted)*	50	**2**	0.023	0.494	0.080
Ceramic plates	**No, surplus**	Int., 0.5 m^3, 1.2 year	10%	**No**	**102**	**5**	0.048	0.792	0.231
MDF panels	Electric	No data	**0%**	*Cutting (not accounted)*	50	**2**	0.033	0.818	0.100
Stone slabs	Electric	**Int., 0.7 m², 0.5 year**	10%	**No**	**11.5**	**11**	0.013	0.152	0.006
PV panels	Electric	**Int.,** 0.5 m^3**, 0.75 year**	0%	No	50	**5**	0.012	9.471	0.000
Dressing	No, surplus	No	10%	*Manufacturing (not accounted)*	**0**	**5**	0.022	0.865	0.100
WC/urinals	Electric	Int., 9.7 m^3, 1.2 year	0%	**No**	**3.7**	**5**	0.004	2.462	0.014
Washtub	Electric	**No storage**	0%	**No**	**0**	**10**	0.002	4.499	0.007
Kitchen	Electric	**No storage**	0%	**No**	**0**	**10**	0.002	10.889	0.204
Sinks	Electric	**No storage**	0%	**No**	**0**	**10**	0.002	2.348	0.013

Table 9: Description of the reused elements and associated activities in the Primeo Energy Cosmos case study

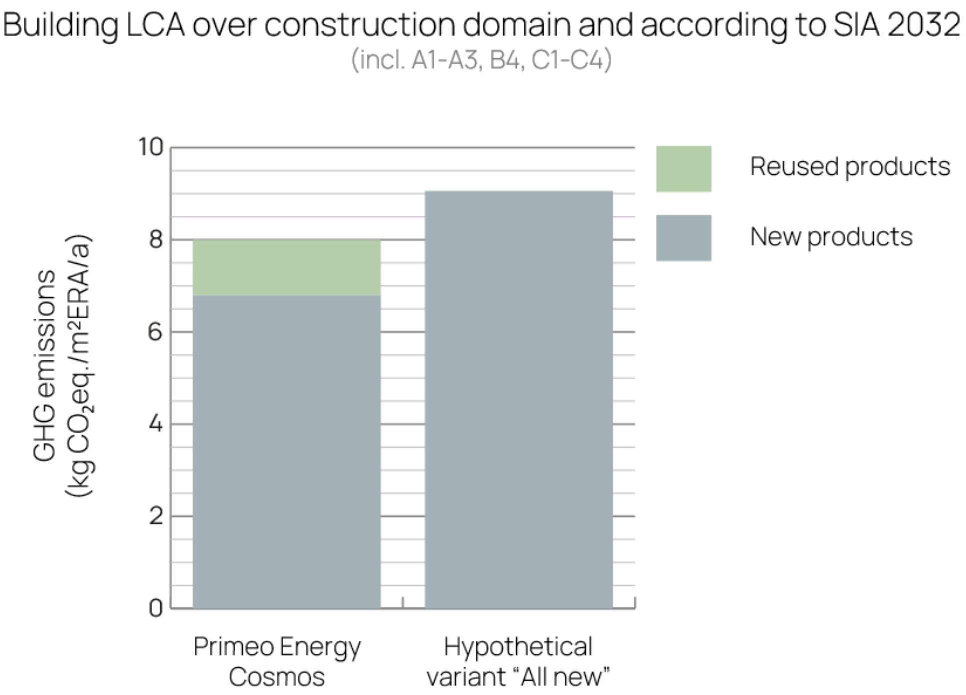

Figure 48: GHG emissions of the Primeo Energy Cosmos building studied in the Reuse-LCA project and comparison with a hypothetical variant with only new elements

7.2 Impact factors for building materials until 2050

material categories

ID-Nummer KBOB 2022	ID-Nummer KBOB future	BAUMATERIALIEN KBOB 2022	BAUMATERIALIEN KBOB future	Rohdichte/ Flächen-masse Masse volumique/ surface KBOB 2022	Rohdichte/ Flächen-masse Masse volumique/ surface KBOB future	Bezug Référence KBOB 2022	Bezug Référence KBOB future	production GHG Emissions KBOB future (kg CO2-eq) 2020	end-of-life GHG Emissions KBOB future (kg CO2-eq) 2020	Total (production & end-of-life) GHG Emissions KBOB 2022 (kg CO2-eq) 2020	production GHG Emissions KBOB future (kg CO2-eq) 2030	end-of-life GHG Emissions KBOB future (kg CO2-eq) 2030	Interpolated Total GHG Emissions (kg CO2-eq) 2030	production GHG Emissions KBOB future (kg CO2-eq) 2040	end-of-life GHG Emissions KBOB future (kg CO2-eq) 2040	Interpolated Total GHG Emissions (kg CO2-eq) 2040	production GHG Emissions KBOB future (kg CO2-eq) 2050	end-of-life GHG Emissions KBOB future (kg CO2-eq) 2050	Total (production & end-of-life) GHG Emissions KBOB future (kg CO2-eq) 2050
00	00-F	Vorbereitungsarbeiten	Vorbereitungsarbeiten																
00.001	00.001-F	Baugrubensicherung, Bohrpfahlwand, gespriesst	Baugrubensicherung, Bohrpfahlwand, gespriesst	-	-	m2	m2	801	60.5	861	599.6666667	44.6	644	398	29	427	197	12.9	210
00.002	00.002-F	Baugrubensicherung, Bohrpfahlwand, unverankert	Baugrubensicherung, Bohrpfahlwand, unverankert	-	-	m2	m2	761	60.5	821	568	45	612	375	29	404	182	12.9	195
00.003	00.003-F	Baugrubensicherung, Bohrpfahlwand, verankert	Baugrubensicherung, Bohrpfahlwand, verankert	-	-	m2	m2	495	40	535	374	30	403	252	19	272	131	8.54	140
00.004	00.004-F	Baugrubensicherung, Nagelwand	Baugrubensicherung, Nagelwand	-	-	m2	m2	112	8.78	121	84	6	91	57	4	61	29.1	1.88	31
00.005	00.005-F	Baugrubensicherung, Rühlwand, auskragend	Baugrubensicherung, Rühlwand, auskragend	-	-	m2	m2	256	14.2	270	196	10	206	136	7	142	75.4	3.03	78.4
00.006	00.006-F	Baugrubensicherung, Rühlwand, gespriesst	Baugrubensicherung, Rühlwand, gespriesst	-	-	m2	m2	178	8.26	187	137	6	143	95	4	100	54.1	1.76	55.8
00.007	00.007-F	Baugrubensicherung, Rühlwand, verankert	Baugrubensicherung, Rühlwand, verankert	-	-	m2	m2	187	9.54	197	143	7	150	99	5	103	54.7	2.04	56.7
00.008	00.008-F	Baugrubensicherung, Schlitzwand, 400 mm	Baugrubensicherung, Schlitzwand, 400 mm	-	-	m2	m2	393	30.3	423	301	22	324	210	14	224	118	6.34	125
00.009	00.009-F	Baugrubensicherung, Schlitzwand, 800 mm	Baugrubensicherung, Schlitzwand, 800 mm	-	-	m2	m2	749	59.8	809	570	44	615	392	28	420	213	12.6	226
00.010	00.010-F	Baugrubensicherung, Spundwand, auskragend	Baugrubensicherung, Spundwand, auskragend	-	-	m2	m2	168	1.06	169	130	1	130	91	0	91	52.5	0	52.5
00.011	00.011-F	Baugrubensicherung, Spundwand, gespriesst	Baugrubensicherung, Spundwand, gespriesst	-	-	m2	m2	95.1	0.58	95.7	73.2	0.4	73.6	51.3	0.2	51.5	29.4	0	29.4
00.012	00.012-F	Baugrubensicherung, Spundwand, verankert	Baugrubensicherung, Spundwand, verankert	-	-	m2	m2	185	2.49	187	143	2	145	101	1	102	59.6	0	59.6
00.013	00.013-F	Tiefgründung, Mikrobohrpfahl	Tiefgründung, Mikrobohrpfahl	-	-	m	m	31.4	0	31.4	24.1	0.0	24.1	16.8	0.0	16.8	9.51	0	9.51
00.014	00.014-F	Tiefgründung, Ortbetonbohrpfahl, 700 mm	Tiefgründung, Ortbetonbohrpfahl, 700 mm	-	-	m	m	163	0	163	123	0	123	82	0	82	41.8	0	41.8
00.015	00.015-F	Tiefgründung, Ortbetonbohrpfahl, 900 mm	Tiefgründung, Ortbetonbohrpfahl, 900 mm	-	-	m	m	244	0	244	183	0	183	123	0	123	62.4	0	62.4
00.016	00.016-F	Tiefgründung, Ortbetonbohrpfahl, 1200 mm	Tiefgründung, Ortbetonbohrpfahl, 1200 mm	-	-	m	m	379	0	379	285	0	285	191	0	191	96.9	0	96.9
00.017	00.017-F	Tiefgründung, Ortbetonverdrängungspfahl 560/480 mm	Tiefgründung, Ortbetonverdrängungspfahl 560/480 mm	-	-	m	m	76.4	0	76.4	57.4	0.0	57.4	38.5	0.0	38.5	19.5	0	19.5
00.018	00.018-F	Tiefgründung, Ortbetonverdrängungspfahl 660/580 mm	Tiefgründung, Ortbetonverdrängungspfahl 660/580 mm	-	-	m	m	95.9	0	95.9	72.2	0.0	72.2	48.5	0.0	48.5	24.8	0	24.8
00.019	00.019-F	Tiefgründung, Rüttelstopfsäule	Tiefgründung, Rüttelstopfsäule	-	-	m	m	6.74	0	6.74	5.06	0.00	5.06	3.39	0.00	3.39	1.71	0	1.71
00.020	00.020-F	Tiefgründung, Vorgefertigter Betonpfahl	Tiefgründung, Vorgefertigter Betonpfahl	-	-	m	m	29.2	0	29.2	21.9	0.0	21.9	14.7	0.0	14.7	7.44	0	7.44
00.021	00.021-F	Wasserhaltung, Pumphöhe 2.5 m	Wasserhaltung, Pumphöhe 2.5 m	-	-	m3	m3	0.00515	0	0.00515	0.00406	0.00000	0.00406	0.00297	0.00000	0.00297	0.00188	0	0.00188
00.022	00.022-F	Wasserhaltung, Pumphöhe 5 m	Wasserhaltung, Pumphöhe 5 m	-	-	m3	m3	0.00602	0	0.00602	0.00475	0.00000	0.00475	0.00347	0.00000	0.00347	0.0022	0	0.0022
00.023	00.023-F	Wasserhaltung, Pumphöhe 7.5 m	Wasserhaltung, Pumphöhe 7.5 m	-	-	m3	m3	0.00699	0	0.00699	0.00551	0.00000	0.00551	0.00403	0.00000	0.00403	0.00255	0	0.00255
00.024	00.024-F	Wasserhaltung, Pumphöhe 10 m	Wasserhaltung, Pumphöhe 10 m	-	-	m3	m3	0.00804	0	0.00804	0.00634	0.00000	0.00634	0.00463	0.00000	0.00463	0.00293	0	0.00293
01	01-F	Beton	Beton	kg/m3	kg/m3			0	0		0	0		0	0		0	0	
01.001	01.001-F	Magerbeton (ohne Bewehrung)	Magerbeton (ohne Bewehrung)	2150	2150	kg	kg	0.0502	0.0126	0.0628	0.0375	0.0092	0.0467	0.0248	0.0057	0.0305	0.0121	0.00232	0.0144
01.002	01.002-F	Hochbaubeton (ohne Bewehrung)	Hochbaubeton (ohne Bewehrung)	2300	2300	kg	kg	0.0887	0.0126	0.101	0.066	0.009	0.075	0.043	0.006	0.049	0.0208	0.00268	0.0235
01.003	01.003-F	Tiefbaubeton (ohne Bewehrung)	Tiefbaubeton (ohne Bewehrung)	2350	2350	kg	kg	0.0963	0.0125	0.109	0.072	0.009	0.081	0.048	0.006	0.054	0.0232	0.00268	0.0258
01.004	01.004-F	Bohrpfahlbeton (ohne Bewehrung)	Bohrpfahlbeton (ohne Bewehrung)	2325	2325	kg	kg	0.106	0.0125	0.119	0.079	0.009	0.089	0.052	0.006	0.058	0.0251	0.00267	0.0277
01.041	01.041-F	Betonfertigteil, hochfester Beton, ab Werk	Betonfertigteil, hochfester Beton, ab Werk	2770	2770	kg	kg	0.265	0.0111	0.276	0.191	0.008	0.199	0.116	0.005	0.121	0.0418	0.00236	0.0442
01.042	01.042-F	Betonfertigteil, Normalbeton, ab Werk	Betonfertigteil, Normalbeton, ab Werk	2500	2500	kg	kg	0.165	0.0121	0.177	0.123	0.009	0.131	0.080	0.006	0.086	0.0375	0.00259	0.0401
01.043	01.043-F	Hanfbeton	Hanfbeton	600	600	kg	kg	0.324	0.0000732	0.324	0.312	0.000	0.312	0.300	0.000	0.300	0.288	0.00015	0.288
02	02-F	Mauersteine	Mauersteine	kg/m3	kg/m3			0	0		0	0		0	0		0	0	
02.001	02.001-F	Backstein	Backstein	900	900	kg	kg	0.254	0.0127	0.266	0.182	0.009	0.191	0.110	0.006	0.116	0.0384	0.00255	0.0409
02.002	02.002-F	Kalksandstein	Kalksandstein	1400	1400	kg	kg	0.149	0.0127	0.162	0.140	0.009	0.149	0.130	0.006	0.136	0.121	0.00241	0.123
02.003	02.003-F	Leichtlehmstein	Leichtlehmstein	700	700	kg	kg	0.167	0.0127	0.18	0.16	0.01	0.17	0.15	0.01	0.16	0.148	0.00255	0.15
02.004	02.004-F	Leichtzementstein, Blähton	Leichtzementstein, Blähton	1200	1200	kg	kg	0.415	0.0127	0.428	0.374	0.009	0.384	0.334	0.006	0.340	0.293	0.00262	0.296
02.005	02.005-F	Leichtzementstein, Naturbims	Leichtzementstein, Naturbims	1200	1200	kg	kg	0.2	0.0127	0.212	0.148	0.009	0.156	0.095	0.006	0.101	0.0428	0.00262	0.0454
02.006	02.006-F	Porenbetonstein	Porenbetonstein	500	500	kg	kg	0.413	0.0127	0.426	0.341	0.009	0.351	0.270	0.006	0.276	0.198	0.00255	0.201
02.007	02.007-F	Zementstein	Zementstein	1700	1700	kg	kg	0.114	0.0127	0.126	0.085	0.009	0.094	0.056	0.006	0.061	0.0266	0.00234	0.0289
03	03-F	Andere Massivbaustoffe	Andere Massivbaustoffe	kg/m3	kg/m3			0	0		0	0		0	0		0	0	
03.001	03.001-F	Betonziegel	Betonziegel	2300	2300	kg	kg	0.196	0.0127	0.209	0.151	0.009	0.161	0.106	0.006	0.112	0.0617	0.00255	0.0642
03.002	03.002-F	Faserzement-Dachschindel	Faserzement-Dachschindel	1800	1800	kg	kg	0.686	0.0132	0.699	0.538	0.010	0.547	0.390	0.006	0.396	0.242	0.00262	0.244
03.003	03.003-F	Faserzementplatte gross	Faserzementplatte gross	1800	1800	kg	kg	1.02	0.0132	1.03	0.80	0.01	0.81	0.59	0.01	0.59	0.374	0.00262	0.377
03.004	03.004-F	Faserzement-Wellplatte	Faserzement-Wellplatte	1800	1800	kg	kg	0.636	0.0132	0.649	0.487	0.010	0.497	0.338	0.006	0.344	0.189	0.00262	0.192
03.005	03.005-F	Flachglas beschichtet	Flachglas beschichtet	2500	2500	kg	kg	1.18	0.0191	1.2	0.9	0.0	0.9	0.6	0.0	0.6	0.242	0.00348	0.246
03.006	03.006-F	Flachglas unbeschichtet	Flachglas unbeschichtet	2500	2500	kg	kg	1.12	0.0191	1.14	0.82	0.01	0.84	0.52	0.01	0.53	0.222	0.00348	0.226
03.007	03.007-F	Gipsfaserplatte	Gipsfaserplatte	1200	1200	kg	kg	0.533	0.0186	0.552	0.529	0.014	0.543	0.525	0.008	0.534	0.521	0.00332	0.525
03.008	03.008-F	Gipskartonplatte	Gipskartonplatte	850	850	kg	kg	0.283	0.0187	0.301	0.248	0.014	0.261	0.214	0.008	0.222	0.179	0.00329	0.182
03.016	03.016-F	Gips-Wandbauplatte / Vollgipsplatte	Gips-Wandbauplatte / Vollgipsplatte	1000	1000	kg	kg	0.298	0.0185	0.317	0.298	0.013	0.312	0.297	0.008	0.306	0.297	0.00327	0.301
03.009	03.009-F	Hartsandsteinplatte	Hartsandsteinplatte	2500	2500	kg	kg	0.0279	0.0127	0.0406	0.022	0.009	0.031	0.016	0.006	0.022	0.0107	0.00241	0.0131
03.017	03.017-F	Kalksteinplatte	Kalksteinplatte	2500	2600	kg	kg	0.061	0.0127	0.0736	0.060	0.009	0.069	0.058	0.006	0.064	0.057	0.00241	0.0595
03.010	03.010-F	Keramik-/Steinzeugplatte	Keramik-/Steinzeugplatte	2600	2600	kg	kg	0.78	0.0127	0.793	0.716	0.009	0.726	0.653	0.006	0.659	0.589	0.00255	0.592
03.011	03.011-F	Kies gebrochen	Kies gebrochen	2000	2000	kg	kg	0.005	0.0126	0.0176	0.004	0.009	0.013	0.003	0.006	0.009	0.00204	0.00236	0.00439
03.012	03.012-F	Rundkies	Rundkies	2000	2000	kg	kg	0.00305	0.0126	0.0157	0.002	0.009	0.012	0.002	0.006	0.007	0.00103	0.00236	0.00339
03.013	03.013-F	Sand	Sand	2000	2000	kg	kg	0.00305	0.0126	0.0157	0.002	0.009	0.011	0.002	0.005	0.006	0.00103	0.000528	0.00156
03.014	03.014-F	Sanitärkeramik	Sanitärkeramik	2000	2000	kg	kg	2.37	0.0127	2.38	2.21	0.01	2.22	2.05	0.01	2.06	1.89	0.00	1.90
03.020	03.020-F	Stampflehm	Stampflehm	2000	2000	kg	kg	0.0183	0.00115	0.0194	0.018	0.002	0.019	0.017	0.002	0.019	0.0163	0.00284	0.0191
03.015	03.015-F	Tonziegel	Tonziegel	1700	1700	kg	kg	0.373	0.0127	0.385	0.354	0.009	0.363	0.335	0.006	0.341	0.316	0.00255	0.319
04	04-F	Mörtel und Putze	Mörtel und Putze	kg/m3	kg/m3			0	0		0	0		0	0		0	0	
04.008	04.008-F	Baukleber/Einbettmörtel mineralisch	Baukleber/Einbettmörtel mineralisch	1400	1400	kg	kg	0.393	0.0127	0.406	0.333	0.010	0.343	0.273	0.006	0.279	0.213	0.00327	0.216
04.010	04.010-F	Baukleber/Einbettmörtel mineralisch Leichtzuschlag	Baukleber/Einbettmörtel mineralisch Leichtzuschlag	1100	1100	kg	kg	0.414	0.0127	0.426	0.346666667	0.009556667	0.356	0.279333333	0.006413333	0.286	0.212	0.00327	0.216
04.002	04.002-F	Baukleber/Einbettmörtel organisch	Baukleber/Einbettmörtel organisch	1670	1670	kg	kg	0.764	0.0127	0.777	0.722333333	0.009556667	0.732	0.680666667	0.006413333	0.687	0.639	0.00327	0.642
04.017	04.017-F	Gips-Kalk-Putz	Gips-Kalk-Putz	925	925	kg	kg	0.145	0.0127	0.158	0.145	0.009556667	0.155	0.145	0.006413333	0.152	0.145	0.00327	0.149
04.001	04.001-F	Gips-/Weissputz	Gips-/Weissputz	1100	1100	kg	kg	0.138	0.0127	0.151	0.138	0.009556667	0.148	0.138	0.006413333	0.145	0.138	0.00327	0.142
04.003	04.003-F	Kunststoffputz (Dispersionsputz)	Kunststoffputz (Dispersionsputz)	1540	1540	kg	kg	0.957	0.0127	0.97	0.92	0.01	0.93	0.88	0.01	0.89	0.843	0.00327	0.846
04.013	04.013-F	Kalk-Zement/Zement-Kalk-Putz	Kalk-Zement/Zement-Kalk-Putz	1550	1550	kg	kg	0.251	0.0127	0.263	0.219	0.010	0.229	0.188	0.006	0.194	0.156	0.00327	0.16
04.004	04.004-F	Lehmputz	Lehmputz	1800	1800	kg	kg	0.0195	0.0127	0.0322	0.0172	0.0089	0.0261	0.0149	0.0052	0.0201	0.0126	0.0014	0.014
04.015	04.015-F	Leichtputz mineralisch	Leichtputz mineralisch	1000	1000	kg	kg	0.36	0.0127	0.372	0.305	0.010	0.314	0.249	0.006	0.255	0.194	0.00327	0.197
04.011	04.011-F	Silikatputz (Dispersionssilikatputz)	Silikatputz (Dispersionssilikatputz)	1880	1880	kg	kg	1.07	0.0127	1.08	1.03	0.01	1.03	0.98	0.01	0.99	0.937	0.00327	0.94
04.012	04.012-F	Silikonharzputz	Silikonharzputz	1670	1670	kg	kg	1.13	0.0127	1.14	1.08	0.01	1.09	1.03	0.01	1.04	0.987	0.00327	0.991
04.016	04.016-F	Sumpfkalkputz	Sumpfkalkputz	1350	1350	kg	kg	0.497	0.0127	0.51	0.48	0.01	0.49	0.46	0.01	0.46	0.438	0.00327	0.442
04.005	04.005-F	Unterlagsboden Anhydrit, 60 mm	Unterlagsboden Anhydrit, 60 mm	2000	2000	kg	kg	0.0784	0.0127	0.0911	0.0717	0.0096	0.0813	0.0649	0.0066	0.0715	0.0582	0.00353	0.0617
04.006	04.006-F	Unterlagsboden Zement, 85 mm	Unterlagsboden Zement, 85 mm	1850	1850	kg	kg	0.107	0.0127	0.12	0.08	0.01	0.09	0.05	0.01	0.06	0.0246	0.00327	0.0278
04.007	04.007-F	Wärmedämmputz EPS	Wärmedämmputz EPS	250	250	kg	kg	0.714	0.0127	0.727	0.544	0.010	0.554	0.374	0.006	0.380	0.204	0.00327	0.207
04.014	04.014-F	Weisszementputz	Weisszementputz	1550	1550	kg	kg	0.341	0.0127	0.353	0.327	0.010	0.336	0.314	0.006	0.320	0.3	0.00327	0.303
04.009	04.009-F	Zementputz	Zementputz	1550	1550	kg	kg	0.248	0.0127	0.261	0.197	0.010	0.206	0.145	0.006	0.151	0.0935	0.00327	0.0967
05	05-F	Fenster, Sonnenschutz, Fassadenverkleidungen	Fenster, Sonnenschutz, Fassadenverkleidungen	kg/m2	kg/m2			0	0		0	0		0	0		0	0	
05.008	05.008-F	Fassade, Pfosten-Riegel, Alu/Glas 1	Fassade, Pfosten-Riegel, Alu/Glas	-	-	m2	m2	169	13.1	182	145	13	157	120	12	133	96.1	11.7	108
05.022	05.022-F	Fassadenplatte, Aluverbund, 4 mm	Fassadenplatte, Aluverbund, 4 mm	7.1	7.1	m2	m2	35.7	7.65	43.3	30.9	7.9	38.8	26.0	8.2	34.2	21.2	8.53	29.7
05.023	05.023-F	Fassadenplatte, Hochdrucklaminatplatte (HPL), 8.1 mm	Fassadenplatte, Hochdrucklaminatplatte (HPL), 8.1 mm	11.6	11.6	m2	m2	33.3	12.6	45.9	31.5	9.3	40.8	29.6	6.1	35.7	27.8	2.81	30.6
05.025	05.025-F	Fassadenplatte, Kalkstein, 30 mm	Fassadenplatte, Kalkstein, 30 mm	78	78	m2	m2	4.75	0.989	5.74	4.65	0.72	5.37	4.55	0.46	5.01	4.45	0.188	4.64
05.024	05.024-F	Fassadenplatte, Kunststoff glasfaserverstärkt (GFK), 1.6 mm	Fassadenplatte, Kunststoff glasfaserverstärkt (GFK), 1.6 mm	2.4	2.4	m2	m2	16.6	5.51	22.1	15.6	4.0	19.7	14.6	2.6	17.2	13.6	1.11	14.8
05.004	05.004-F	Fensterrahmen Aluminium 2,5	Fensterrahmen Aluminium	-	-	m2	m2	117	14.9	132	142	13	155	167	11	177	192	8.44	200
05.005	05.005-F	Fensterrahmen Holz 2,6	Fensterrahmen Holz	-	-	m2	m2	30.3	5.89	36.2	37.4	9.9	47.4	44.6	14.0	58.6	51.7	18	69.8
05.006	05.006-F	Fensterrahmen Holz-Metall 2,6	Fensterrahmen Holz-Aluminium	-	-	m2	m2	58.6	7.11	65.7	70.9	12.3	83.1	83.1	17.6	100.6	95.4	22.8	118
05.007	05.007-F	Fensterrahmen Kunststoff/PVC 2,6	Fensterrahmen Kunststoff/PVC	-	-	m2	m2	53.2	10.2	63.4	63.9	12.9	76.9	74.7	15.7	90.5	85.4	18.4	104
05.001	05.001-F	Isolierverglasung 2-fach, Ug-Wert 1.1 W/m2K, Dicke 24 mm 3	Isolierverglasung 2-fach, Ug-Wert 1.1 W/m2K, Dicke 24 mm	-	-	m2	m2	40.7	3.6	44.3	30.7	3.7	34.3	20.6	3.7	24.4	10.6	3.77	14.4
05.009	05.009-F	Isolierverglasung 2-fach, Ug-Wert 1.1 W/m2K, Dicke 18 mm 3	Isolierverglasung 2-fach, Ug-Wert 1.1 W/m2K, Dicke 18 mm	-	-	m2	m2	45.7	2.84	48.6	34.3	2.9	37.1	22.8	2.9	25.7	11.4	2.88	14.2
05.010	05.010-F	Isolierverglasung 2-fach, ESG, Ug-Wert 1.1 W/m2K 3	Isolierverglasung 2-fach, ESG, Ug-Wert 1.1 W/m2K	-	-	m2	m2	48.5	3.6	52.1	36.5	3.7	40.1	24.5	3.7	28.2	12.5	3.77	16.2
05.002	05.002-F	Isolierverglasung 2-fach, VSG, Ug-Wert 1.1 W/m2K 3	Isolierverglasung 2-fach, VSG, Ug-Wert 1.1 W/m2K	-	-	m2	m2	72.6	6.68	79.3	55.2	6.8	62.0	37.8	6.9	44.7	20.4	7	27.4
05.011	05.011-F	Isolierverglasung 2-fach, ESG/VSG, Ug-Wert 1.1 W/m2K 3	Isolierverglasung 2-fach, ESG/VSG, Ug-Wert 1.1 W/m2K	-	-	m2	m2	80.4	6.68	87	61	7	68	42	7	48	22.2	7	29.2
05.003	05.003-F	Isolierverglasung 3-fach, Ug-Wert 0.5 W/m2K, Dicke 36 mm 3	Isolierverglasung 3-fach, Ug-Wert 0.5 W/m2K, Dicke 36 mm	-	-	m2	m2	73.3	4.92	78.3	54.9	5.0	60.0	36.6	5.0	41.6	18.2	5.09	23.3
05.012	05.012-F	Isolierverglasung 3-fach, Ug-Wert 0.6 W/m2K, Dicke 40 mm 3	Isolierverglasung 3-fach, Ug-Wert 0.6 W/m2K, Dicke 40 mm	-	-	m2	m2	62.1	5.7	67.8	46.8	5.8	52.6	31.6	5.9	37.5	16.3	6	22.3
05.013	05.013-F	Isolierverglasung 3-fach, ESG/ESG, Ug-Wert 0.6 W/m2K 3	Isolierverglasung 3-fach, ESG/ESG, Ug-Wert 0.6 W/m2K	-	-	m2	m2	77.6	5.7	83.3	58.4	5.8	64.2	39.2	5.9	45.1	20	6	26
05.014	05.014-F	Isolierverglasung 3-fach, ESG/ESG/ESG, Ug-Wert 0.6 W/m2K 3	Isolierverglasung 3-fach, ESG/ESG/ESG, Ug-Wert 0.6 W/m2K	-	-	m2	m2	85.4	5.7	91.1	64.2	5.8	70.0	43.0	5.9	48.9	21.8	6	27.8

05.015	05.015-F	Isolierverglasung 3-fach, VSG, Ug-Wert 0.6 W/m2K 3	Isolierverglasung 3-fach, VSG, Ug-Wert 0.6 W/m2K	-	-	m2	m2	94	8.78	103	71	9	80	49	9	58	26.1	9.23	35.3
05.016	05.016-F	Isolierverglasung 3-fach, ESG/VSG, Ug-Wert 0.6 W/m2K 3	Isolierverglasung 3-fach, ESG/VSG, Ug-Wert 0.6 W/m2K	-	-	m2	m2	103	8.78	111	78	9	86	53	9	62	28.2	9.23	37.4
05.020	05.020-F	Putzträgerplatte kunstharzgebunden 13 mm	Putzträgerplatte kunstharzgebunden 13 mm	6.3	6.3	m2	m2	8.03	0.0799	8.11	7.84	0.06	7.90	7.65	0.04	7.69	7.46	0.0206	7.48
05.021	05.021-F	Putzträgerplatte mineralisch gebunden 12.5 mm	Putzträgerplatte mineralisch gebunden 12.5 mm	14.4	14.4	m2	m2	6.12	0.183	6.31	6.06	0.14	6.20	6.00	0.09	6.10	5.94	0.0471	5.99
05.018	05.018-F	Sonnenschutz, Ausstellstoren motorisiert 4	Sonnenschutz, Ausstellstoren motorisiert	-	-	m2	m2	65.9	1.91	67.8	55.3	1.4	56.7	44.6	0.9	45.5	34	0.346	34.4
05.017	05.017-F	Sonnenschutz, Lamellenstoren motorisiert 4	Sonnenschutz, Lamellenstoren motorisiert	-	-	m2	m2	58.5	1.47	59.9	49.4	1.1	50.5	40.4	0.7	41.0	31.3	0.26	31.6
05.019	05.019-F	Sonnenschutz, Rollladen motorisiert 4	Sonnenschutz, Rollladen motorisiert	-	-	m2	m2	74	0.694	74.7	62.0	0.5	62.5	50.1	0.3	50.4	38.1	0.0961	38.2
06	06-F	Metallbaustoffe	Metallbaustoffe	kg/m3	kg/m3			0	0		0	0		0	0		0	0	
06.001	06.001-F	Aluminiumblech, blank	Aluminiumblech, blank	2690	2690	kg	kg	5.57	0.00792	5.58	4.55	0.01	4.56	3.53	0.00	3.53	2.51	0	2.51
06.002	06.002-F	Aluminiumprofil, blank	Aluminiumprofil, blank	2690	2690	kg	kg	5.69	0.00792	5.69	4.64	0.01	4.64	3.58	0.00	3.58	2.53	0	2.53
06.003	06.003-F	Armierungsstahl	Armierungsstahl	7850	7850	kg	kg	0.773	0.0122	0.785	0.612	0.008	0.620	0.452	0.004	0.456	0.291	0	0.291
06.014	06.014-F	Blei	Blei	11340	11340	kg	kg	1.01	0.00792	1.02	0.87	0.01	0.88	0.73	0.00	0.73	0.589	0	0.589
06.004	06.004-F	Chromnickelstahlblech 18/8 blank	Chromnickelstahlblech 18/8 blank	7900	7900	kg	kg	4.11	0.00693	4.12	3.11	0.00	3.12	2.11	0.00	2.11	1.11	0	1.11
06.005	06.005-F	Chromnickelstahlblech 18/8 verzinnt	Chromnickelstahlblech 18/8 verzinnt	7900	7900	kg	kg	5.87	0.00693	5.87	4.70	0.00	4.70	3.53	0.00	3.53	2.36	0	2.36
06.006	06.006-F	Chromstahlblech blank	Chromstahlblech blank	7700	7700	kg	kg	2.73	0.00693	2.74	2.28	0.00	2.28	1.82	0.00	1.83	1.37	0	1.37
06.007	06.007-F	Chromstahlblech verzinnt	Chromstahlblech verzinnt	7700	7700	kg	kg	4.48	0.00693	4.49	3.86	0.00	3.87	3.24	0.00	3.24	2.62	0	2.62
06.008	06.008-F	Kupferblech, blank	Kupferblech, blank	8900	8900	kg	kg	2.2	0.00792	2.2	1.6	0.0	1.6	1.1	0.0	1.1	0.511	0	0.511
06.009	06.009-F	Messing-/Baubronzeblech	Messing-/Baubronzeblech	8300	8300	kg	kg	2.7	0.00792	2.71	2.07	0.01	2.08	1.45	0.00	1.45	0.818	0	0.818
06.010	06.010-F	Stahlblech, blank	Stahlblech, blank	7850	7850	kg	kg	2.79	0.00693	2.8	2.1	0.0	2.1	1.5	0.0	1.5	0.803	0	0.803
06.011	06.011-F	Stahlblech, verzinkt	Stahlblech, verzinkt	7850	7850	kg	kg	4.48	0.00693	4.49	3.57	0.00	3.57	2.65	0.00	2.66	1.74	0	1.74
06.012	06.012-F	Stahlprofil, blank	Stahlprofil, blank	7850	7850	kg	kg	0.729	0.00693	0.736	0.574	0.005	0.579	0.420	0.002	0.422	0.265	0	0.265
06.013	06.013-F	Titanzinkblech	Titanzinkblech	7200	7200	kg	kg	4.02	0.00792	4.02	3.23	0.01	3.23	2.43	0.00	2.43	1.64	0	1.64
07	07-F	Holz und Holzwerkstoffe	Holz und Holzwerkstoffe	kg/m3	kg/m3			0	0		0	0		0	0		0	0	
07.001	07.001-F	3- und 5-Schicht Massivholzplatte	3-Schicht Massivholzplatte, PVAc-gebunden	453	470	kg	kg	0.414	0.0553	0.469	0.323	0.050	0.372	0.231	0.044	0.276	0.14	0.0389	0.179
07.003	07.003-F	Brettschichtholz	Brettschichtholz, MF-gebunden, Feuchtbereich	439	470	kg	kg	0.285	0.0492	0.335	0.249	0.047	0.296	0.212	0.045	0.258	0.176	0.0424	0.219
07.003.01	07.003.01-F	Brettschichtholz, Produktion Schweiz	Brettschichtholz, MF-gebunden, Feuchtbereich, Produktion Schw	439	470	kg	kg	0.204	0.0492	0.253	0.193	0.047	0.239	0.181	0.045	0.226	0.17	0.0424	0.212
07.002	07.002-F	Brettschichtholz	Brettschichtholz, UF-gebunden, Trockenbereich	439	470	kg	kg	0.285	0.0492	0.335	0.237	0.047	0.285	0.190	0.045	0.235	0.142	0.0424	0.185
07.004	07.004-F	Hartfaserplatte	Hartfaserplatte	955	955	kg	kg	1.03	0.0441	1.07	0.97	0.04	1.01	0.92	0.04	0.96	0.859	0.0444	0.903
07.005	07.005-F	Holzwolle-Leichtbauplatte, zementgebunden	Holzwolle-Leichtbauplatte, zementgebunden	400	400	kg	kg	0.498	0.0357	0.534	0.375	0.026	0.402	0.253	0.017	0.269	0.13	0.00702	0.137
07.008	07.008-F	Massivholz Buche / Eiche, kammergetrocknet, gehobelt	Massivholz Buche / Eiche, kammergetrocknet, gehobelt	675	675	kg	kg	0.113	0.039	0.152	0.086	0.028	0.115	0.060	0.018	0.078	0.0333	0.00728	0.0406
07.007	07.007-F	Massivholz Buche / Eiche, kammergetrocknet, rau	Massivholz Buche / Eiche, kammergetrocknet, rau	675	675	kg	kg	0.0962	0.039	0.135	0.073	0.028	0.101	0.050	0.018	0.068	0.0271	0.00728	0.0344
07.006	07.006-F	Massivholz Buche / Eiche, luftgetrocknet, rau	Massivholz Buche / Eiche, luftgetrocknet, rau	705	705	kg	kg	0.0812	0.039	0.12	0.06	0.03	0.09	0.04	0.02	0.06	0.0226	0.00667	0.0293
07.011	07.011-F	Massivholz Fichte / Tanne / Lärche, kammergetr., gehobelt	Massivholz Fichte / Tanne / Lärche, kammergetr., gehobelt	465	465	kg	kg	0.134	0.039	0.173	0.104	0.028	0.132	0.073	0.018	0.091	0.043	0.00728	0.0503
07.010	07.010-F	Massivholz Fichte / Tanne / Lärche, luftgetr., gehobelt	Massivholz Fichte / Tanne / Lärche, luftgetr., gehobelt	485	485	kg	kg	0.117	0.039	0.156	0.091	0.028	0.119	0.064	0.017	0.081	0.0375	0.00667	0.0442
07.009	07.009-F	Massivholz Fichte / Tanne / Lärche, luftgetrocknet, rau	Massivholz Fichte / Tanne / Lärche, luftgetrocknet, rau	485	485	kg	kg	0.0904	0.039	0.129	0.069	0.028	0.097	0.049	0.017	0.066	0.0276	0.00667	0.0343
07.012	07.012-F	Mitteldichte Faserplatte (MDF), UF-gebunden	Mitteldichte Faserplatte (MDF), UF-gebunden	685	685	kg	kg	0.854	0.1	0.954	0.819	0.081	0.901	0.784	0.063	0.847	0.749	0.0444	0.794
07.013	07.013-F	OSB Platte, PF-gebunden, Feuchtbereich	OSB Platte, PF-gebunden, Feuchtbereich	605	605	kg	kg	0.483	0.0798	0.563	0.412	0.068	0.480	0.340	0.056	0.397	0.269	0.0446	0.314
07.015	07.015-F	Spanplatte, PF-gebunden, Feuchtbereich	Spanplatte, PF-gebunden, Feuchtbereich	640	640	kg	kg	0.45	0.0798	0.529	0.419	0.068	0.486	0.387	0.056	0.443	0.356	0.0446	0.4
07.016	07.016-F	Spanplatte, UF-gebunden, beschichtet, Trockenbereich	Spanplatte, UF-gebunden, beschichtet, Trockenbereich	640	640	kg	kg	0.641	0.0945	0.735	0.598	0.078	0.675	0.554	0.061	0.615	0.511	0.0446	0.555
07.014	07.014-F	Spanplatte, UF-gebunden, Trockenbereich	Spanplatte, UF-gebunden, Trockenbereich	640	640	kg	kg	0.45	0.0798	0.529	0.419	0.068	0.486	0.387	0.056	0.443	0.356	0.0446	0.4
07.018	07.018-F	Sperrholz/Multiplex, PF-gebunden, Feuchtbereich	Sperrholz/Multiplex, PF-gebunden, Feuchtbereich	500	500	kg	kg	1.35	0.0798	1.43	1.17	0.07	1.23	0.98	0.05	1.03	0.795	0.0389	0.834
07.017	07.017-F	Sperrholz/Multiplex, UF-gebunden, Trockenbereich	Sperrholz/Multiplex, UF-gebunden, Trockenbereich	500	500	kg	kg	0.868	0.0798	0.948	0.766	0.066	0.832	0.663	0.053	0.716	0.561	0.0389	0.6
08	08-F	Klebstoffe und Fugendichtungsmassen	Klebstoffe und Fugendichtungsmassen	kg/m3	kg/m3			0	0		0.000	0.000		0.000	0.000		0	0	
08.001	08.001-F	2-Komponenten Klebstoff	2-Komponenten Klebstoff	1500	1500	kg	kg	4.65	0.187	4.84	4.61	0.27	4.88	4.58	0.35	4.93	4.54	0.429	4.97
08.002	08.002-F	Heissbitumen	Heissbitumen	1000	1000	kg	kg	0.906	0.187	1.09	0.79	0.91	1.69	0.67	1.63	2.30	0.557	2.35	2.9
08.003	08.003-F	Kautschukdichtungsmasse	Kautschukdichtungsmasse	1500	1500	kg	kg	2.23	0.187	2.42	2.05	1.17	3.22	1.86	2.16	4.03	1.68	3.14	4.83
08.004	08.004-F	Polysulfiddichtungsmasse	Polysulfiddichtungsmasse	1600	1600	kg	kg	1.53	0.187	1.72	1.30	1.17	2.47	1.07	2.16	3.23	0.835	3.14	3.98
08.005	08.005-F	Silicon-Fugenmasse	Silicon-Fugenmasse	1000	1000	kg	kg	2.72	0.187	2.91	2.59	1.17	3.76	2.46	2.16	4.62	2.33	3.14	5.47
09	09-F	Dichtungsbahnen und Schutzfolien	Dichtungsbahnen und Schutzfolien	kg/m3; kg/m2	kg/m3			0	0		0.000	0.000		0.000	0.000		0	0	
09.001	09.001-F	Dampfbremse bituminös	Dampfbremse bituminös	1100	1100	kg	kg	1.31	2.33	3.64	1.08	2.34	3.41	0.84	2.34	3.19	0.611	2.35	2.96
09.002	09.002-F	Dampfbremse Polyethylen (PE)	Dampfbremse Polyethylen (PE)	920	920	kg	kg	2.75	2.67	5.42	2.64	2.64	5.27	2.53	2.60	5.13	2.42	2.57	4.98
09.003	09.003-F	Dichtungsbahn bituminös	Dichtungsbahn bituminös	1100	1100	kg	kg	1	2.33	3.33	0.85	2.34	3.19	0.71	2.34	3.05	0.559	2.35	2.91
09.004	09.004-F	Dichtungsbahn Gummi (EPDM)	Dichtungsbahn Gummi (EPDM)	1100	1100	kg	kg	2.74	3.1	5.84	2.49	3.11	5.61	2.25	3.13	5.38	2	3.14	5.15
09.005	09.005-F	Dichtungsbahn Polyolefin (FPO)	Dichtungsbahn Polyolefin (FPO)	1000	1000	kg	kg	2.52	2.67	5.18	2.52	2.79	5.30	2.52	2.90	5.42	2.52	3.02	5.54
09.006	09.006-F	Kraftpapier	Kraftpapier	650	650	kg	kg	1.61	0.058	1.67	1.41	0.05	1.46	1.20	0.04	1.24	1	0.0313	1.03
09.007	09.007-F	Polyethylenfolie (PE)	Polyethylenfolie (PE)	920	920	kg	kg	2.75	2.67	5.42	2.64	2.64	5.27	2.53	2.60	5.13	2.42	2.57	4.98
09.008	09.008-F	Polyethylenvlies (PE)	Polyethylenvlies (PE)	920	920	kg	kg	2.96	2.67	5.63	2.91	2.64	5.54	2.85	2.60	5.45	2.8	2.57	5.36
10	10-F	Wärmedämmstoffe	Wärmedämmstoffe	kg/m3	kg/m3			0	0		0.000	0.000		0.000	0.000		0	0	
10.014	10.014-F	Aerogel-Vlies	Aerogel-Vlies	150	150	kg	kg	48.4	0.289	48.7	47.8	0.3	48.1	47.1	0.3	47.4	46.5	0.29	46.8
10.012	10.012-F	Blähperlit	Blähperlit	65-140	65-140	kg	kg	1.04	0.0127	1.05	0.99	0.01	1.00	0.95	0.01	0.95	0.898	0.00348	0.902
10.011	10.011-F	Blähvermiculit	Blähvermiculit	65-140	65-140	kg	kg	0.382	0.0127	0.394	0.332	0.009	0.341	0.282	0.006	0.287	0.232	0.00255	0.234
10.016	10.016-F	Flachsfasern	Flachsfasern	30	30	kg	kg	0.777	0.235	1.01	0.77	0.23	1.00	0.76	0.22	0.98	0.753	0.218	0.971
10.017	10.017-F	Flachsfasern, feuerfest	Flachsfasern, feuerfest	30	30	kg	kg	1.22	0.235	1.45	1.21	0.23	1.43	1.19	0.22	1.42	1.18	0.218	1.4
10.001	10.001-F	Glaswolle	Glaswolle	20-100	20-100	kg	kg	1.04	0.0592	1.1	0.8	0.0	0.9	0.6	0.0	0.7	0.422	0.00348	0.425
10.002	10.002-F	Korkplatte	Korkplatte	120	120	kg	kg	1.07	0.0387	1.11	0.91	0.05	0.96	0.75	0.06	0.82	0.595	0.0777	0.673
10.003	10.003-F	Phenolharz (PF)	Phenolharz (PF)	40	40	kg	kg	4.17	3.09	7.26	3.92	2.28	6.20	3.68	1.47	5.15	3.43	0.658	4.09
10.004	10.004-F	Polystyrol expandiert (EPS)	Polystyrol expandiert (EPS)	15-40	15-40	kg	kg	4.51	3.09	7.6	3.7	2.3	6.0	2.8	1.5	4.3	1.99	0.706	2.7
10.005	10.005-F	Polystyrol extrudiert (XPS)	Polystyrol extrudiert (XPS)	30-35	30-35	kg	kg	11.3	3.09	14.4	8.1	2.3	10.4	4.9	1.5	6.4	1.75	0.706	2.46
10.006	10.006-F	Polyurethan (PUR/PIR)	Polyurethan (PUR/PIR)	30	30	kg	kg	4.79	2.65	7.44	3.82	2.06	5.88	2.86	1.46	4.32	1.89	0.872	2.76
10.007	10.007-F	Schaumglas	Schaumglas	100-165	100-165	kg	kg	1.17	0.0127	1.19	1.11	0.01	1.13	1.05	0.01	1.06	0.997	0.00348	1
10.013	10.013-F	Schaumglasschotter	Schaumglasschotter	125-150	125-150	kg	kg	0.148	0.0127	0.16	0.15	0.01	0.16	0.15	0.01	0.15	0.148	0.00284	0.15
10.008	10.008-F	Steinwolle	Steinwolle	32-160	32-160	kg	kg	1.13	0.0592	1.19	0.94	0.04	0.98	0.76	0.02	0.78	0.57	0.00348	0.573
10.015	10.015-F	Strohballenwand	Strohballenwand	215	215	kg	kg	0.0956	0	0.0956	0.0871	0.0000	0.0871	0.0785	0.0000	0.0785	0.07	0	0.07
10.009	10.009-F	Weichfaserplatte	Weichfaserplatte	147.5	147.5	kg	kg	0.633	0.0921	0.725	0.502	0.074	0.576	0.370	0.056	0.426	0.239	0.0376	0.277
10.010	10.010-F	Zellulosefasern	Zellulosefasern	35-60	35-60	kg	kg	0.209	0.0709	0.28	0.20	0.06	0.26	0.19	0.04	0.23	0.18	0.0313	0.212
11	11-F	Bodenbeläge	Bodenbeläge	kg/m2	kg/m2			0	0		0.000	0.000		0.000	0.000		0	0	
11.001	11.001-F	2K-Fliessbelag Industrie (Epoxidharz), 2.25 mm	2K-Fliessbelag Industrie (Epoxidharz), 2.25 mm	4.55	4.55	m2	m2	11.1	7.24	18.4	10.9	5.5	16.4	10.6	3.7	14.4	10.4	1.95	12.4
11.002	11.002-F	2K-Fliessbelag Wohnen/Verwaltung (Epoxidharz, PU), 2 mm	2K-Fliessbelag Wohnen/Verwaltung (Epoxidharz, PU), 2 mm	3.6	3.6	m2	m2	10	3.87	13.9	8.7	3.1	11.8	7.3	2.4	9.7	5.96	1.66	7.63
11.003	11.003-F	Gummigranulat versiegelt, 7.5 mm	Gummigranulat versiegelt, 7.5 mm	8.25	8.25	m2	m2	14.9	11.9	26.8	13.4	10.9	24.3	11.9	9.9	21.7	10.4	8.88	19.2
11.004	11.004-F	Gussasphalt, 27.5 mm	Gussasphalt, 27.5 mm	63.3	63.3	m2	m2	14.7	1.22	15.9	13.8	1.0	14.8	12.8	0.9	13.7	11.9	0.7	12.6
11.005	11.005-F	Hartbeton einschichtig, 27.5 mm	Hartbeton einschichtig, 27.5 mm	57.8	57.8	m2	m2	15.7	0.733	16.4	12.7	0.5	13.1	9.6	0.3	9.9	6.55	0.0267	6.58
11.006	11.006-F	Hartbeton zweischichtig, 35 mm	Hartbeton zweischichtig, 35 mm	73.5	73.5	m2	m2	15.4	0.932	16.4	12.3	0.6	12.9	9.1	0.3	9.5	5.99	0.0337	6.03
11.007	11.007-F	Kautschuk, 2 mm	Kautschuk, 2 mm	3.36	3.36	m2	m2	11	3.19	14.1	9.7	3.7	13.4	8.5	4.2	12.6	7.19	4.72	11.9
11.008	11.008-F	Keramik-/Steinzeugplatte, 9 mm	Keramik-/Steinzeugplatte, 9 mm	18	18	m2	m2	14	4.11	18.1	12.9	2.8	15.6	11.7	1.4	13.2	10.6	0.0459	10.7
11.009	11.009-F	Kork Fertigparkett, 10.5 mm	Kork Fertigparkett, 10.5 mm	7.8	7.8	m2	m2	7.77	1.3	9.06	7.0	1.1	8.1	6.2	0.9	7.1	5.42	0.722	6.15
11.010	11.010-F	Kork PVC-beschichtet, 3.2 mm	Kork PVC-beschichtet, 3.2 mm	2.7	2.7	m2	m2	4.75	3.52	8.28	3.9	2.7	6.6	3.1	1.8	4.9	2.28	0.999	3.28
11.011	11.011-F	Korkparkett geölt/versiegelt, 5.3 mm	Korkparkett geölt/versiegelt, 5.3 mm	2.7	2.7	m2	m2	1.96	1.3	3.26	1.6	1.0	2.5	1.2	0.6	1.8	0.845	0.277	1.12
11.012	11.012-F	Kunststeinplatte zementgebunden, 10 mm	Kunststeinplatte zementgebunden, 10 mm	21.5	21.5	m2	m2	4.51	5.86	10.4	3.3	3.9	7.3	2.1	2.0	4.1	0.953	0.0548	1.01
11.013	11.013-F	Laminat, 8.5 mm	Laminat, 8.5 mm	8.5	8.5	m2	m2	8.1	2.3	10.4	7.7	1.6	9.2	7.2	0.8	8.1	6.82	0.0686	6.89
11.014	11.014-F	Linoleum, 2.5 mm	Linoleum, 2.5 mm	2.9	2.9	m2	m2	5.84	0.516	6.36	5.2	0.4	5.6	4.6	0.3	4.9	4.02	0.173	4.19
11.015	11.015-F	Natursteinplatte geschliffen, 15 mm	Natursteinplatte geschliffen, 15 mm	40.5	40.5	m2	m2	16.3	0.514	16.8	12.2	0.4	12.6	8.1	0.2	8.4	4.02	0.103	4.13
11.016	11.016-F	Natursteinplatte geschnitten, 15 mm	Natursteinplatte geschnitten, 15 mm	40.5	40.5	m2	m2	12.9	0.514	13.4	9.6	0.4	10.0	6.4	0.2	6.6	3.1	0.103	3.2
11.017	11.017-F	Natursteinplatte poliert, 15 mm	Natursteinplatte poliert, 15 mm	40.5	40.5	m2	m2	19.1	0.514	19.6	14.3	0.4	14.7	9.5	0.2	9.8	4.77	0.103	4.88
11.018	11.018-F	Parkett 2-Schicht werkversiegelt, 11 mm	Parkett 2-Schicht werkversiegelt, 11 mm	6.1	6.1	m2	m2	7.46	0.337	7.8	6.1	0.2	6.3	4.7	0.1	4.9	3.38	0.0439	3.42
11.019	11.019-F	Parkett 3-Schicht werkversiegelt, 15 mm	Parkett 3-Schicht werkversiegelt, 15 mm	7.9	7.9	m2	m2	7.65	0.437	8.09	6.3	0.3	6.6	4.9	0.2	5.1	3.48	0.0599	3.54
11.020	11.020-F	Parkett Mosaik werkversiegelt, 8 mm	Parkett Mosaik werkversiegelt, 8 mm	5.6	5.6	m2	m2	3.35	0.218	3.57	2.7	0.2	2.9	2.1	0.1	2.2	1.48	0.0372	1.52
11.021	11.021-F	PVC homogen, 2 mm	PVC homogen, 2 mm	3.1	3.1	m2	m2	8.16	6.22	14.4	6.7	4.9	11.6	5.3	3.5	8.8	3.89	2.15	6.04
11.022	11.022-F	Steinholz versiegelt, 16.5 mm	Steinholz versiegelt, 16.5 mm	22	22	m2	m2	12.7	0.279	12.9	12.2	0.2	12.4	11.7	0.1	11.8	11.2	0.0657	11.3
11.023	11.023-F	Synthetische thermoplastische Beläge (TPO), 2 mm	Synthetische thermoplastische Beläge (TPO), 2 mm	3.4	3.4	m2	m2	5.87	10.1	16	5	8	13	5	5	10	4.06	2.37	6.44
11.024	11.024-F	Teppich Kunstfaser getuftet	Teppich Kunstfaser getuftet	2.1	2.1	m2	m2	10.5	6.25	16.7	10.3	4.5	14.8	10.1	2.8	12.8	9.91	1.03	10.9
11.025	11.025-F	Teppich Nadelfilz	Teppich Nadelfilz	1.3	1.3	m2	m2	5.97	3.87	9.84	5.75	2.87	8.61	5.52	1.86	7.39	5.3	0.861	6.16
11.026	11.026-F	Teppich Naturfaser	Teppich Naturfaser	2.7	2.7	m2	m2	3.22	1.85	5.08	2.96	1.61	4.57	2.69	1.38	4.07	2.43	1.14	3.56
11.027	11.027-F	Terrazzo versiegelt, 40 mm	Terrazzo versiegelt, 40 mm	95	95	m2	m2	16.1	1.2	17.3	12.3	0.8	13.1	8.4	0.4	8.8	4.57	0.0423	4.61
12	12-F	Türen	Türen	-	-			0	0		0.000	0.000		0.000	0.000		0	0	
12.001	12.001-F	Aussentüre, Holz, aluminiumbeplankt	Aussentüre, Holz, aluminiumbeplankt	-	-	m2	m2	108	7.64	116	84	6	90	60	4	64	35.4	2	37.4
12.002	12.002-F	Aussentüre, Holz, Glaseinsatz	Aussentüre, Holz, Glaseinsatz	-	-	m2	m2	76	9.7	85.7	67.8	8.0	75.8	59.6	6.2	65.8	51.4	4.49	55.9

12.003	12.003-F	Innentüre, Zimmertüre, Holz, Holzrahmen	Innentüre, Holz	-	-	m2	m2	26.9	5.39	32.3	25.5	4.8	30.2	24.0	4.2	28.2	22.6	3.55	26.1
12.004	12.004-F	Innentüre, Zimmertüre, Holz, Glaseinsatz, Holzrahmen	Innentüre, Holz, Glaseinsatz	-	-	m2	m2	52.8	6.92	59.7	48.1	6.6	54.7	43.4	6.3	49.7	38.7	6	44.7
13	13-F	Rohre	Rohre	kg/m3	kg/m3			0	0		0.000	0.000		0.000	0.000		0	0	
13.001	13.001-F	Acrylnitril-Butadien-Styrol (ABS)	Acrylnitril-Butadien-Styrol (ABS)	1050	1050	kg	kg	4.92	2.75	7.67	4.82	2.84	7.66	4.73	2.93	7.66	4.63	3.02	7.65
13.005	13.005-F	Gusseisen	Gusseisen	7850	7850	kg	kg	2.09	0.00693	2.09	1.79	0.00	1.79	1.48	0.00	1.48	1.18	0	1.18
13.002	13.002-F	Polyethylen (PE)	Polyethylen (PE)	960	960	kg	kg	2.38	2.37	4.75	2.31	2.59	4.89	2.23	2.80	5.04	2.16	3.02	5.18
13.003	13.003-F	Polypropylen (PP)	Polypropylen (PP)	910	910	kg	kg	2.4	2.37	4.77	2.33	2.59	4.92	2.25	2.80	5.06	2.18	3.02	5.21
13.004	13.004-F	Polyvinylchlorid (PVC)	Polyvinylchlorid (PVC)	1390	1390	kg	kg	2.38	2.1	4.48	1.82	1.62	3.44	1.26	1.14	2.40	0.698	0.658	1.36
14	14-F	Anstrichstoffe, Beschichtungen	Anstrichstoffe, Beschichtungen	kg/m2	kg/m2			0	0		0.000	0.000		0.000	0.000		0	0	
14.002	14.002-F	Anstrich, lösemittelverdünnbar, 2 Anstriche	Anstrich, lösemittelverdünnbar, 2 Anstriche	0.3	0.3	m2	m2	0.919	0.0562	0.975	0.865	0.276	1.140	0.812	0.496	1.305	0.758	0.716	1.47
14.001	14.001-F	Anstrich, wasserverdünnbar, 2 Anstriche	Anstrich, wasserverdünnbar, 2 Anstriche	0.3	0.3	m2	m2	0.645	0.0562	0.701	0.611	0.276	0.887	0.578	0.496	1.074	0.544	0.716	1.26
14.003	14.003-F	Bitumenemulsion, 1 Anstrich	Bitumenemulsion, 1 Anstrich	0.25	0.25	m2	m2	0.134	0.0468	0.181	0.118	0.227	0.345	0.102	0.407	0.510	0.0867	0.587	0.674
14.004	14.004-F	Emaillieren, Metall	Emaillieren, Metall	-	-	m2	m2	8.11	0	8.11	6.18	0.00	6.18	4.26	0.00	4.26	2.33	0	2.33
14.005	14.005-F	Pulverbeschichten, Aluminium	Pulverbeschichten, Aluminium	-	-	m2	m2	3.64	0	3.64	3.40	0.00	3.40	3.16	0.00	3.16	2.92	0	2.92
14.006	14.006-F	Pulverbeschichten, Stahl	Pulverbeschichten, Stahl	-	-	m2	m2	4.38	0	4.38	4.09	0.00	4.09	3.81	0.00	3.81	3.52	0	3.52
14.007	14.007-F	Verchromen, Stahl	Verchromen, Stahl	-	-	m2	m2	0.609	0	0.609	0.514	0.000	0.514	0.420	0.000	0.420	0.325	0	0.325
14.008	14.008-F	Verzinken, Stahl	Verzinken, Stahl	-	-	m2	m2	6.09	0	6.09	5.24	0.00	5.24	4.39	0.00	4.39	3.54	0	3.54
15	15-F	Kunststoffe	Kunststoffe	kg/m3	kg/m3			0	0		0.000	0.000		0.000	0.000		0	0	
15.001	15.001-F	Plexiglas (PMMA, Acrylglas)	Plexiglas (PMMA, Acrylglas)	1180	1180	kg	kg	8.68	2.92	11.6	8.7	3.0	11.6	8.7	3.0	11.7	8.66	3.02	11.7
15.002	15.002-F	Polyamid (PA) glasfaserverstärkt	Polyamid (PA) glasfaserverstärkt	1360	1360	kg	kg	8.89	2.62	11.5	8.7	2.0	10.6	8.4	1.3	9.8	8.22	0.701	8.92
15.003	15.003-F	Polycarbonat (PC)	Polycarbonat (PC)	1200	1200	kg	kg	8.49	2.92	11.4	8.4	3.0	11.4	8.3	3.0	11.3	8.26	3.02	11.3
15.004	15.004-F	Polyester (UP) glasfaserverstärkt	Polyester (UP) glasfaserverstärkt	1500	1500	kg	kg	6.92	2.92	9.84	6.51	2.10	8.61	6.09	1.28	7.38	5.68	0.464	6.15
15.005	15.005-F	Polystyrol (PS)	Polystyrol (PS)	1050	1050	kg	kg	3.64	3.08	6.72	3.64	3.06	6.70	3.64	3.04	6.68	3.64	3.02	6.66
21	21-F	Kücheneinbauten und -möbel	Kücheneinbauten und -möbel	-	-			0	0		0.000	0.000		0.000	0.000		0	0	
21.001	21.001-F	Abfalltrennsystem	Abfalltrennsystem	-	-	Stk.	Stk.	16.1	8.13	24.2	15.0	8.0	22.9	13.8	7.8	21.7	12.7	7.66	20.4
21.002	21.002-F	Arbeitsplatte Chromstahl, high-end	Arbeitsplatte Chromstahl, high-end	-	-	m2	m2	332	0.444	332	244	0	244	157	0	157	69.3	0	69.3
21.003	21.003-F	Arbeitsplatte Chromstahl, Standard	Arbeitsplatte Chromstahl, Standard	-	-	m2	m2	55.7	1.05	56.8	40.8	0.9	41.7	25.9	0.7	26.7	11	0.551	11.6
21.004	21.004-F	Arbeitsplatte Kompositwerkstoff (auf Aluminiumhydroxidbasis)	Arbeitsplatte Kompositwerkstoff (auf Aluminiumhydroxidbasis)	-	-	m2	m2	76.2	19.2	95.5	73.9	18.4	92.3	71.5	17.6	89.2	69.2	16.8	86
21.005	21.005-F	Arbeitsplatte kunstharzbeschichtet	Arbeitsplatte kunstharzbeschichtet	-	-	m2	m2	19	1.2	20.2	17.6	1.3	18.9	16.1	1.4	17.5	14.7	1.49	16.2
21.006	21.006-F	Arbeitsplatte Massivholz	Arbeitsplatte Massivholz	-	-	m2	m2	11.7	0.915	12.6	9.2	0.7	9.9	6.7	0.4	7.1	4.19	0.171	4.36
21.007	21.007-F	Arbeitsplatte Naturstein	Arbeitsplatte Naturstein	-	-	m2	m2	40	1.05	41.1	30.4	0.8	31.2	20.7	0.5	21.2	11.1	0.21	11.3
21.008	21.008-F	Dampfabzug	Dampfabzug	-	-	Stk.	Stk.	133	17.1	151	110	16	127	87	15	102	64.2	14	78.1
21.009	21.009-F	Küche, Massivholz, 16-teilig	Küche, Massivholz, 16-teilig	-	-	Stk.	Stk.	418	51.3	470	340	48	389	263	45	307	185	41.1	226
21.010	21.010-F	Küche, Metall, 16-teilig	Küche, Metall, 16-teilig	-	-	Stk.	Stk.	2720	51	2770	2257	43	2297	1793	35	1823	1330	26.4	1350
21.011	21.011-F	Küche, Spanplatte, 16-teilig	Küche, Spanplatte, 16-teilig	-	-	Stk.	Stk.	557	74.8	632	491	73	565	426	72	498	360	70.4	431
21.012	21.012-F	Spüle Chromstahl	Spüle Chromstahl	-	-	Stk.	Stk.	43.6	4.92	48.6	34.4	4.8	39.2	25.1	4.7	29.9	15.9	4.55	20.5
21.013	21.013-F	Spüle Kompositwerkstoff (auf Gesteinsmehlbasis)	Spüle Kompositwerkstoff (auf Gesteinsmehlbasis)	-	-	Stk.	Stk.	30.5	0.178	30.7	29.7	2.2	31.9	28.9	4.3	33.2	28.1	6.29	34.4

7.3 List of products not included in life cycle GHG emissions interpolation between 2020-2050

The materials/components marked in blue refer to specific manufacturers listed in the KBOB database.

Materials/components categories	**Materials/components**
Beton	Hanfbeton, ARBIO
Mauersteine	Backstein, perlitgefüllt, zzwancor
	Kalksandstein, FBB
	Kalksandstein, Hunziker Kalksandstein AG
	Erdstein, aus gepresster Erde, Terrabloc
	Hanfsteine, Schönthaler AG
Andere Massivbaustoffe	Betongranulat
	Glasfaserbeton
	Glasfaserbeton Ecomur
	Mischgranulat
Fenster, Sonnenschutz, Fassadenverkleidungen	Fassadenplatte, Glasfaserbeton
	Fassadenplatte, Glasfaserbeton Ecomur, 15mm
	Fassadenplatte, Glasfaserbeton Ecomur, 18mm
	Fensterrahmen Aluminium, WICLINE 75evo, hergestellt mit Hydro CIRCAL 75R 2,5
	Fensterrahmen Holz, Saphir integral 67/55, G. Baumgartner AG 2,6
	Fensterrahmen Holz-Metall, Saphir integral 55/55, G. Baumgartner AG 2,6
	Rahmenverbreiterung, PVC
	Rahmenverbreiterung, Spanplatte
Metallbaustoffe	Aluminiumprofil blank, WICONA, hergestellt mit Hydro CIRCAL 75R
Holz und Holzwerkstoffe	Balkenschichtholz
	Brettschichtholz, Produktion Schweiz
	Brettsperrholz
	Brettsperrholz, Produktion Schweiz
	Furniersperrholz
	Konstruktionsvollholz
	Massivholz Buche / Eiche, kammergetrocknet, gehobelt, Produktion Schweiz
	Massivholz Buche / Eiche, kammergetrocknet, rau, Produktion Schweiz
	Massivholz Buche / Eiche, luftgetrocknet, rau, Produktion Schweiz
	Massivholz Fichte / Tanne / Lärche, kammergetr., gehobelt, Produktion Schweiz

	Massivholz Fichte / Tanne, kammergetr., Vollholzhaus holzpur
	Massivholz Fichte / Tanne / Lärche, luftgetr., gehobelt, Produktion Schweiz
	Massivholz Fichte / Tanne / Lärche, luftgetrocknet, rau, Produktion Schweiz
	Röhrenspanplatte
	Stabschichtholz, Buche
	Stabschichtholz, Buche, fagus
Dichtungsbahnen und Schutzfolien	Bituminöse Dichtungsbahn, swissporBIKUPLAN ECO
	Bituminöse Dichtungsbahn, swissporBIKUTOP
	Bituminöse Dichtungsbahn, swissporBIKUTOP ECO
	Bituminöse Dichtungsbahn, swissporBIKUTOP
	Bituminöse Dichtungsbahn, swissporBIKUTOP ECO
	Bituminöse Dichtungsbahn, swissporBIKUTOP
	Bituminöse Dichtungsbahn, swissporBIKUTOP ECO
	Bituminöse Dichtungsbahn, swissporBIKUTOP
	Bituminöse Dichtungsbahn, swissporBIKUTOP ECO
	Bituminöse Dichtungsbahn, swissporBIKUTOP
	Bituminöse Dichtungsbahn, swissporBIKUTOP ECO
	Elastomerbitumen-Dichtungsbahn Sopravap EVA 35 flam
	Elastomerbitumen-Dichtungsbahn Sopralen EGV 3
	Elastomerbitumen-Dichtungsbahn Sopralen EGV 3.5
	Elastomerbitumen-Dichtungsbahn Sopralen Premier EP 5 ard flam
	Elastomerbitumen-Dichtungsbahn Sopralen Jardin EP 5 ard flam
	Elastomerbitumen-Dichtungsbahn Sopragum Flam HT-O Jardin S5
	Elastomerbitumen-Dichtungsbahn SOPREMA Vapro Alpino
	Elastomerbitumen-Dichtungsbahn SOPREMA Vapro Nature
Wärmedämmstoffe	Flachsfasern, MAGRIPOL, Premium
	Flachsfasern, feuerfest, MAGRIPOL, Premium+
	Glaswolle, Isover, phenolbasiertes Bindemittel
	Glaswolle, Isover, pflanzliches Bindemittel
	Glaswolle, SUPAFIL
	Polystyrol expandiert, SwissporEPS
	Polystyrol expandiert, 44% Recyclinganteil, SwissporEPS Roof Eco
	Polystyrol expandiert, 100% Recyclinganteil, SwissporEPS R 100%
	Polystyrol extrudiert, SwissporXPS
	Polyurethan, SwissporPIR

	Schaumglas, GLAPOR
	Schaumglasschotter, Misapor
	Steinwolle, Flumroc
	Zellulosefasern, Isofloc
Bodenbeläge	Natursteinplatte geschliffen, Europa, 15 mm
	Natursteinplatte geschliffen, Schweiz, 15 mm
	Natursteinplatte geschliffen, Übersee, 15 mm
Türen	Aussentüre, Aluminium, Glaseinsatz
	Aussentüre, Aluminium, Paneelfüllung
	Aussentüre, Holz
	Innentüre, Aluminium, Glaseinsatz
	Innentüre, Funktionstüre, Holz, Holzrahmen
	Innentüre, Funktionstüre, Holz, Stahlzarge
	Innentüre, Zimmertüre, Holz, Glaseinsatz, Stahlzarge
	Innentüre, Zimmertüre, Holz, Stahlzarge

7.4 Comparison of building standards and labels

SIA documents and Swiss labels	Type of project		Life cycle phases / System boundaries (EN15804)																											
			Construction															Operation												
				A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4		B6.1							B6.2				B6.3
	New building	Renovation	A1-A5 B4 C1-C4	Raw material supply	Transport to the manufacturer	Manufacturing	Transport to the building site	Installation into the building	Use of the installed product	Maintenance	Repair	Replacement	Refurbishment	De-construction and demolition	Transport to waste processing facilities	Waste processing	Waste disposal	B6	Heating	Cooling	Ventilation	Humidification	Deshumidification	Domestic hot water	Fixed (installed) lighting	External lighting	Auxiliary energy	Indoor transport	Other building-related technical systems	Other services consuming energy
SIA 380 :2015	✓	✓																✓	X	X	X	X	X	X	X	X	X	X	(X)	X
SIA 2031 :2016	✓	✓																✓	X	X	X	X	X	X	X	X	X	X	(X)	X
SIA 2032 :2020	✓	✓	✓	X	X	X	(X)	(X)				X		X	X	X	X													
SIA 2040.2017	✓	✓	✓	X	X	X	(X)	(X)				X		X	X	X	X	✓	X	X	X	X	X	X	X	X	X	X	(X)	X
SIA 390:2023 version submitted to public consultation (June 2023), not final	✓	✓	✓	X	X	X	(X)	(X)				X		X	X	X	X	✓	X	X	X	X	X	X	X	X	X	X	(X)	X
MoPEC 2014	✓																	✓	X	X	X									
CECB/GEAK 2.1.0	✓	✓																✓	X		X			X	X	X	X	X	X	X
Minergie-(P/A) pre-2023																			X											
Minergie-(P/A) 2023	✓	✓	✓	X	X	X	(X)	(X)	0	0	0	X	0	X	X	X	X	✓	X											
Minergie-Eco 2023	✓	✓	✓	X	X	X	(X)	(X)	0	0	0	X	0	X	X	X	X													
SNBS 2.1 (2021)	✓	✓	✓	X	X	X	(X)	(X)				X		X	X	X	X	✓	X	X	X	X	X	X	X	X	X	X	(X)	X
SNBS 2023	✓	✓	✓	X	X	X	X	X	X	X	X	X	X	X	X	X	X	✓	X	X	X	X	X	X	X	X	X	X	(X)	X
SméO - Énergie	✓	✓																✓	X	X	X	X	X	X	X	X	X	X	(X)	X
SméO "Énergie-Environnement"	✓	✓	✓	X	X	X	(X)	(X)	0	0	0	X	0	X	X	X	X													

SIA documents and Swiss labels	Building category	Reference document (calculation method and/or requirements)			Further information	Method to define the indicators	Reference / source	Type of indicators included					Reference unit to report the indicator	Assessment methodology		
	According to SIA 380/1	Construction	Operation	Mobility				Greenhouse Gas (GHG) emissions (fossil only?)	Total primary energy	Non renewable primary energy	Other energy indicators (e.g., final ponderated energy)	Ecopoints		Type of assessment	Assessment details provided: - indicative, target, limit values - scope: global, by domain, by component	Requirements for the indicators
SIA 380 :2015	All	-	-	-		LCA-based	KBOB 2014	✓	✓	✓	Final energy, ponderated		per m² ERA	-	-	-
SIA 2031 :2016	All	-	-	-	These two approaches are available:	LCA-based	SIA380 (KBOB 2014)	✓	✓				per m² ERA	Classes	° Energy classes (A to G), based on total primary energy ° Envelope classes (A to G), based on building heating needs ° CO2 classes (A to G)	-
						National factors	EnDK				Final energy, ponderated				Energy class (A to G), based on final ponderated energy	
SIA 2032 :2020	All	-	-	-		LCA-based	KBOB 2016	✓		✓			per m² ERA	-	-	-
SIA 2040.2017	I à VI	SIA 2032	SIA 380/1:2016	SIA 2039		LCA-based	Construction: KBOB 2016 Operation: SIA380 (KBOB 2014) mobility: SIA 2039	✓		✓			per m² ERA	Comparison with target values	Indicative values for each domain (construction, operation and mobility), for new buildings and renovation projects, but not mandatory to be below for each domain	Project should comply either with ° target value "construction + operation + mobility" (sum of the indicative values) or ° target value "construction + operation" (sum of the indicative values)
SIA 390:2023 version submitted to public consultation (June 2023), not final	I à VI	SIA 2032	SIA 380/1:2016	SIA 2039		LCA-based	Construction: KBOB 2022 Operation: KBOB 2022 mobility: SIA 2039	✓		(✓) (for info only)			per m² ERA	Comparison with limit value	° Indicative values (target and limit) for each domain (construction, operation and mobility), for new buildings and renovation projects ° Target values can only be reached when the initial situation is favourable and when using all means currently available. Negative emissions can only be taken into accound then trying to reach target value.	Project should comply with both ° global limit value (sum of indicative limit values) ° limit value "construction + operation" (sum of indicative limit values)
MoPEC 2014	All	-	-	-		National factors	EnDK				Final energy, ponderated		per m² ERA	Comparison with limit values	Limit values, by square meter, for each building category	Project should comply with limit value
CECB/GEAK 2.1.0	I to VI	-	SIA 380/1:2016 SIA 2031	-	Before 1/1/ 2023	National factors	EnDK				Final energy, ponderated		per m² ERA	Classes	° Global efficiency class (A to G), based on ponderated final energy ° Thermal envelope class (A to G)	-
					Since 1/1/2023	National factors	° direct CO2 emission (operation scope 1): Ordonnance loi CO_2, Annexe 2.1, al.6 ° GHG emissions (operation scope 3): KBOB 2022 ° Ponderated final energy: EndK	✓			Final energy, ponderated				° Global efficiency class (A to G), based on ponderated final energy ° Thermal envelope class (A to G) ° CO2 class (A to G) ° No class or target value for GHG emissions	
Minergie-(P/A) pre-2023		-	MoPEC (SIA 380/1:2016)			National factors	EnDK				*Final energy, ponderated*					° Heating demand limit (new buildings & renovation)
Minergie-(P/A) 2023	Minergie-(P) I à XII Minergie-A I à XI	SIA2032	GEAK 2.1.0	-		Construction: LCA-based Operation: National factors	Construction: KBOB2022 Operation: KBOB2022	✓			*Final energy, ponderated*		per m² ERA	Comparison with limit value	° Operation: energy limit values for each category of building (new construction & renovation), based on MOPEC2014 (requirements I & II) if existing, otherwise Minergie (Minergie index) ° Construction: GHG limit values for each building catgory, by m² of SRE	° Heating demand limit (new buildings & renovation) ° Construction GHGe limit (new buildings)
Minergie-Eco 2023	All except (VII, X and XII)	SIA 2032	GEAK 2.1.0	-		LCA-based	KBOB 2022	✓		✓			per m² ERA	Comparison with limit value	° New building: target and limit values for each building category (by m²), increased when special equipment is used (solar collectors, geothermal probes). ° Renovation: target and limit values per square meter of building element renovated/added or technical system renovated/added.	* Construction GHGe: limit value is lower than in Minergie and target value
SNBS 2.1 (2021)	I to IV	Minergie Eco	Minergie / MoPEC 2014	SIA2039	The two approaches on the left are available	Construction: LCA-based Operation: National factors	Construction: KBOB2022 Operation: MoPEC / Minergie Mobility: SIA2039	✓		✓ (constr.)	Final energy, ponderated (oper.)		per m² ERA	Points	Construction, operation and mobility evaluation for non renewable primary energy and GHG each gives between 1 to 6 points (max 36 points), which are later taken into account in the evaluation of the "envionment" domain.	The number of points is based on: ° Construction: comparison with Minergie ECO limit and target values ° Operation: comparison with Minergie, Minergie-A, Minergie-P requirements for heating demand ° Mobility: comparison with SIA 2040 mobility indicative value
		SIA 2040	SIA 2040	SIA2039		LCA-based	Construction: KBOB2016 Operation: SIA380 (KBOB2014) Mobility: SIA2039	✓		✓			per m² ERA			The number of points for each domain is based on SIA2040 construction, operation and mobility indicative values
SNBS 2023	I to IV	Minergie ECO 2023 & SIA 2032	GEAK 2.1	SIA2039		Construction: LCA-based Operation: National factors	Construction: KBOB2022 Operation: KBOB2022 Mobility: SIA2039	✓		✓ (constr.)	Final energy, ponderated (oper.)		per m² ERA	Points	Construction, operation and mobility evaluation for GHG each gives between 1 to 6 points. Construction and operation evaluation for non renewable energy also givers 1 to 6 points. Max is 30 points for these cirteria, which are later taken into account in the evaluation of the "enviornment" domain.	The number of points is based on: ° Construction: comparison with Minergie ECO limit and target values, taking also into account residual value of demolished building ° Operation: comparison with pre-defined SNBS values ° Mobility: comparison with SIA2040 mobility indicative value
SméO - Énergie	I to VI + VIII	-	MoPEC 2014	-	Both are required	National factors	EnDK				Final energy, ponderated		per m² ERA	Comparison with limit value		New construction: MoPEC 2014. Renovation: 150% limit values for new construction
			SIA 2040	-		LCA-based	KBOB	✓		✓					-	Project should comply with SIA2040 "Operation" indicative values
SméO "Énergie-Environnement"	I to VI + VIII	SIA 2032 & SIA 2040	-	-	Label complementary to the SméO "Energy" label.	LCA-based	KBOB	✓		✓			per m² ERA	Comparison with limit value	-	Project should comply with SIA2040 "Construction" indicative values

SIA documents and Swiss labels	Other requirements (Carbon storage in buildings, reused…) or additional assessments	Suitability of the assessment in achieving a net zero GHG emissions target	Measures that reduce GHG emissions [ignore, information, assessement, recommendation, requirement, (empty means out of scope)]																	
			Frame conditions				*Definition of objectives*			*Preliminary study*					*Project phase*			*Tendering*	*Other*	
			Densification	Planning suffiency	Extension and availability of networks	Decarbonisation of the industry	Transform vs New	Performance sufficiency	Choice of site	Size and compactness	Reduce undeground	Reduce/optimize window to wall ratio	Re-use	Energy concept	Choice and dimensionning of materials	Technical installations [reduce and efficiency]	Technical installations [renewable energies]	Suppliers	Carbon storage, negative emissions technologies	Other various
SIA 380 :2015	-	No whole life cycle GHG emissions assessment						Set requirements for heating needs												
SIA 2031 :2016	-	No whole life cycle GHG emissions assessment					Recommendation	Assessment and promotion through energy and CO2 classes						Encouraged by means of assessment and energy performance class		Assessment and promotion through energy classes	Assessment and promotion through energy classes			
SIA 2032 :2020	-	Only construction domain assessment	Recommendation	Recommendation			Recommendation and calculation method to assess the residual embodied GHG of an existing building under 60 years old.	Recommendation		Recommendation	Recommendation	Recommendation	Ignored		Recommendation	Recommendation	Recommendation	Recommendation		
SIA 2040.2017	-	Whole life cycle GHG emissions are assessed. Target values are set but not in accordance with a net-zero objective. Negative emissions are not accounted.	Recommendation	Recommendation	Recommendation		Recommendation	Recommendation	Encouraged through evaluation of mobility (location with good access to public transport and commodities)	Recommendation	Recommendation	Recommendation	Ignored		Recommendation	Recommendation	Recommendation	Recommendation		Building products with long durability, easy replacement and maintenance
SIA 390:2023 version submitted to public consultation (June 2023), not final	Annexe A (Informative) Dérivation des valeurs limites et valeurs cibles Annexe B (informative) Contributions to carbon neutrality (net zero emission building's definition, negative emissions compatibility, accounting of reused components) Annexe D (normative) Surface areas per person	Whole life cycle GHG emissions are assessed. Limit and target values are set in accordance with a net-zero objective for "Construction" and "Operation" domains separatly and jointly, for New construction and Transformation. Negative emissions compatible.	Recommendation	Recommendation. The average m²SRE/occupant at national scale influence the definition of the limit and target values. Hence can indirectly encourages sufficiency.			Recommendation	Recommendation	Encouraged through evaluation of mobility (location with good access to public transport and commodities)	Recommendation	Recommendation	Recommendation	Assessment and recommendation. Reuse elements have GHG emissions of production equal to 20% of their new counterpart.		Recommendation	Recommendation	Recommendation	Recommendation		Building products with long service life, easy replacement and maintenance, raise awareness among occupants during operation
MoPEC 2014	Various additional requirements: ° Thermal insulation in winter ° Thermal protection in summer ° Technical systems (382/1 & 384/1) ° On-site electricity production ° Use of renewable energy when replacing heating system ° Replacement of electrical heat production ° Electrical consumption ° ...	No whole life cycle GHG emissions assessment						Requirements: same heating needs limit value than in SIA 380/1						Encouraged by means of the other requirements		Requirements	Requirements			
CECB/GEAK 2.1.0	° Thermal envelope: average U-values for each kind of construction element ° Heating: grade based on ponderated final energy for heating divided by heating demand ° DHW: grade based on ponderated final energy for DHW divided by DHW demand ° Electricity: grade based on electricity needs and PV electricity produced on site	No whole life cycle GHG emissions assessment. GHG emissions (scope 2) of operation but without limit or target values.			Encourages connecting to heat network with high share of renewable source or waste valorisation through weighting factors in the calculation of the energy performance indice		Inform and plans energy refurbishment strategies	Encourages by means of (non-LCA) calculation and energy performance class						Encourages by means of (non-LCA) calculation and energy performance class		Encourages by means of (non-LCA) calculation and energy performance class	Encourages by means of (non-LCA) calculation and energy performance class			
Minergie-(P/A) pre-2023																				
Minergie-(P/A) 2023	Various other criteria are evaluated: exploiting solar potential, thermal envelope insulation and air tightness, summer thermal protection, air renewal, zero-CO2 operation, energy monitoring	GHGe limit values for "Construction" domain based higher than SIA 2040 values and only for New Construction. GHGe (scope 2) of operation is calculated for information (no limit or target values).			Requires connecting to heat network with less than 50% fossil source	Requires the valorisation of waste heat		Requirements over heating needs 10% to 30% lower than in MoPEC/SIA 380/1						Requirement about the energy performance Minergie indice	Encouraged by means of limit values over "Construction" domain's GHG emissions	Requirements equal or higher than MoPEC 2014	Requirements of PV or thermal solar panel covering the roof are, 60% for construction, 30% for transformation ; no fossil fuel for domestic generation of heat and hot water except cogeneration ; embodied GHGe of solar panels (PV and thermal) and geothermal probes increases the limit value (burden free).			Indicative value is calculated for biogenic carbon content in the building
Minergie-Eco 2023	Various other criteria are taken into account: indoor climate, accoustics and noise protection, natural lighing, occupants health, ressources depletion and climate protection, building concept and circular economy, biodiversity and water cycle, resilience to climate change, innovation	Complement to Minergie, standard LCA calculation for GHG emissions of the construction. Lower limit values and additional target for "Construction" domain adapted from SIA 2040, for New Construction and Transformation. GHGe (scope 2) of operation is calculated for information (no limit or target values).	Promotes building extension (horizontal or vertical) for transformation (+20% m² SRE)	Encourages flexbility and adaptability of the building			Encourages Transformation of existing by applying a penalty to New construction if they are about to deconstruct existing building based on their residual embodied GHG. Calculation based on SIA 2032.						°Deconstruction: encourages a reclamation audit, and 75%-vol. of reuse °New construction or transformation: encourages 10 to 20%-vol. of reused elements. Reused elements have zero GHG emissions in A1-A3. Encourages design for disassembly measures		Requirements about origin of wood (non-certified non-european wood is excluded) and amount of concrete from recycled granulates. Encourages lower GHG emissions cement. Encourages bio-based materials.			Promotes the use of local resources (under 25 km for sand, gravel, clay etc.) and building products (under 100 km)		Encourages "innovative" measures and solutions that would reduces GHG emissions.
SNBS 2.1 (2021)	Various other social, economic and environmental criteria are evaluated. Points for these three domains are averaged in order to obtain a single grade.	Whole life cycle GHG emissions assessment. Limit and target values for "Construction" and "Operation" domains from Minergie-ECO and SIA 2040.																		
SNBS 2023	Various other social, economic and environmental criteria are evaluated. Points for these three domains are averaged in order to obtain a single grade.	Whole life cycle GHG emissions assessment. Limit and target values for "Construction" and "Operation" domains from Minergie-ECO and SIA 2040. "Operation" GHG emissions are calculated based on CECB/GEAK 2.1	Encourages new construction with high plot density contributing to inward urban development. Encourages transformation that increases density (elevation).	Encourages sufficiency and reducing SRE per occupant, along with social criterias that could help public acceptance such as accessibility and facilities, participation, etc. Interestingly, in documentation the criteria 222 "Density of occupancy" is not presented as related to SDG 13 "Climate action" but should.			Encourages Transformation of existing by applying a penalty to New construction if they are about to deconstruct existing building based on their residual embodied GHG. Simplified calculation with 8 kgCO2eq/m² for existing and 10 kgCO2eq/m² for New.	Encourages to attain performance sufficiency at least according to MoPEC/MuKEN 2014, Minergie P/A are best	Can be assessed in the criterias "Objectives and specifications", and "Urban planning and architecture".				Encourages reuse with zero GHG emissions in A1-A3 for reused elements. Encourages a reclamation audit in case of deconstruction. Conversely to Minergie-ECO, there is no incentive to reach a certain volume of reused elements. Encourage design for disassembly.	Encourages GHG emissions of operation lower than 7.5 kgCO2eq./m² (grade 4). Best grade is under 2.5 kg CO2eq./m²	Encourages bio-based materials (same as Minergie-ECO)	Encourages the regulation and optimisation of operation right after commissioning				
SméO - Énergie																				
SméO "Énergie-Environnement"																				

SIA documents and Swiss labels	Suitability of the measures in achieving a net zero GHG emissions target
SIA 380 :2015	Centered on heating needs, the required limit values values helps attain performance sufficiency. Many other measures are not covered thus not suitable to achieve net zero
SIA 2031 :2016	Centered on the certification and classes definition of operational energy and GHG emissions in building, the information provided helps promote measures of energy sufficiency, energy concept, and technical installations. No stringent measures centered on GHG emissions reduction.
SIA 2032 :2020	A large set of measures over all phases (from frame conditions to tendering) are recommended but as a standard there are no requirement or constraint over the measures
SIA 2040.2017	Similar to SIA 2032 with a broader scope, the recommendations are completed with aspects on regional planning and choices of site. No requirement or constraint over the measures.
SIA 390:2023 version submitted to public consultation (June 2023), not final	Measures from SIA 2032/2040 are completed, notably with reuse. No requirement or constraint over the measures.
MoPEC 2014	MoPEC 2014 is centered on the energy efficiency of buildings, it complete the requirement of SIA 380/1 over heating needs with recommendations about performance sufficiency and technical installations. No measures that directly adress GHG emissions reduction are incorporated.
CECB/GEAK 2.1.0	Centered on the evaluation of heating needs and final energy consumption of an existing building. The effects of the measures are not assessed through an LCA-based GHG emissions calculation but with national weighting factors. No required measures that directly adress GHG emissions reduction.
Minergie-(P/A) pre-2023	Required measures focus on global energy performance and high share of renewables. Even though construction GHG emissions are calculated, no measures are required toward low carbon construction (materials, reuse) or building desing (compactness, window to wall ratio).
Minergie-(P/A) 2023	
Minergie-Eco 2023	Additional requirements to Minergie about short-distance suppliers (not included in the scope A1-A3), building extension, and reuse. Promote transformation over new construction. No measures are strictly required to attain low carbon construction.
SNBS 2.1 (2021)	
SNBS 2023	SNBS 2023 can be combined with Minergie and Minergie-ECO. It adds numerous incentives to include sustainable and urban planning aspects from the start of a project in the definition of objectives and specifications. Urban densification, planning sufficiency, and transformation instead of deconstruction, are encouraged consistently along with economic and social measures that could enhance public acceptance and well-being. On the operational energy side, it is the only label that encourages decreasing GHG emissions for operation and rewards it with points according to target values. However, out of the 35 criteria, 15 criteria relate to GHG emissions reduction and weight for 33% to 50% of the certification.
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SméO "Énergie-Environnement"	

8 Appendix II - Sensitivity of design choices on GHG emissions

8.1 Additional results

8.1.1 Overall sensitivity on multi-family house

Figure 49 presents the individual local sensitivity of the selected measures applied to the base model of a multi-family house. The grey area represents the range of existing GHG targets, with the upper bound reflecting the least ambitious Minergie target and the lower bound representing the more ambitious target set by the prSIA390/1. Key observations include the following:

- Size and compactness: The building's size and compactness, particularly the above- and below-ground volumes, strongly influence GHG emissions. Compact designs with fewer underground floors perform better, while larger, more spread-out design increase GHG emissions.
- Material choices: Structural and non-structural material choices also have a significant impact. Low-carbon and bio-based materials such as timber, straw or earth help reduce GHG emissions.
- Energy supply and technical installations: Particularly the choice of energy supply for heating is critical. Fossil-based systems cause a significant spike in emissions, underscoring the urgent need to prioritize renewable energy systems.

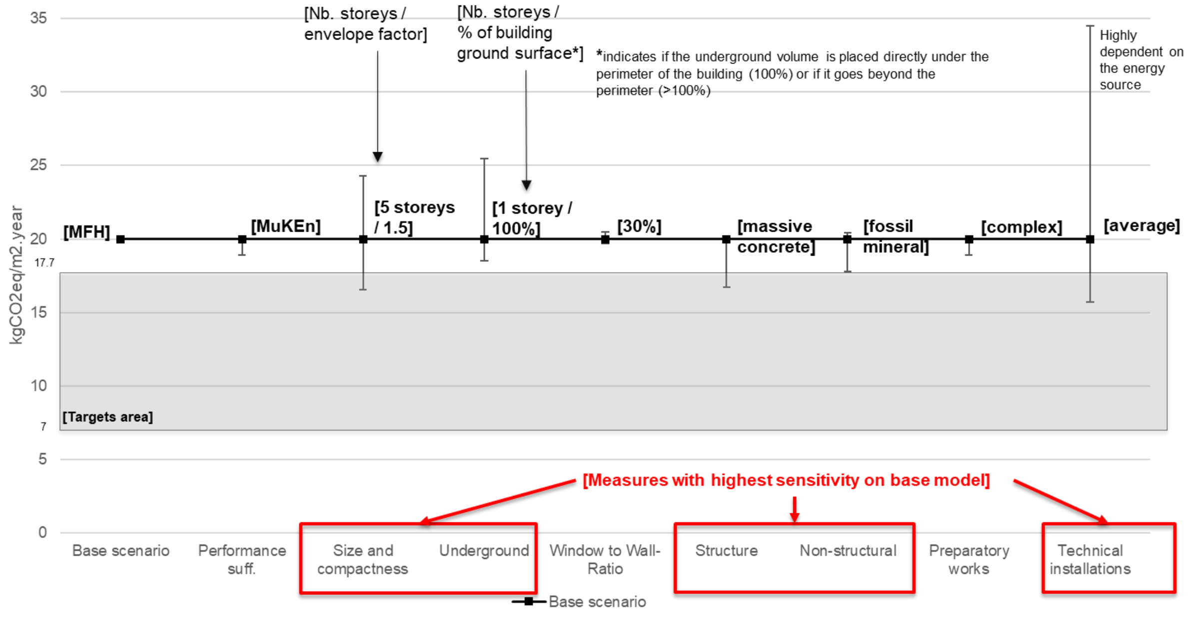

Figure 49: Individual local sensitivity of the selected measures on the base model of a MFH. Grey area represents the area of existing GHG targets with the upper bound corresponding to the higher value of Minergie and the lower bound to the ambitious value of the prSIA390/1.

8.1.2 Detailed sensitivity and dependencies of single measures

To dig deeper in some individual measures and their possible dependencies with other measures and building elements, hereunder the sensitivity of single measures, considering multiple parameters.

Figure 50 shows the sensitivity of the “performance sufficiency” measure that integrates three levels of energy performance: MOPEC (minimum law requirements), Minergie, and Minergie-P. The measure is examined in relation to its dependency on the insulation material (EPS, wood wool, and straw) and electricity mix carbon intensity (current KBOB consumption mix and future average consumption mix). Results show that moving from basic legal requirements (MOPEC) to Minergie standards reduces overall GHG emissions. However, going a step further with Minergie-P standard does not always result in proportional GHG reductions, especially when combined with carbon-intensive materials or energy sources. This highlights the importance of carefully balancing performance levels with carbon intensity of building materials and energy supply.

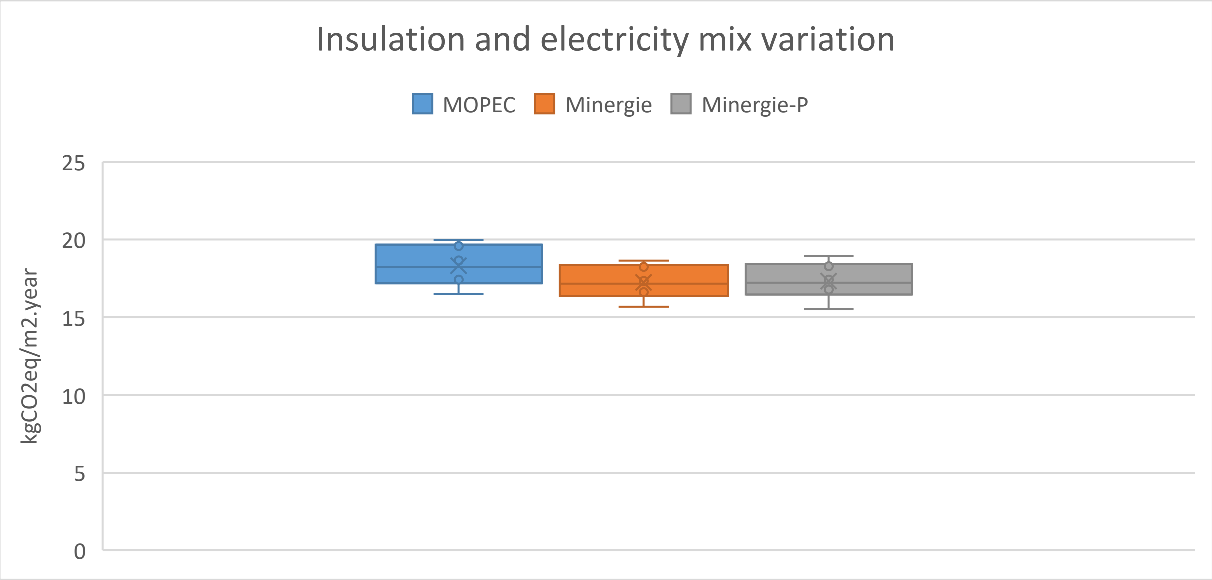

Figure 50: Sensitivity of performance sufficiency measure on MFH base model with dependency on insulation material and electricity mix.

Figure 51 presents the sensitivity of the measure “size and compactness”. The envelope factor (ratio of envelope surface to energy reference area) is used as key parameter for this measure. This factor is though dependant on the size and shape of the building (e.g., number of floors above-ground) with SFH with less vertical development achieving higher envelope factors and therefore higher GHG emissions related to the envelope. Results on the base MFH model show that increasing the number of above-ground floors has less impact on GHG emissions than the overall development of the building envelope. A more compact design with fewer exposed surfaces reduces energy and materials demands.

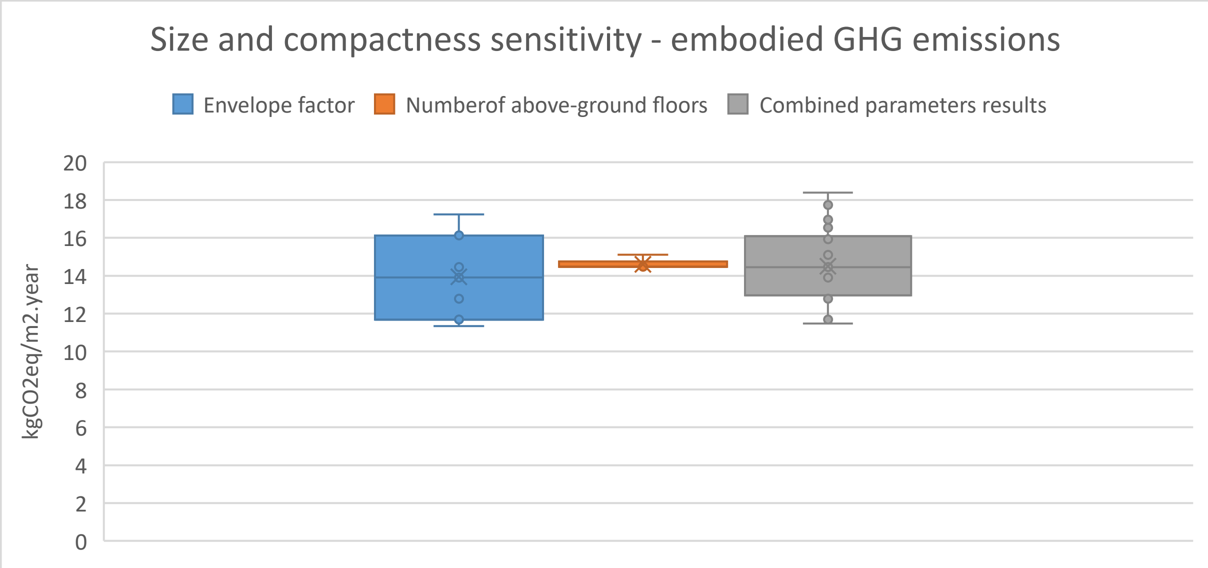

Figure 51: Sensitivity of size and compactness measure on MFH base model with dependency on envelope factor and number of above-ground floors.

In Figure 52 the sensitivity of underground developments can be seen. This impact is affected by the number of underground floors, the size of the underground volume (under the above-ground volume or bigger), and the type of preparatory works (simple or complex). Results show that at equivalent size and complexity of preparatory works, the number of underground floors has the highest impact. Nevertheless, increasing the size by going beyond the above-ground perimeter can significantly increase GHG emissions.

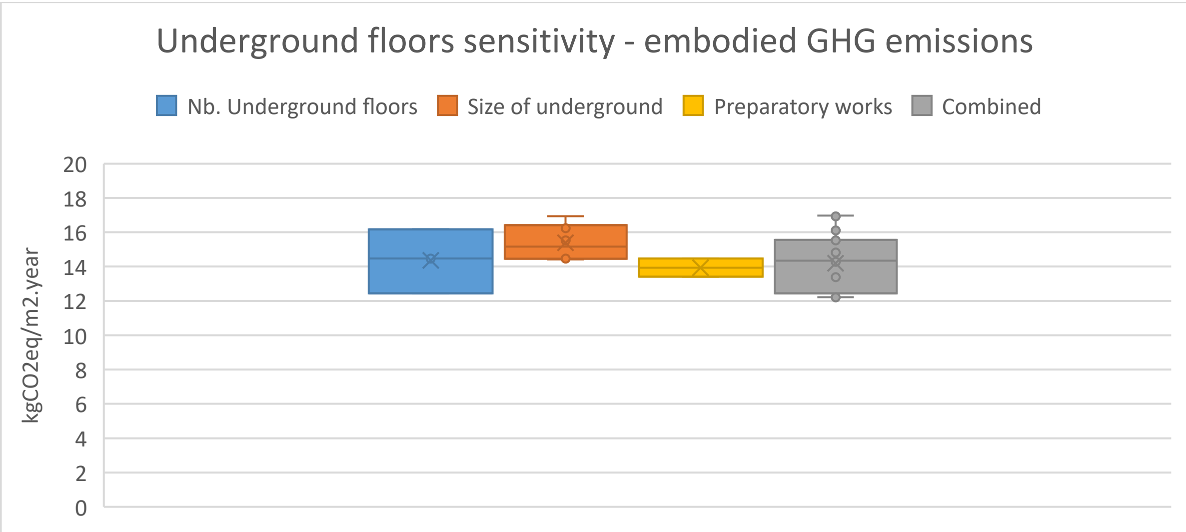

Figure 52: Sensitivity of underground construction and preparatory works measures on MFH base model with dependency on number of underground floors, size of underground volume, type of preparatory works.

Figure 53 shows the sensitivity of structural materials throughout the different building elements. Results show that in the base MFH model, the material choice for the structure of internal slabs has the highest impact on GHG emissions.

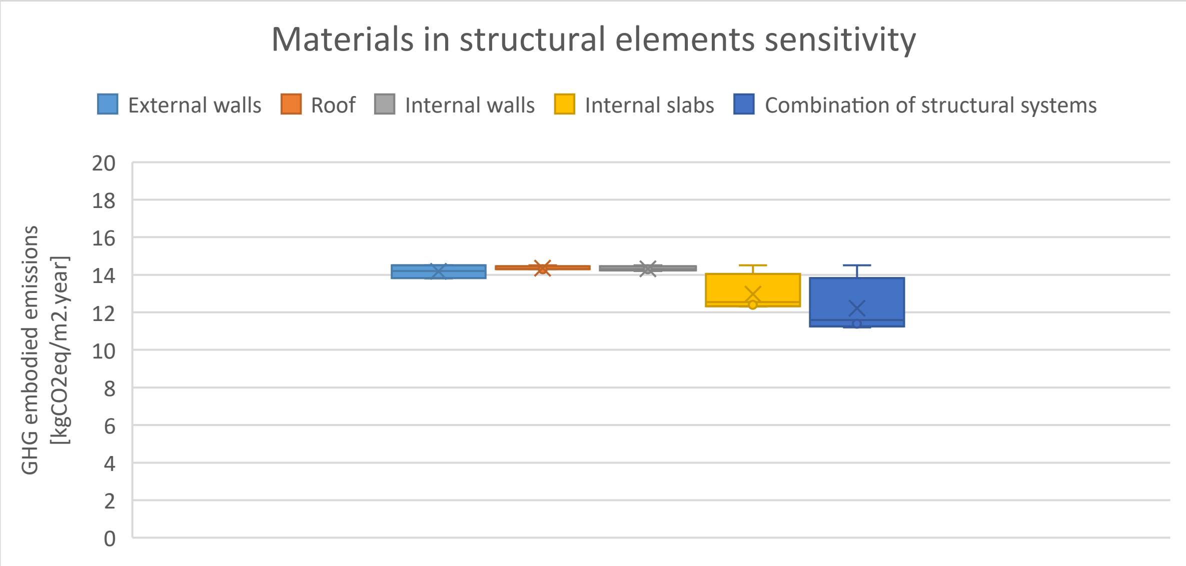

Figure 53: Sensitivity of structural materials measures on MFH base model divided into main structural elements.

Finally, Figure 54 shows the sensitivity of the last measure linked to technical installations and energy supply. As expected, the largest variability comes from the energy supply used for heating. Fossil-based systems result in significant peaks in total GHG emissions.

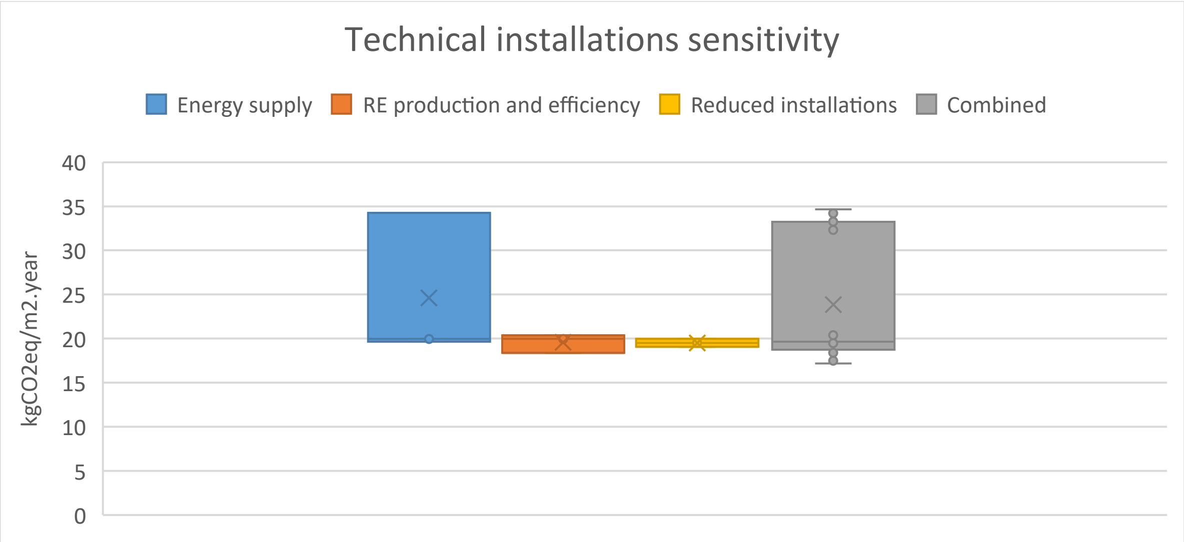

Figure 54: Sensitivity of installations and energy supply measures on MFH base model with dependency on energy supply for heating demand, size and efficiency of renewable energy production on site, and technical installations.

8.2 Conclusions

The sensitivity analysis conducted in this study clearly demonstrates that thoughtful design decisions can substantially influence building's GHG emissions.

In conclusion, the cumulative effect of well-considered design choices can bring buildings significantly closer to meeting or exceeding current GHG emissions targets. Future studies should focus on more complex simulations to assess the interdependencies between multiple measures and optimize planning processes further.