Housing construction from 4 to 1 planet

24 best practice cases

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BUILD DEPARTMENT OF THE BUILT ENVIRONMENT
AALBORG UNIVERSITY

BUILD REPORT

2023:12

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TITLE	Housing construction from 4 to 1 planet: 24 Best Practice Cases
SERIES TITLE	BUILD Report 2023:12
FORMAT	Digital
EDITION	2nd edition
YEAR PUBLISHED	2024
PUBLISHED DIGITALLY	February
AUTHORS	Agnes Garnow, Buket Tozan, Lea Hasselsteen Nielsen, Liv Kristensen Stranddorf, Kin Sun Tsang, Camilla Ernst Andersen, Christian Grau Sørensen and Harpa Birgisdóttir
LANGUAGE	English
PAGES	203
LITERATURE REF	19
KEYWORDS	Life-cycle assessment, environmental impact, case collection, biogenic materials, best practice, housing construction from 4 to 1 planet
ISBN	978-87-945-6102-0
ISSN	2597-3118
COVER	Agnes Garnow
PUBLISHER	Department of the Built Environment, Aalborg University A.C. Meyers Vænge 15, 2450 Copenhagen SV, build@build.aau.dk, www.build.aau.dk This publication is covered by the Danish Copyright Act.

CONTENTS

FOREWORD

This report is part of the initiative Housing Construction from 4 to 1 Planet's body of knowledge, which sets out to gather, analyse, and present knowledge about best-practice housing construction to ensure that the initiative rests on a strong foundation of knowledge and makes use of the best possible tools, as well as inspiring and showing the way forward for future housing construction with a lower carbon footprint.

Data and experience from building case studies are obtained in collaboration with architects, engineers, architectural technologists and construction managers, and building owners.

The initiative is funded by the philanthropical association Realdania and the non-profit foundation VILLUM FONDEN.

In the 2nd edition of this report, case E06 has been excluded due to inconsistencies in the calculation. It is BUILD's assessment that results from the 1st edition of this report are inconclusive. It is especially the subject of extensive overheating in the building that have resulted in the decision to exclude the case from "best practice".

The report was prepared by BUILD during the period August 2022–June 2023 by Agnes Garnow, Buket Tozan, Lea Hasselsteen Nielsen, Liv Kristensen Stranddorf, Kin Sun Tsang, Camilla Ernst Andersen, Christian Grau Sørensen, & Harpa Birgisdóttir

Calculation methodology and life-cycle analyses are a collaborative effort between BUILD and Artelia prepared during the period August 2022–May 2023. From Artelia, contributions were made by Steffen Maagaard, Louise Østergaard Pedersen, Emma Frank Smidt, and Julie Thyregod Jepsen. From BUILD, contributions were made by the staff members mentioned above and Senior researcher Jørgen Rose.

Moreover, special words of thanks are due to the key actors involved as well as Stig Hessellund, project manager, Realdania, and to Michael K. Rasmussen, project manager acting for VILLUM FONDEN.

BUILD – Department of the Built Environment, Aalborg University Copenhagen, Division of Sustainability, Energy Efficiency, and Indoor Climate.
May 2023

Tine Steen Larsen
Divisional Head

INTRODUCTION

BACKGROUND

Possibly the most serious problem facing today's world is the global climate crisis, whose impact becomes more acute by the day. International climate agreements such as the Paris Agreement (United Nations Climate Change, 2015), strive to minimise global CO_2 emissions in a bid to prevent global surface temperatures from rising beyond 2.0 degrees and preferably 1.5 degrees Celsius. Globally, the building industry is responsible for 37% of the world's total CO_2 emissions (Global Status Report 2022). Nationally, Denmark uses its share of the Earth's total resources four times over according to Earth Overshoot Day (Global Footprint Network). During the period 2015–2020, 66% of completed heated buildings comprised housing, including farm houses, single-family, terraced, and multi-storey housing, student accommodation, other residential housing, and holiday homes (Statistics Denmark), indicating that a major part of resources in Denmark are used for housing construction. To minimise resource consumption and CO_2 emissions resulting from this, the building industry needs to map out and implement housing construction with vastly reduced environmental impact whilst at the same time building healthy and attractive housing.

The initiative "Housing Construction from 4 to 1 Planet" aims to create more sustainable new housing, respecting the resources available to us on the planet. More specifically, the goal is to reduce the carbon footprint for a Danish dwelling by 75% from an average 10 kg CO_2eq./m²/year to 2.5. kg CO_2eq./m²/year before 2030. The carbon footprint for housing construction can be estimated via life-cycle assessments (LCAs), a holistic method used to calculate environmental impact associated with the life-cycle of a product or system (DS/EN ISO 14040:2008).

As a new initiative, this report presents a case collection of best-practice housing construction, demonstrating less traditional construction practices that may result in a lower whole-life carbon footprint compared to conventional housing. The case collection is intended as a reference work to provide inspiration for those aiming to build housing with a lower carbon footprint. The collection comprises 24 residential dwellings, including seven single-family homes, two holiday homes, six terraced housing projects, nine multi-storey housing projects, including three containing studio flats, plus one other type of housing. More specifically, a community centre – included in the collection because of its experimental approach to new-build in, for example, concrete.

Of the 24 case studies, 19 are complete, i.e. the underlying data set is sufficient to present an aggregate result of the environmental impact. The remaining five, so-called 'pixie' cases, are presented with interim results. Pixie cases are projects with interesting potential but not yet fully projected or constructed, or where no conclusive results on environmental impact could be reached due to insufficient data.

The environmental impact from the best practice cases and other housing construction in Denmark is compared with the impact according to the reduction roadmap (Reduction Roadmap, 2022), and whether the buildings remain within a 'safe operating space' for greenhouse gas emissions (Petersen, S. et al., 2022).

Figure 01: Housing construction from 4 to 1 planet

LIFE-CYCLE ASSESSMENT

A life-cycle assessment (LCA) is a standardised method used to assess and evaluate environmental impact and resource consumption associated with a product or a service, including construction (DS/EN15978:2012, DS/EN ISO 14040:2008). For example, an LCA can be used to compare environmental impact from entire buildings as well as smaller units such as specific building components or products. LCAs factor in a building's potential whole-life environmental impact subdivided into life-cycle stages and life-cycle modules. A building's life-cycle stages comprise resource extraction and manufacture of materials, transportation, construction, use, maintenance, as well as waste processing and end-of-life disposal.

A1-5

Carbon emissions occurring here and now and even before the building is occupied are designated upfront emissions. These specifically comprise the embedded environmental impact associated with the production and construction of the building, i.e. the Product stage (modules A1–3) and Construction Process stage (A4–A5).

B1-5
C1-4

Apart from modules A1–5, embedded emissions comprise the building's Use and End of Life stages and related modules. The Use stage includes the modules Use (B1), Maintenance (B2), Repair (B3), Replacement (B4), and Refurbishment (B5), and the End-of-Life stage includes the modules De-construction (C1), Transport (C2), Waste Processing (C3), and Disposal (C4).

B6-7

Operational emissions are associated with energy and water use in the Use stage when the building is occupied, thus covering the life-cycle modules B6-.

D

The last stage in a building's life cycle assesses potential environmental benefits from the reuse, recycling, or recovery of materials. Potential environmental benefits are assessed and designated module D.

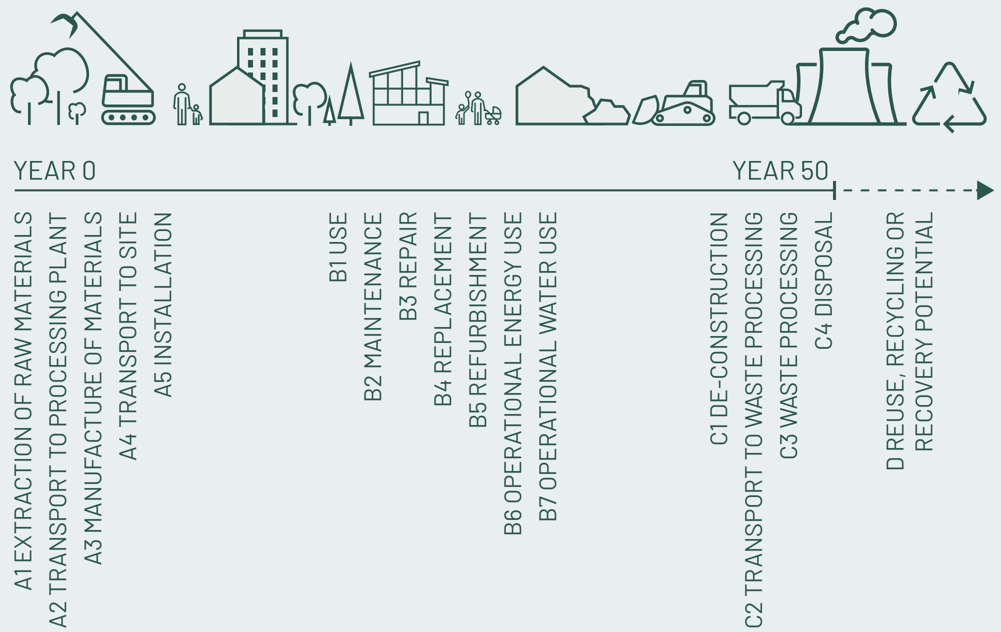


Figure 02: Life-cycle stages and related modules
Whole Life Carbon Impact from: 45 Timber Buildings (Andersen, C. M. E. et al., 2023)

CLIMATE TARGETS > INTERNATIONAL

In 2015, Denmark signed the Paris Agreement (United Nations Climate Change Conference, 2015), placing an obligation on Denmark and 195 other countries to strive to prevent global surface temperatures from rising beyond 2.0 degrees, actively working towards a goal of 1.5 degrees Celsius. EU's 27 member states made a decision to jointly fulfil the goals of the Paris Agreement, effectively pledging to reduce CO_2 emissions by at least 55% in 2030 compared to 1990 levels.

Despite the Paris Agreement coming into force in 2016, global CO_2 emissions have continued an upward trend except for reductions in the usual consumption, productivity, mobility, and general behaviour resulting from the global Covid-19 pandemic (Global Carbon Budget, 2022). The figure shows a timeline for annual fossil CO_2 emissions from 2015 when the Paris Agreement was ratified until 2021.

Further departures from this trend will be attributable to the Russian invasion of Ukraine. Seven months after the start of the war in February 2022, war-related CO_2 emissions are estimated at 100 million tons CO_2eq. (de Klerk, L. et al., 2022), corresponding to more than double Denmark's national CO_2 emissions in 2020 (Reduction Roadmap, 2022).

The UN Intergovernmental Panel on Climate Change's latest report (IPCC, 2023) was published in March 2023, estimating that we are unlikely to meet the ambitious part of the climate targets specified in the Paris Agreement. One of the main findings of the report being that the global population will experience a 1.5-degree rise in temperature already within the next ten years.

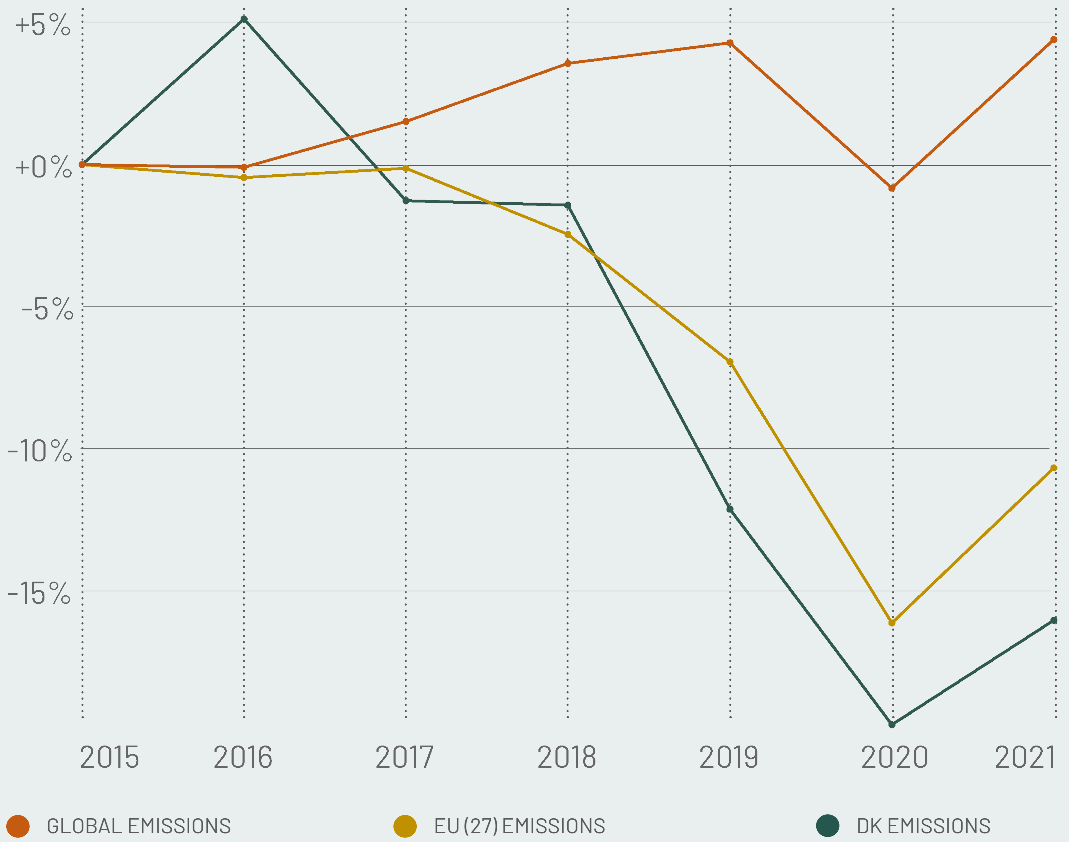


Figure 03: Global emission trends 2015–2021 (Global Carbon Budget, 2022)
Rises and reductions in emissions are shown in the vertical axis as percentages. Years are shown in the horizontal axis.

CLIMATE TARGETS > NATIONAL

Requirements in the Danish Climate Act from 2020 are tightened in a bid to reduce Denmark's CO_2 emissions by 70% in 2030, thus making them legally binding. Further, the Act specifies a target of net zero greenhouse gas emissions by 2050, meaning that in just under thirty years, Denmark must adapt to emitting no more CO_2 than can be recaptured. (Danish Ministry of Climate, Energy, and Utilities, 2020).

As part of the green transition, a political agreement was made by the then government concerning a national strategy for sustainable construction (Ministry of the Interior and Health of Denmark, 2021), specifying strategies for handling CO_2 emissions from the construction sector. Accordingly, the environmental impact of all newbuild must now be calculated via a life-cycle assessment (LCA), and limit values for CO_2 emissions have been stipulated for all newbuild of more than 1000 m^2 of heated floor area. Further, a voluntary low-emission class was added.

Limit values are 12 kg CO_2eq./m^2/year, whereas the voluntary low-emission class is 8 kg CO_2eq./m^2/year and both run for a two-year period starting from 1 January 2023.

Expectations are that the future limit values for 2025 will be revised in tandem with ongoing knowledge-gathering and determined at the end of 2023 and, furthermore, that newbuild below 1000 m^2 will also be required to meet the future limit values. The proposed tightening of requirements is visualised in the figure below, allowing for changes during the revision period.

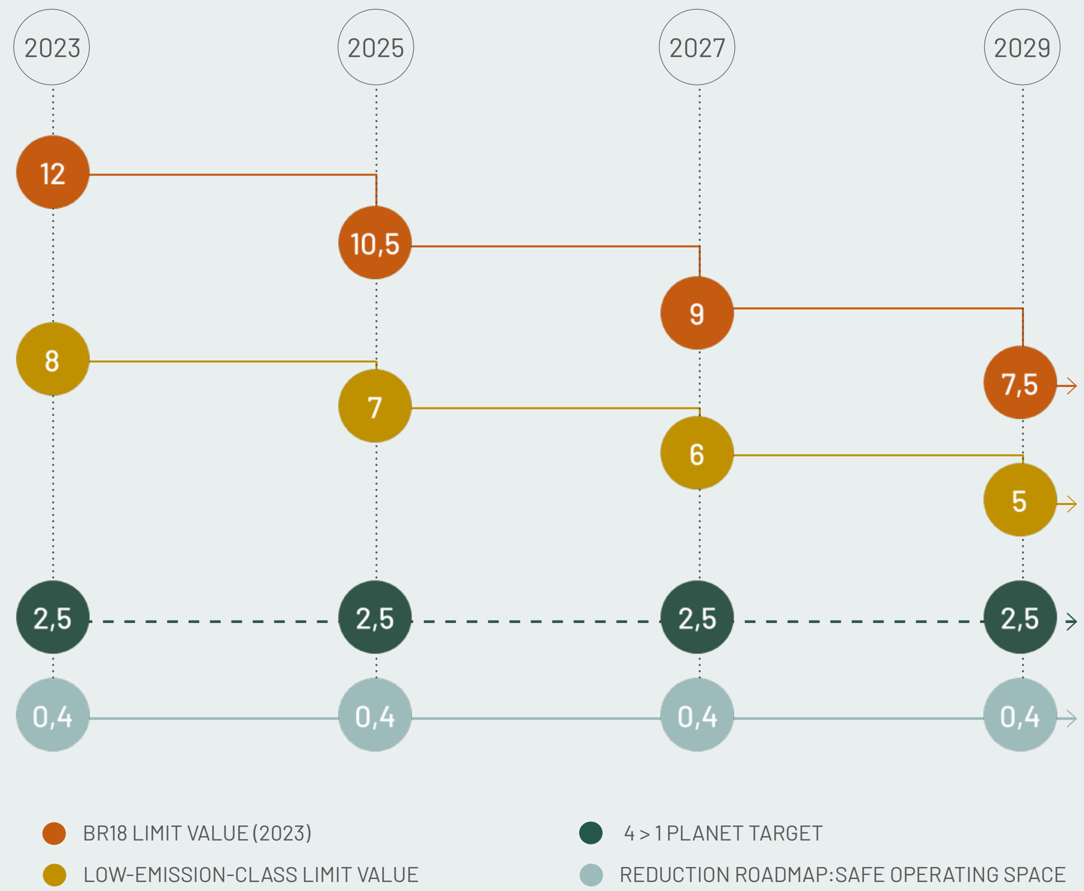


Figure 04: Time schedule for climate targets and limit values for emissions of kg CO_2eq./m^2/year

PLANETARY BOUNDARIES

'Planetary Boundaries' (Rockström, J. et al., 2009), first defined by the Stockholm Resilience Centre, describes in nine key areas how much human impact the planet can be exposed to without unpredictable and irreversible changes occurring in the global environment. Provided that Anthropocene impact can be restricted to a 'safe operating space', planetary boundaries will not be transgressed, however, six out of the nine defined planetary boundaries have already been transgressed, including the planetary boundary for climate change caused, for example, by human emission of greenhouse gases. The unit for carbon emissions (CO_2 equivalent or CO_2eq.) is a value denoting emission of several greenhouse gases, whose contribution to global warming is calculated relative to carbon dioxide (CO_2).

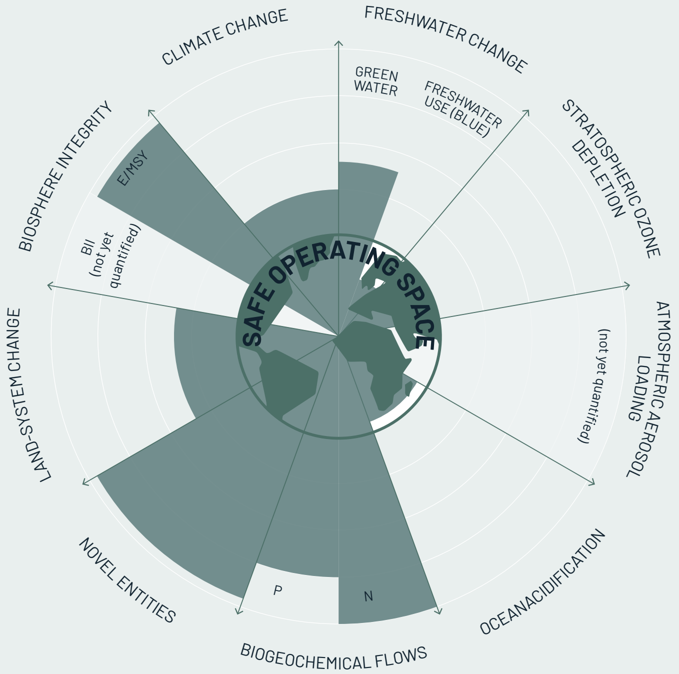


Figure 05a: Planetary boundaries (April 22, as seen in 1st DK edition of this report)
Azote for Stockholm Resilience Centre, based on analysis in Wang-Erlandsson et al. 2022

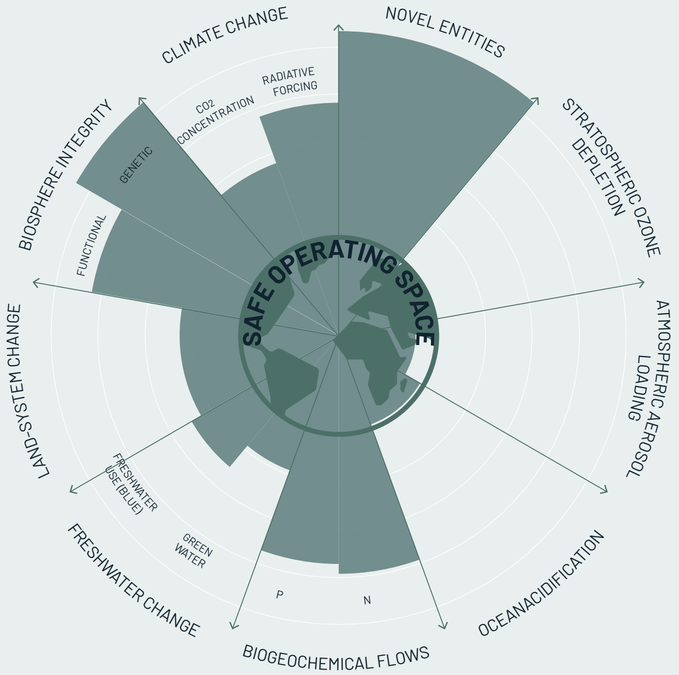


Figure 05b: Planetary boundaries (Sept 23, updated in 2nd edition)
Azote for Stockholm Resilience Centre, based on analysis in Richardson et al. 2023

REDUCTION ROADMAP 1.0

Reduction Roadmap (Reduction Roadmap, 2022) is a new ambitious initiative, translating the Paris Agreement goal of 1.5 degrees Celsius and Den Planetære Grænse for Klimaforandringer (Planetary Boundary for Climate Change) (Petersen, S. et al., 2022) into specific annual reduction targets for new housing construction in Denmark.

With research-based reduction targets, the Reduction Roadmap indicates the rate at which greenhouse gas emissions from the construction sector must be reduced to act within the planet's 'climate budget' and the target set by the Paris Agreement.

The initiative calls for joint action from all actors in the Danish building sector to make the necessary changes to avoid using up the climate budget in five to ten years consistent with the Paris Agreement.

The Reduction Roadmap is based on the current average emissions for Danish housing construction of 9.6 kg CO_2eq./m^2/year (Tozan, B. et al., 2021), ending – with the current rate of building activities – with a reduction target of 0.4 kg CO_2eq./m^2/year.

The reduction must occur within the next 6-13 years (IPCC AR6, 2021), and the roadmap presents three scenarios for linear reduction of CO_2 emissions from housing construction in Denmark, guiding the sector towards the 'safe operating space' at different tempi.

If the construction sector follows the fastest reduction rate scenario, the target will be reached in 2029. If sector emissions are reduced at the 50% probability rate, the target will be reached in 2036. The three different scenarios offer a time window in which to solve the building sector's climate problems starting in 2022.

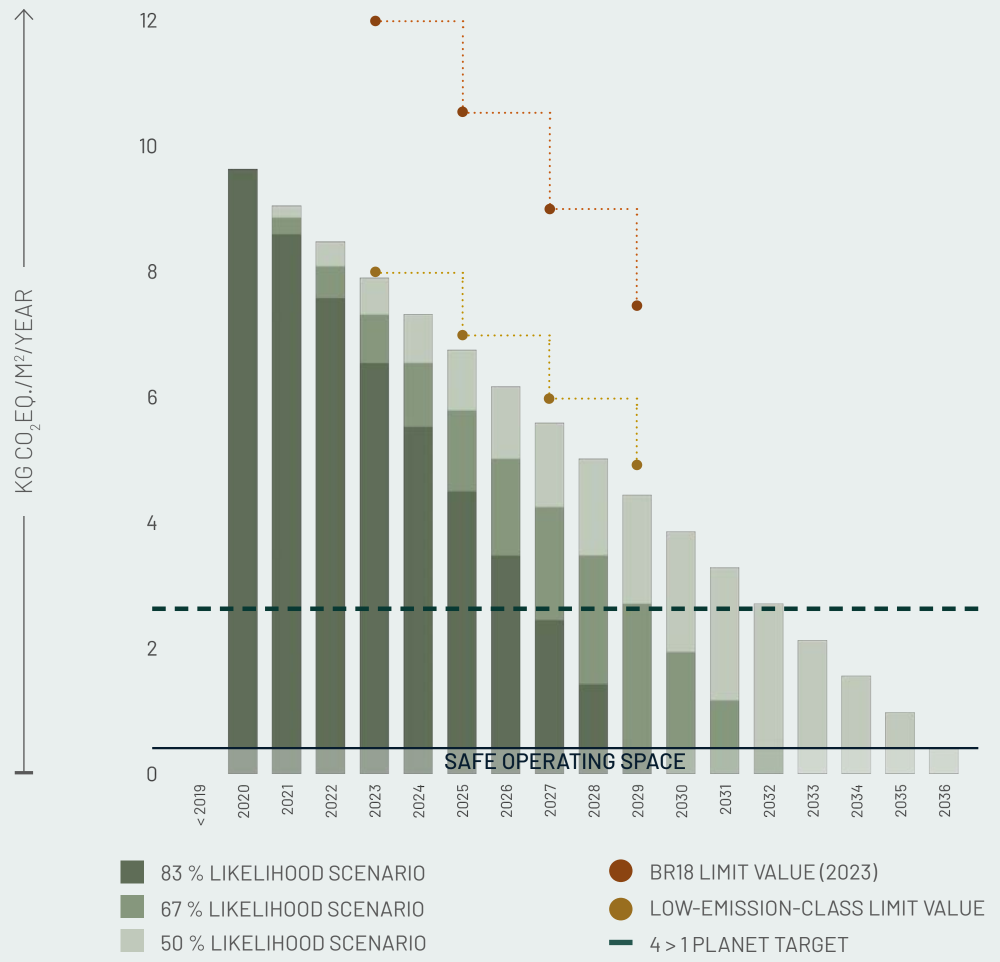


Figure 06: Reduction Roadmap 1.0
Reduction Roadmap, 2022

METHODOLOGY

PROCESS

2022

- S pring 2022: Call for best practice cases
- Summer 2022: Mapping registered best practice cases
- Summer and autumn 2022: Data collection from selected best practice cases

2023

- Autumn 2022 and spring 2023: LCA calculations from collated drawings and quantities (9 cases)
- Winter 2022: Conformity check of collated LCA calculations (15 cases)
- Winter 2022 and spring 2023: Modelling using the tool LCAbyg
- Winter 2022 and spring 2023: Skim-reading the cases
- Spring 2023: Converting to agreed calculation method for all cases in the collection (E06 excepted)
- Spring 2023: Processing findings and publication
- Summer 2023: Report published: Housing Construction from 4 to 1 Planet: 25 Best Practice Cases
- Autumn 2023: Selected cases integrated in online assessment tool *LCAlive*
- Autumn 2023: 2nd revision of cases
- December 2023: 1st edition of english report published (25 cases)

2024

- February 2024: 2nd edition of danish report published (24 cases)
- February 2024: 2nd edition of english report published (24 cases)

METHODOLOGY

All best practice cases are modelled in the LCA tool LCAbyg 2023. The modelling was made from quantity take-off and quantity calculations from the 24 cases. The method used is described in the following section.

BR18 (2023)

In this publication, the environmental impact of the 24 best practice cases is determined in accordance with Building Regulation requirements for environmental impact, sections 297–298. Further, analytical assumptions made to facilitate comparisons between the 25 best practice cases are described below.

Limitations

This study includes life-cycle stages and modules subject to Building Regulation requirements. Thus, the carbon footprint for the best practice cases comprises environmental impact from the Product stage (modules A1–3), Replacement of building products (module B4), Operational energy (module B6), Waste processing (C3), and Disposal (C4). Climate potential (module D) is not factored into the carbon footprint nor are module D results shown. Figure 07 illustrates all modules covered by EN15798 (CEN, 2012) with the modules included in this study written in bold.

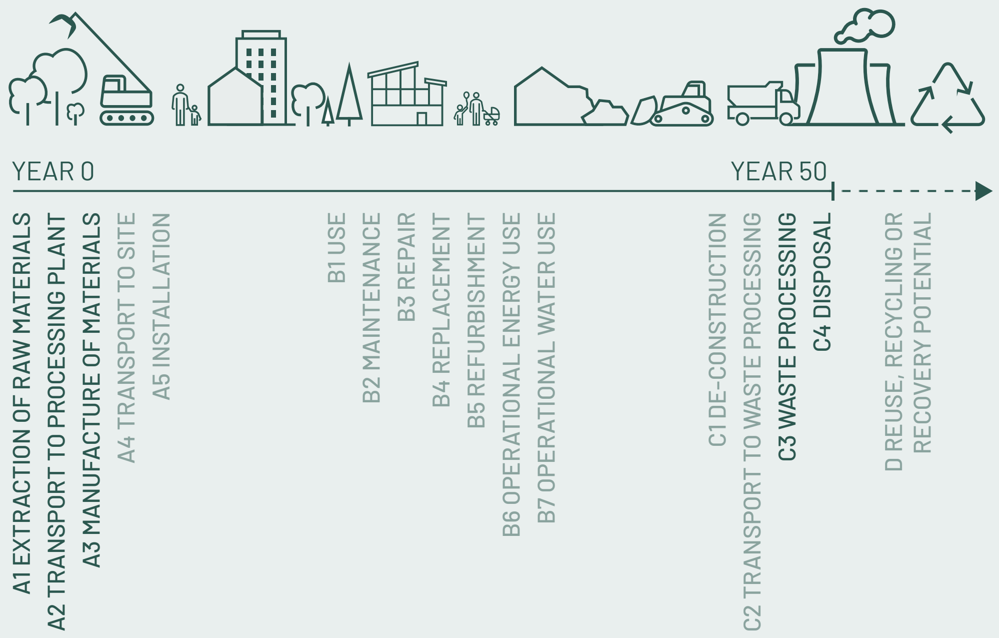


Figure 07: Construction life-cycle stages according to BR18 (2023)
Whole Life Carbon Impact from 45 Timber Buildings (Andersen, C. M. E. et al., 2023)

METHODOLOGY

REFERENCE AREA

To facilitate carbon footprint comparisons between buildings, findings must be normalised as stipulated by the Building Requirements. Here carbon footprints are calculated per square metre of reference area (RFA) for a study reference period of 50 years. The floor area is therefore adapted according to BR18, since 25% of the area comprising integral carports, outbuildings, canopies, sheds, exterior ramps, staircases, fire escapes, balconies, and access balconies are included in the reference area. Similarly, 50% of integral garage spaces are included.

Environmental impact from materials is calculated relative to the floor space in compliance with section 455, modified as follows:

1. All basement areas, grade-level waste-disposal areas, and tech rooms are included.
2. The percentage share of exterior ramps, staircases, fire escapes, balconies, access balconies, and similar is set at 25%.
3. The percentage share of integral garages for single-family housing, terraced housing, and similar, is set at 50%.
4. The percentage share of carports, outbuildings, sheds, and similar is set at 25%.
5. The percentage share of walk-on ceilings and similar is set at 25%.

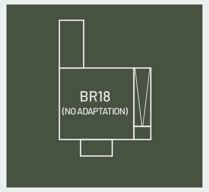


Figure 08. BR18 (2023) without adaptations

Cases complying with BR18 with no further adaptations relative to 1.

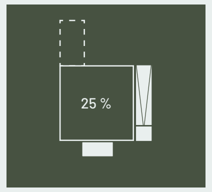


Figure 09. 25%

Cases adapted relative to 2 and/or 4.

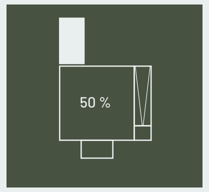


Figure 10. 50%

Cases adapted relative to 3.

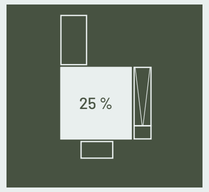


Figure 11. 25%

Cases adapted relative to 5.

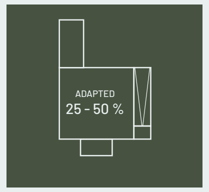


Figure 12. 25 - 50 %

Cases adapted relative to one or more of 2, 3, 4, and 5.

Figures 08 - 12: BR18 (2023) reference area

METHODOLOGY

BUILDING COMPONENTS

The data collection concentrated on streamlining the building components included in LCA calculations in the best practice case collection. The calculations exclude plantation, paving, channels below grade, hollows, and minor fasteners.

Data on technical installations is incomplete in most case studies. For this reason, standard values were used for technical installations in housing (single-family, terraced, and multi-storey), including drains, water, heating, as well as ventilation and cooling.

Standard values are prepared by Artelia (formerly MOE), Sweco, and the Danish Technological Institute for the Danish Housing and Planning Authority (Danish Technological Institute & Sweco, 2022)(MOE, 2022). Technical installations are neither included in Transport to building sites nor Construction process (A4–5) as they are based on generic values and estimated to amount to less than 1% of the overall environmental impact from the buildings.

Specific values were used for the category electrical and mechanical systems, since these are typically photovoltaic systems.

The following building components are included in the LCA calculations, including the building products specified in BR18 section 297 (4):

- FOUNDATIONS
- GRADE DECKS
- EXTERIOR WALLS
- INTERIOR WALLS
- DECKS
- STAIRS AND RAMPS
- COLUMNS AND JOISTS
- BALCONIES AND ACCESS BALCONIES
- ROOFS
- WINDOWS, DOORS AND GLASS FACADES
- ELECTRICAL AND MECHANICAL SYSTEMS
- DRAINS
- WATER
- HEATING, VENTILATION AND COOLING SYSTEMS

ENVIRONMENTAL DATA

LCA calculations in this project are, as far as possible, based on environmental data from product-specific environmental product declarations (EPDs) and EPDs published by Danish trade-associations. According to BR18 section 297 (5), generic data is used for undocumented materials. Using trade and product-specific data helps to minimise uncertainties in LCA results compared with generic data. Generic environmental data is generally more conservative, erring on the side of caution. However, there are instances when product-specific data will result in a significantly higher carbon footprint (Tozan, B. et al., 2022). This happened in some case studies, where a specific product choice and its related environmental data proved to have an unusually great impact on the overall carbon footprint. In the two relevant case studies, one involving photovoltaic systems and the other wood-fibre insulation, a decision was made to replace the environmental data with data from a similar product. This will give a truer picture of the overall potential of the project. Harmonised data use will be outlined in more detail in the section on assumptions.

LIFETIME

Building product lifetimes comply with BR18 section 297 (7), specifying the use of BUILD's lifetime table. Before the new Building Regulations came into force, the carbon footprint from the maintenance of interior surfaces treated with e.g. paint was calculated as Replacement in module B4. However, this was changed in BR18, so that paint no longer figures in the Replacement module. This report departs from the new regulations by including the modules A1–3, B4, C3, and/or C4. The carbon footprint of the best practice cases therefore includes the carbon footprint from ongoing surface-treatment maintenance work.

BIOGENIC MATERIALS

The carbon footprint from biogenic materials is calculated using the -1 /+1 method. Consequently, the Product stage corresponding to modules A1–3 for certain biogenic materials is calculated as CO_2 capture, since CO_2 equivalents will be negative. On the other hand, Waste treatment in module C3 or Disposal in module C4 results in CO_2 equivalents being emitted in year 50. In overall terms, this will typically result in a carbon footprint above zero (Andersen, C. M. E. et al., 2023). Since specific data is still incomplete for many biogenic building materials, environmental impact is calculated using the method specified in the EU-standard. This does not mean, however, that the -1/+1 method will provide a true and fair view of environmental impact for all types of biogenic materials in all cases. An example being that eelgrass is used as insulation in one case study in the best practice case collection (ENF03). Due to its salt content, eelgrass is non-combustible and will not emit CO_2 when burning, which the -1/+1 method allows for in C3 and C4.

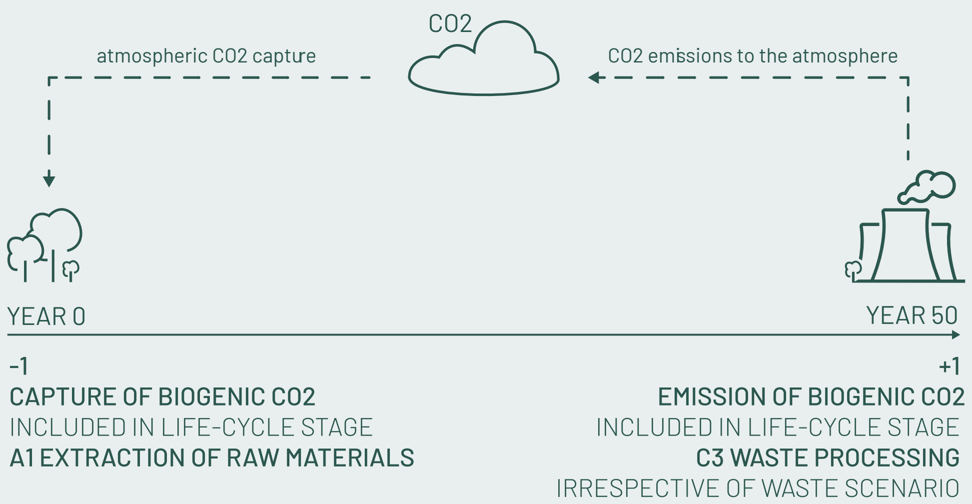


Figure 13: Biogenic CO_2
Whole Life Carbon Impact from 45 Timber Buildings (Andersen, C. M. E. et al., 2023)

REUSE

According to the Building Regulations (BR18), environmental data from the generic data set or from environmental product declarations (EPDs) should be used to describe the environmental impact from materials used in a building. At present, no data exists on reusable materials in the BR18 generic data set. According to BR18, reusable materials are therefore factored in as generic (new) materials or via specific EPDs. Applying the generic data set to reusable materials implies a (computational) failure to achieve the CO_2 reductions potentially obtainable from not having to produce new materials. Consequently, there will be no evidence of CO_2 benefits from reusable materials in the LCA calculation unless an EPD exists for a specific product.

To allow for using reusable materials in these best practice cases, we departed from the standard BR18 regulations.

CO_2 emissions from the Product stages (A1–3) of reusable materials are factored in at 0, while the generic data set is used for a corresponding new material at the End-of-Life stage (C3-4). Further, possible CO_2 emissions from Transport (A2)* and Process (A3)* of specific reusable materials are taken into account. Separate CO_2 emission calculations for reused or mixed materials are made for the Production stage (A1–3).

The above applies to the factoring in of reusable materials in two best practice cases:
ENF07: Upcycle House and A01: Forsamlingshus Fredericia.

In April 2023, an executive amendment order was proposed, including a supplementary agreement to the sustainable construction strategy. The purpose of this agreement is to encourage the reuse of building materials for construction, and specific calculations will therefore be introduced for reusable materials in life-cycle assessments. Specifically, the environmental impact of reusable materials is set at 0 kg CO_2 equivalents in all life-cycle modules according to the limitations in BR18. Amendments to the Building Regulation requirements for calculating the environmental impact of buildings are expected on 1 January 2024.

Figur 14: Factoring in reusable materials in the report

ASSUMPTIONS

Below, a summary of the assumptions made to facilitate comparisons between the 25 best practice cases:

YEAR STARTED
The year of occupancy is set at 2022 to facilitate comparison of environmental impact.

REFERENCE AREA
In cases where exterior structures exist, the floor area is adapted consistently with BR18 section 297(3).

STANDARD VALUES
Bills of quantities for technical installations are inadequate. To streamline the carbon footprint from technical installations, standard values are used for all housing (single-family, terraced, and multi-storey).

DATA HARMONIZATION
In certain case studies, the use of product-specific data had such a prominent effect on the findings that they were replaced by a similar product where relevant. This will give a clearer picture of the overall potential of the project.

USING PRODUCT-SPECIFIC EPDS FOR PHOTOVOLTAIC MODULES
Identical product-specific data for photovoltaic modules is used for all the case studies for the sake of comparability. More specifically, the EPD Sunpower (N EPD-3087-1726-EN). This is done to mitigate the otherwise significant variance between specific products data and the generic data set.

USING PRODUCT-SPECIFIC EPDS FOR WOOD-FIBRE INSULATION
Identical product-specific data for photovoltaic modules and wood-fibre insulation is used for all the case studies for the sake of comparability. More specifically, the EPD Hunton (NEPD-2287-1041-EN). This is done to mitigate the otherwise significant variance regarding the generic data set.

USING TRADE-ASSOCIATION EPDS
Data from Danish trade associations are used in preference to generic data for concrete and timber products according to the data set, BR18, appendix 2 table 6.

USING WITHDRAWN TRADE-ASSOCIATION EPDS IN PREFERENCE TO GENERIC DATA
Withdrawn trade-association data for EPS is used instead of generic data, as they are more representative in a Danish context. (MD-16005-EN)

LIFETIME OF SURFACE TREATMENTS WITH AN ESTIMATED LIFETIME OF <15 YEARS
Lifetimes are set at 15 years to include environmental impacts from replacements in module B4.

READING INSTRUCTIONS

CASE CODE
Each case study is allocated an ID made up of an abbreviated typology, followed by a number. This ID is used in the main results as follows: ENF01: Single-family housing 1//R01: Terraced housing 1//E01: Multi-storey housing 1//A01: Other buildings 1

CONSTRUCTION PRINCIPLE
Generally, five different construction principles distinguish the case collection projects: CLT, panel modules, cassettes, timber-frame, and glulam constructions. Other than that, the term 'hybrid' denotes that two or more of these were used for a project.

STOREYS
The buildings in the case collection are between one and five storeys high, indicated below the icon denoting construction principle.

FINDINGS
The findings are presented differently in this report to give a nuanced picture of the projects. In most cases, the findings will be harmonised with the years specified in the reference study period (per year).

REFERENCE UNIT: kg CO_2eq./m^2/year
Embedded impact from building products (life-cycle modules A1–3, B4, C3, and C4) are harmonised with the building's gross or reference area. Emissions from operational energy use (life-cycle module B6) come from energy-performance-framework calculations and are harmonised with the square metreage of heated floor space. The overall environmental impact of a building is obtained by adding the embedded and operational impact.

REFERENCE UNIT: kg CO_2eq./person/year
Further, the overall carbon footprint for each case study is harmonised with the number of occupants in the dwelling. The number of occupants in each dwelling is set at two persons for the first or only bedroom and one person for the remaining bedrooms.

COMPARISON: mass and environmental impact of biogenic materials
This is a comparison of the building's share of biogenic, hybrid, and other materials quoted in kg per category of material, including emission of kg CO_2eq per category of material, offering a perspective on the significance these materials have on the carbon footprint.

COMPARISON: mass and environmental impact of building components
This is a comparison of material distribution of selected building components quoted in kg per category of material, including emission of kg CO_2eq per category of material, offering a perspective on the significance these materials have on the carbon footprint.

REFERENCE UNIT: m^2 floor space / occupant
Further, the analysis will highlight floor space per occupant, thus calling for a debate on compact housing architecture as a potential solution to the massive use of resources in construction.

REFERENCE UNIT: m^2 of building component / m^2 of floor space
Further, the building component ratio/floor space is highlighted to give a better understanding of the nature of the findings, for example, m^2 exterior wall/m^2 floor space.

BEST PRACTICE CASES

SINGLE-FAMILY HOUSING

ENF01
LIVING PLACES I
BUILT 2023
147 m^2
3 STOREYS
4 OCCUPANTS

ENF02
SUNLIGHTHOUSE
BUILT 2010
292 m^2
2 STOREYS
4 OCCUPANT
(INTERNATIONAL CASE)

ENF03
ECOHOUSING
BUILT 2021
86 m^2
1 STOREY
4 OCCUPANTS

ENF04
KLIMAKASSEN
BUILT 2022
86 m^2
1 STOREY
2 OCCUPANTS

ENF05
SNOEZELHUSET
BUILT 2022
195 m^2
1 STOREY
4 OCCUPANTS

ENF06
CBCI LIVING LAB GHENT
BUILT 2022
84 m^2
3 STOREY
2 OCCUPANTS
(INTERNATIONAL CASE)

ENF07
UPCYCLE HOUSE
BUILT 2013
143 m^2
1 STOREY
5 OCCUPANTS

TERRACED HOUSING

R02
SKADEMOSEN
BUILT 2021
4146 m^2
2 STOREYS
148 OCCUPANTS

R03
TØMMERGÅRDEN
BUILT 2016
531 m^2
1 - 2 STOREYS
19 OCCUPANTS

R04
DANMARKSGRUNDEN
BUILT 2014
8378 m^2
3 - 4 STOREYS
207 OCCUPANTS

R05
SKRÅNINGEN I
BUILT 2019
4788 m^2
2 STOREYS
216 OCCUPANTS

R06
SKRÅNINGEN II
BUILT 2021
5070 m^2
2 STOREYS
222 OCCUPANTS

MULTI-STOREY HOUSING

E01
MINICO2 MULTI-STOREY
TIMBER
IN PROGRESS (2023)
579 m^2
5 STOREYS
18 OCCUPANTS

E02
TANKEFULD II
BUILT 2020
2853 m^2
2 STOREYS
128 OCCUPANTS

E03
STORE SOLVÆNGET
BUILT 2020
2853 m^2
3 - 4 STOREYS
189 OCCUPANTS

E04
IBIHAVEN
BUILT 2020
5813 m^2
2 STOREYS
204 OCCUPANTS

E05
SLU
BUILT 2021
17539 m^2
2 - 4 STOREYS
520 OCCUPANTS

E07
SOLARHOUSE
BUILT 2014
536 m^2
5 STOREYS
5,5 - 12 OCCUPANTS
(INTERNATIONAL CASE)

E08
CPH VILLAGE VESTERBRO
BUILT 2020
154 m^2
2 STOREYS
8 OCCUPANTS

PIXIE CASES

ENF08 (SINGLE-FAMILY)
ECOMODUL360
IN PROGRESS (2023)
59 M2
1 STOREY
2 OCCUPANTS

ENF09 (SINGLE-FAMILY)
PRAMVEJEN
IN PROGRESS (2023)
122 M2
1 STOREY
4 OCCUPANTS

R01 (TERRACED)
LIVING PLACES II
NOT BUILT (2023)
1029 m^2
3 STOREYS
28 OCCUPANTS

E09 (MULTI-STOREY)
CPH VILLAGE
TUNNELFABRIKKEN
NOT BUILT (2023)
154 m^2
2 - 3 STOREYS
8 OCCUPANTS

A01 (OTHER)
COMMUNITY CENTRE
KANALBYEN
IN PROGRESS (2023)
162 m^2
1 STOREY
4 OCCUPANTS

BPC > YEAR STARTED 2022

In this report , the life-cycle assessments operate with 2022 as the year of occupancy to facilitate comparisons of carbon footprint from operative emissions. A couple of the cases studied were built many years ago and are therefore modelled as if built today. This is to say, using applicable data representative of present-day construction, but not necessarily of the factual emissions from the existing building. All case studies in the collection comply with one of the three reduction rates specified in the roadmap. Of the 24 case studies, 21 come within the 83% likelihood scenario.

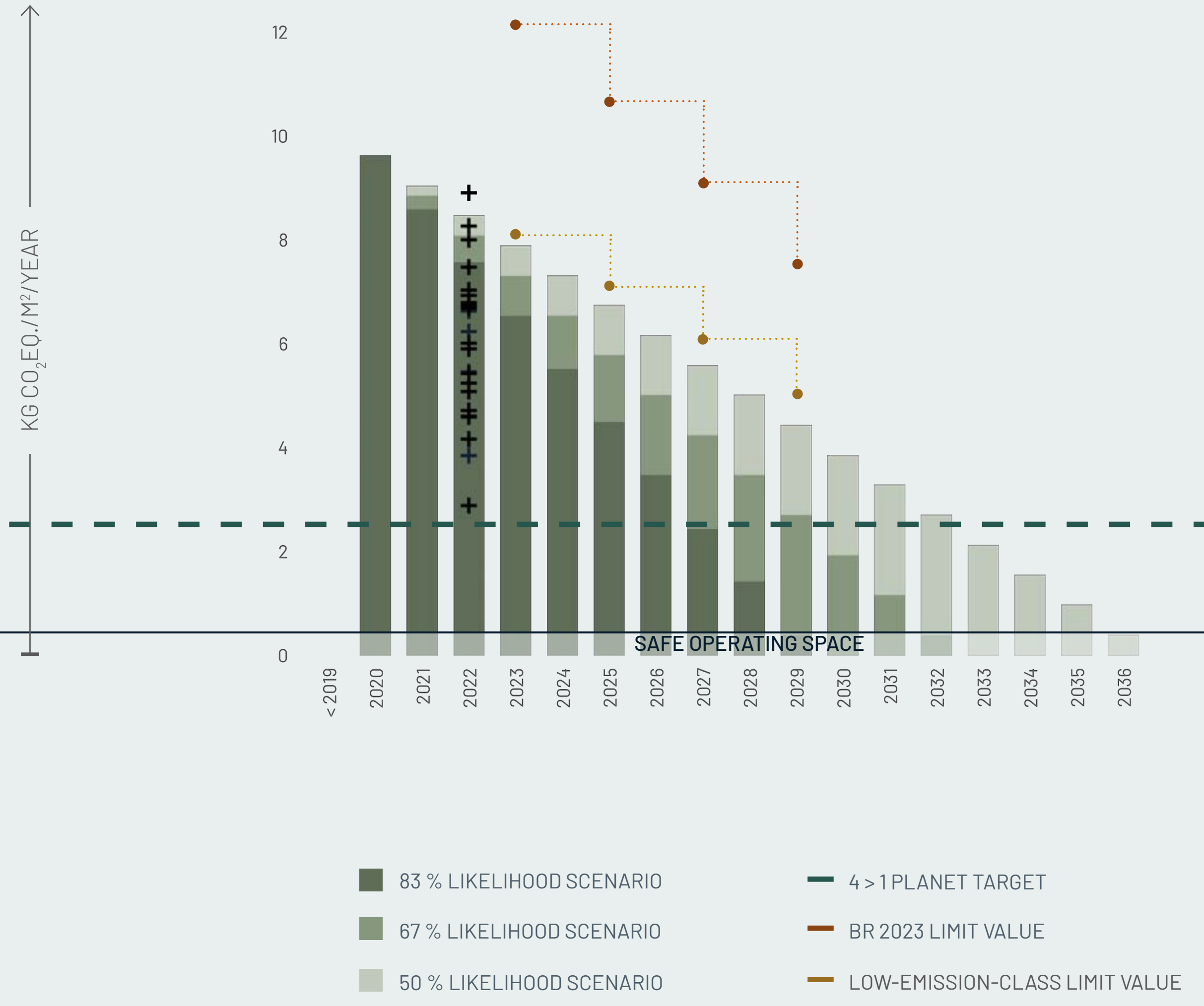


Figure 15: Reduction Roadmap
The 24 best practice cases are shown with 2022 as year start and in relation to the Reduction Roadmap and 4 t 1 planet goal of 2.5 kg CO_2eq./m²/year shown here.

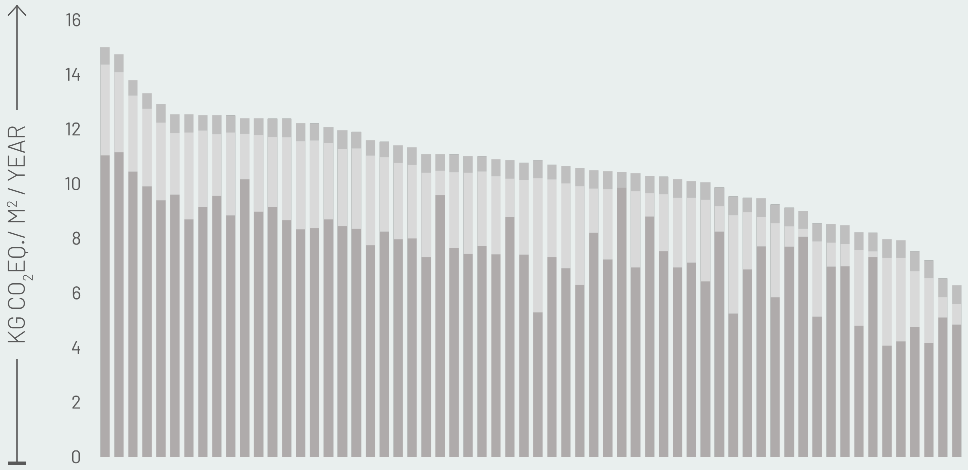
BPC > ACTUAL YEAR OF CONSTRUCTION

This shows the 24 case studies in the Reduction Roadmap by the year they were constructed. The life-cycle assessment still calculates with 2022 as the year of occupancy, i.e showing the same result. The result for a case built in 2010 is slightly above 6 kg CO_2eq./m²/year, and the results for two cases built in 2014 and 2019, respectively, are around 5 kg CO_2eq./m²/year. This indicates that knowledge about constructing far below the limit values and rate of reduction in the RR has been available for years. The cases with the lowest emissions are 8–9 kg CO_2eq./m²/year below the limit value of 12 kg CO_2eq./m²/year.

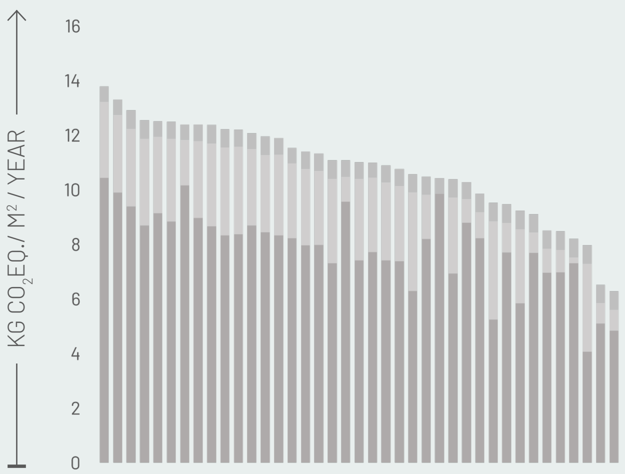
Figure 16: Reduction Roadmap
The 24 best practice cases are shown with their actual year of construction in relation to the Reduction Roadmap and to the 4 to 1 planet goal of 2.5 kg CO_2eq./m²/year.

STANDARD PRACTICE CASES

For some years, BUILD has collected and analysed the environmental impact from Danish and international construction case studies. In this report , the original technical installations have been taken out of the housing data held in BUILD's case bank and adjusted to the separate standard values for installations in the various typologies. This summary view of the housing has a median value of 10.8 kg CO_2eq./m²/year and is further subdivided into typology with a variable median. Single-family housing has the highest median of 11.1 kg CO_2eq./m²/year, terraced housing the lowest median of 9.5 kg CO_2eq./m²/year, whereas with a median of 10.5 kg CO_2eq./m²/year, multi-storey housing comes closest to the median for housing generally.



MEDIAN ALL HOUSING (SPC): 10,8 KG CO_2EQ./M²/YEAR

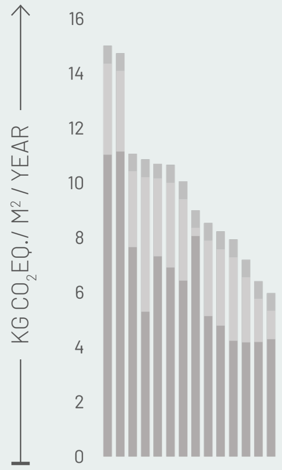


MEDIAN SINGLE-FAMILY HOUSING (SPC): 11,1 KG CO_2EQ./M²/YEAR

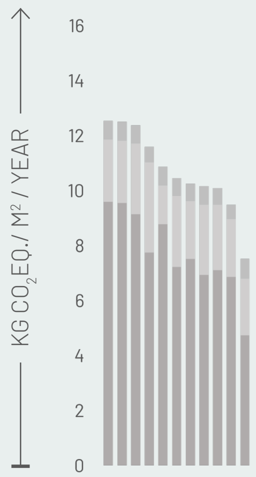
- SPC: TECHNICAL INSTALLATIONS (S.V)
- SPC: OPERATIONAL ENERGY USE (B6)
- SPC: MATERIALS (A1-3, B4, C3-4)

Figures 17 - 18: Standard Practice Cases
The horizontal axis shows BUILD's existing housing case collection. The vertical axis shows the emission of CO_2eq./m²/year.

STANDARD PRACTICE CASES



MEDIAN TERRACED HOUSING (SPC): 9,5 KG CO_2EQ./M²/YEAR



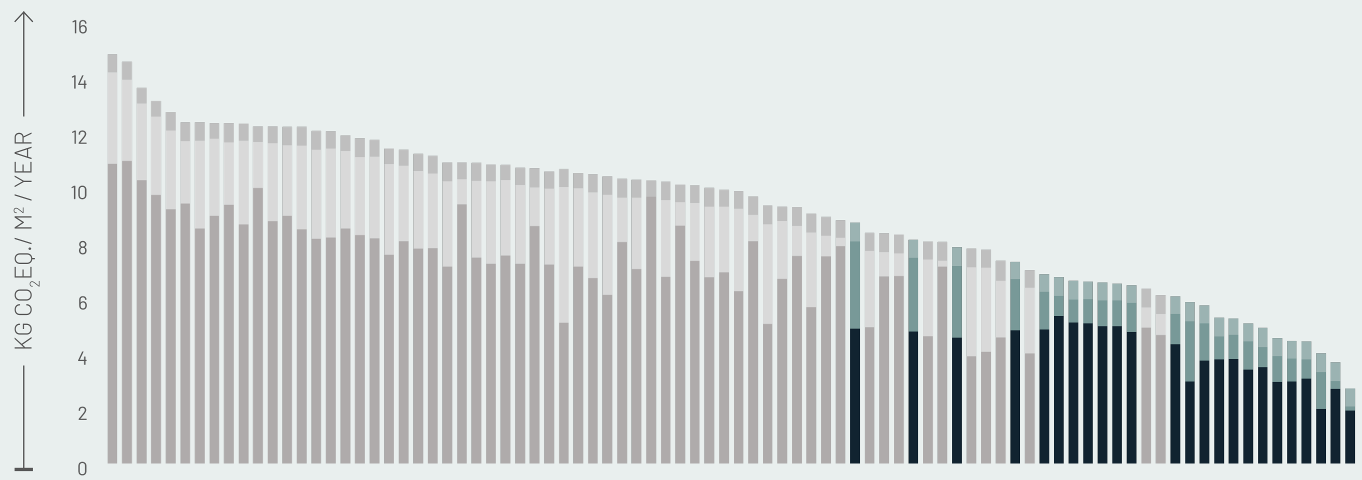
MEDIAN MULTI-STOREY HOUSING (SPC): 10,5 KG CO_2EQ./M²/YEAR

- SPC: TECHNICAL INSTALLATIONS (S.V)
- SPC: OPERATIONAL ENERGY USE (B6)
- SPC: MATERIALS (A1-3, B4, C3-4)

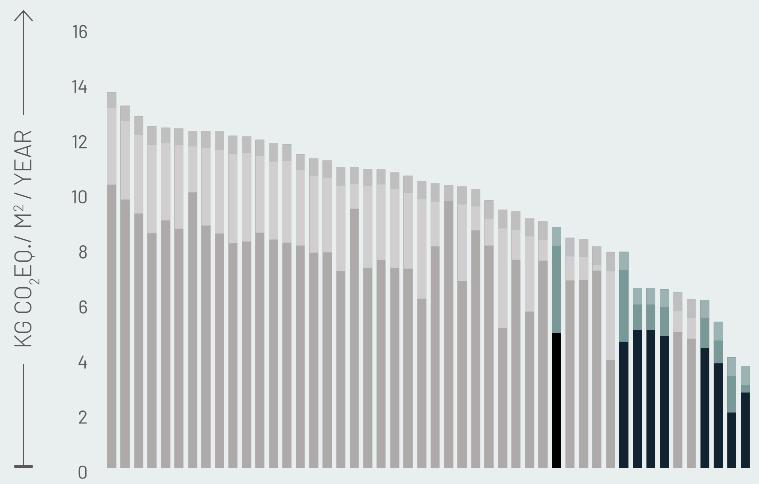
Figures 19 - 20: Standard Practice Cases
The horizontal axis shows BUILD's existing housing case collection. The vertical axis shows the emission of CO_2eq./m²/year.

STANDARD + BEST PRACTICE CASES

BUILD's housing cases (SPC) are shown here with best practice cases (BPC). The housing is shown in aggregate and subdivided by typology. The median value for the best practice housing is 6.1 kg CO_2eq./m²/year, and the variation for each typology shows a similar trend as in the standard practice cases: the median for single-family housing is higher (6.7 kg CO_2eq./m²/year), the median for terraced housing is lower (4.9 kg CO_2eq./m²/year), and the median for multi-storey housing is the highest of the three typologies (6.9 CO_2eq./m²/year).



MEDIAN ALL BEST PRACTICE CASES: 6,1 CO_2EQ./M²/YEAR

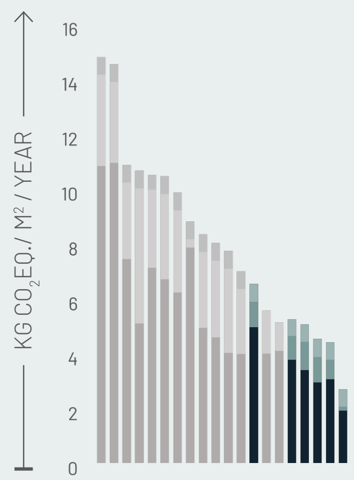


MEDIAN BEST PRACTICE SINGLE-FAMILY HOUSING: 6,7 KG CO_2EQ./M²/YEAR

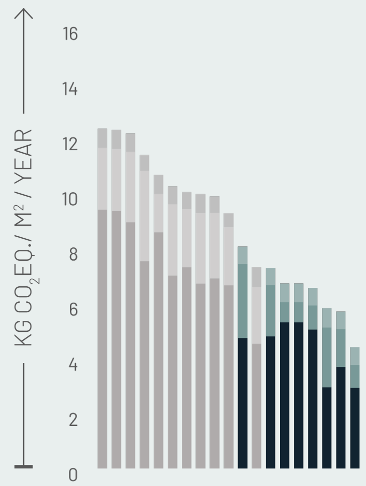
SPC: TECHNICAL INSTALLATIONS (S.V)
SPC: OPERATIONAL ENERGY USE (B6)
SPC: MATERIALS (A1-3, B4, C3-4)
BPC: TECHNICAL INSTALLATIONS (S.V)
BPC: OPERATIONAL ENERGY USE (B6)
BPC: MATERIALS (A1-3, B4, C3-4)

Figures 21–22: Best Practice Cases
The horizontal axis shows BUILD's existing housing case collection and cases from the 4 to 1 planet case collection. The vertical axis shows the emission of CO_2eq./m²/year.

STANDARD + BEST PRACTICE CASES



MEDIAN BEST PRACTICE TERRACED HOUSING: 4,9 KG CO_2EQ./M²/YEAR



MEDIAN BEST PRACTICE MULTI-STOREY HOUSING: 6,9 KG CO_2EQ./M²/YEAR

SPC: TECHNICAL INSTALLATIONS (S.V)
SPC: OPERATIONAL ENERGY USE (B6)
SPC: MATERIALS (A1-3, B4, C3-4)
BPC: TECHNICAL INSTALLATIONS (S.V)
BPC: OPERATIONAL ENERGY USE (B6)
BPC: MATERIALS (A1-3, B4, C3-4)

Figures 23–24: Best Practice Cases
The horizontal axis shows BUILD's existing housing case collection and cases from the 4 to 1 planet case collection. The vertical axis shows the emission of CO_2eq./m²/year.

RESULTS RELATIVE TO LIMIT VALUES

The axis represents the unit kg CO_2eq./m²/year, showing emissions from buildings subdivided into three categories. Emissions from materials (A1–3, B4, C3–4), operational energy use (B6), and technical installations (A1–3, B4, C3–4). The latter is separate from materials due to standard values being used in this report . Carbon emissions from buildings are shown with four limit values for emissions of CO_2eq./m²/year.

The case-study results show a variation of around 5 kg CO_2eq./m²/year from the lowest to the highest emission rate. All 24 cases are below the limit values in BR18 (2023), 22 cases are below the limit value in the low-emission class, and 11 cases are below 6 kg CO_2eq./m²/year, i.e. less than half of the current limit value stated in the Building Regulations.

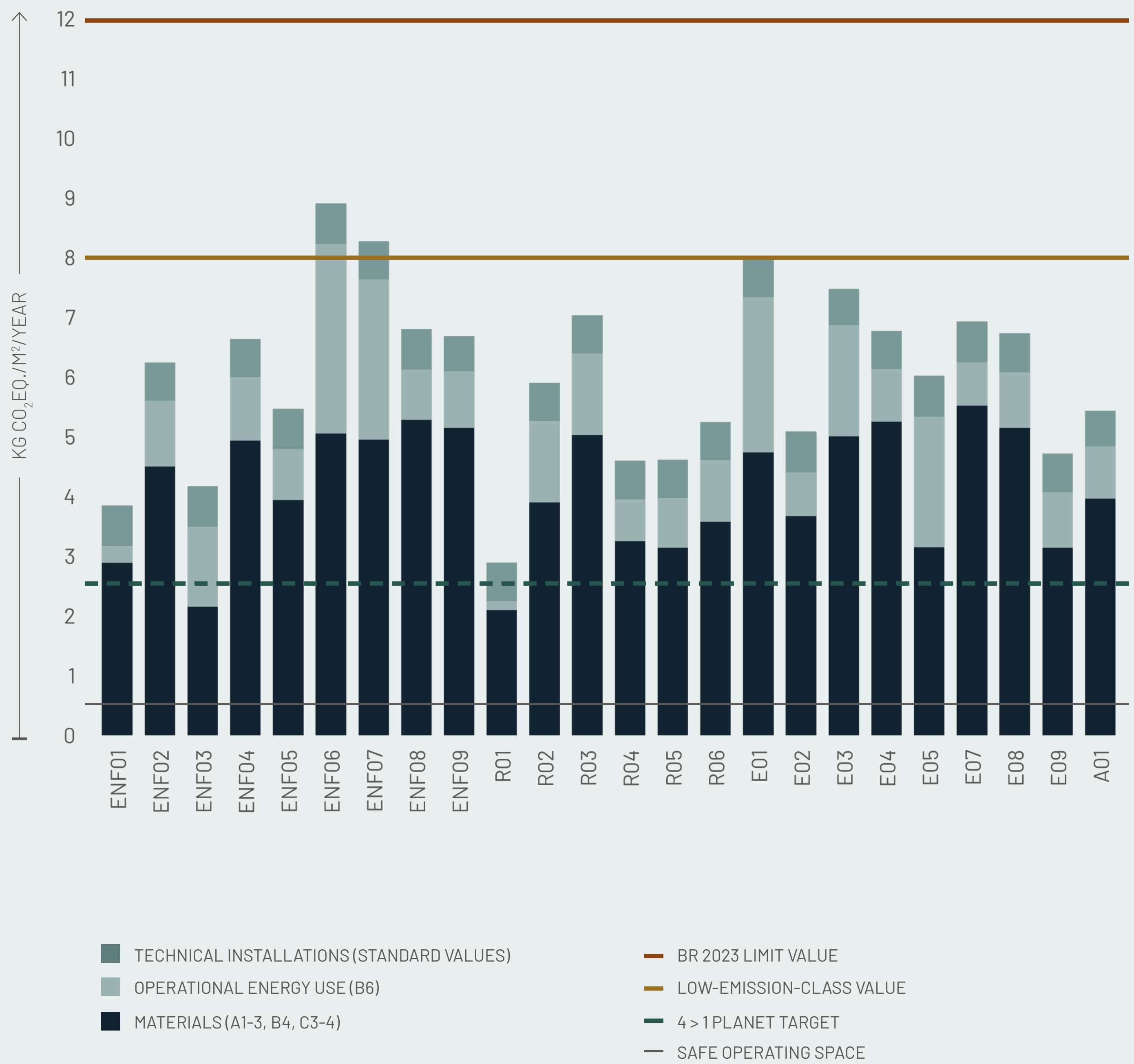


Figure 25. Limit values
The 24 cases in relation to BR2023 limit values, the voluntary CO_2 class, the 4 to 1 planet goal of 2.5 kg CO_2eq./m²/year, and the "safe operating space".

SELECTED RESULTS

The axis represents the unit kg CO_2eq./m²/year, showing emissions from buildings divided into three categories. Emissions from materials (A1–3, B4, C3–4), operational energy use (B6), and technical installations (A1–3, B4, C3–4). In this analysis, the latter shows emissions from the total number of technical installations per case study. The emissions from buildings are shown with four limit values for emissions of CO_2eq./m²/year.

The four selected cases are shown with actual specifications of technical installations, and they therefore vary from the results using standard values. It should not be inferred, however, that standard values always have the same effect on results. There is a rise in total emissions of kg CO_2eq./m²/year in the studies R01 and E02, whereas total emissions are lower in the studies ENF01 and R05.

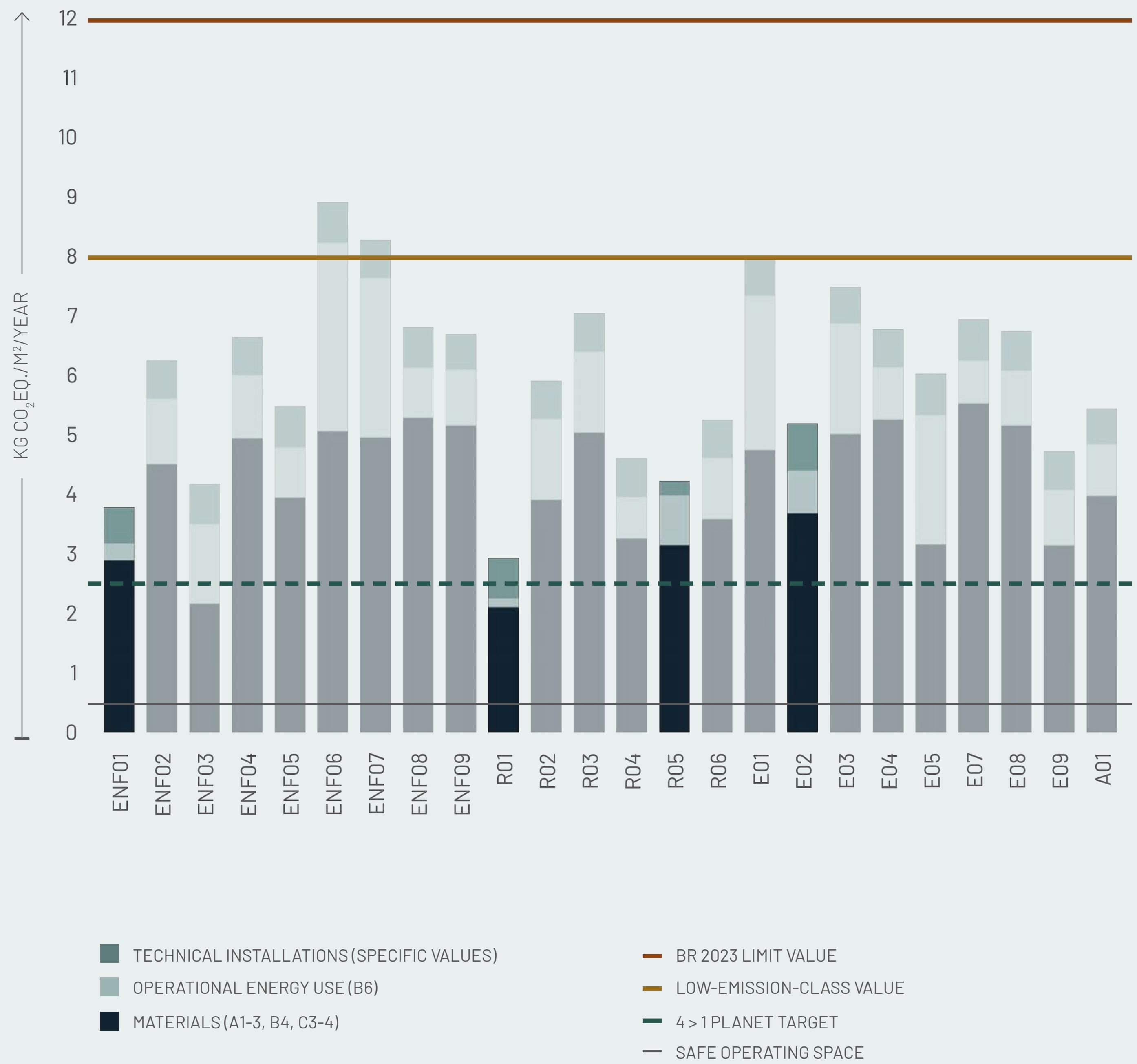


Figure 26. Selected case studies with specific listings of technical installations
The 24 cases in relation to BR2023 limit values, the voluntary CO_2 class, the 4 to 1 planet goal of 2.5 kg CO_2eq./m²/year, and the "safe operating space". The selected cases are written in bold.

BIOGENIC SHARE: GWP

The axis represents the unit kg CO_2eq./m²/year, showing the various building components' share of emissions. When using the -1/+1 calculation method, biogenic materials capture CO_2 in the Product stages (A1–3), emitting CO_2 in stages C3–4, which means that, in these results, much of the emission attributable to biogenic materials does not occur at present but in the long term. The emissions in these results depend on how the biogenic materials are handled in the Waste processing stage in module C3 or Disposal in module C4.

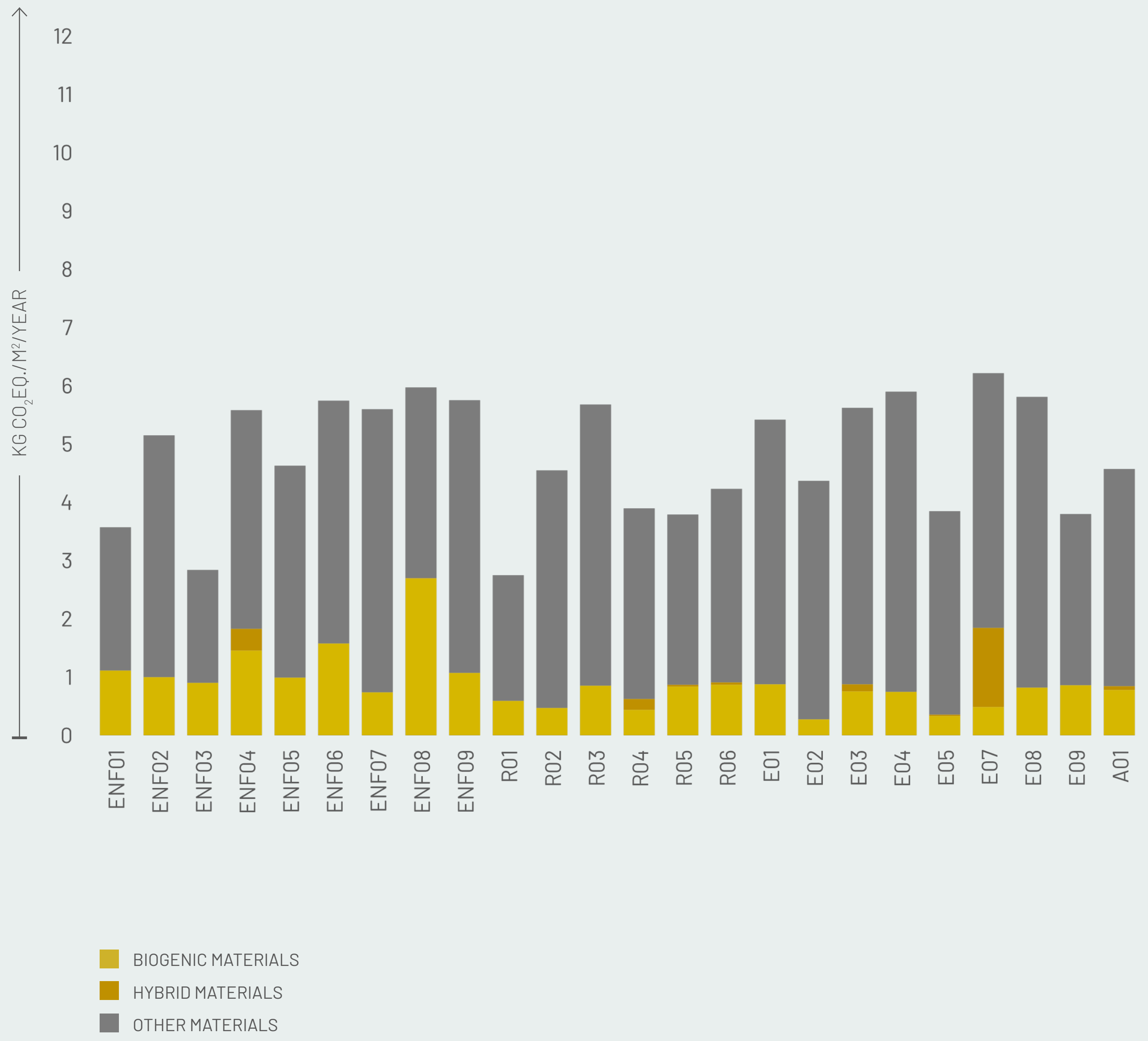


Figure 27: Biogenic share: GWP
The figure shows CO_2eq./m²/year emissions from the 24 buildings in three overall categories: biogenic materials, hybrids, and other materials.

BIOGENIC SHARE: MASS

The axis represents the unit kg of material/m², showing the building's material mass sorted into the categories: biogenic materials, hybrids, and other materials. An example of recurrent biogenic material in the case collection is wood, others are eelgrass, straw, and hemp. An example of a hybrid is hempcrete, a mixture of hemp, lime, and water. Finally, examples of "other materials" in this context are concrete, steel, or plastic.

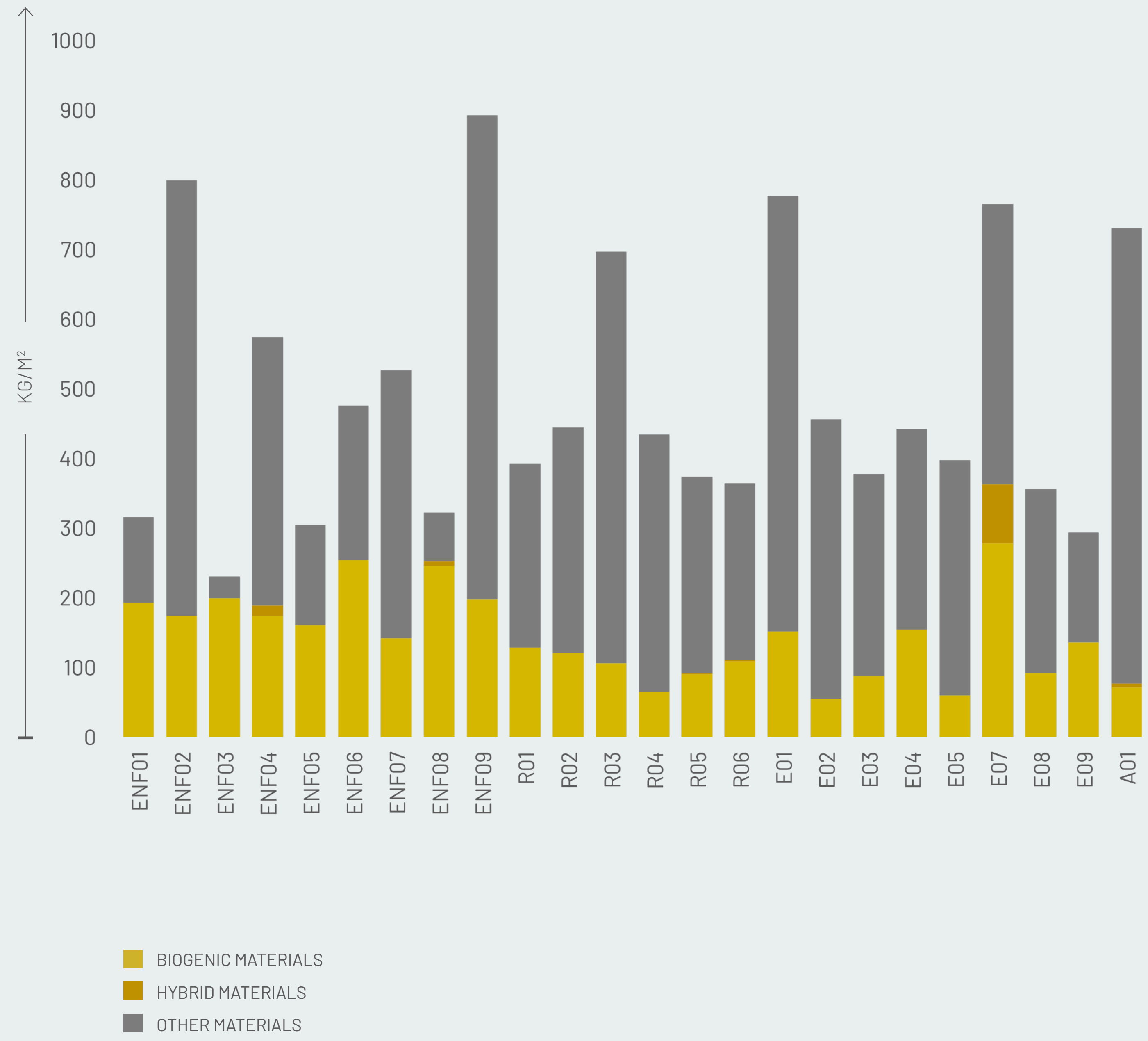


Figure 28: Biogenic share: MASS
The figure shows kg material/m² from the 24 buildings in the study subdivided into three overall categories: biogenic materials, hybrids, and other materials.

BUILDING COMPONENTS

The axis represents the unit kg CO_2eq./m²/year, showing emissions from the various building components. The three lowermost building components are technical installations, for which this report has applied standard values. The technical installations are shown in the lower part of each column. They vary somewhat depending on whether the reference area is roughly identical with the heated area. If the reference area of the building is greater, the standard values applied to the building's heated area will account for less in the result.

From the bottom of the column and up, the following parts are responsible for most of the emissions: windows, doors and glass facades, roofs, exterior walls, grade decks, and, in a handful of studies, foundations. It is evident that the grade deck accounts for more in single-family housing than in terraced and multi-storey housing, whereas emissions are relatively evenly distributed on grade decks and other decks. For a review of the case collection's heavier building components, please see the chapter on structural design in the report.

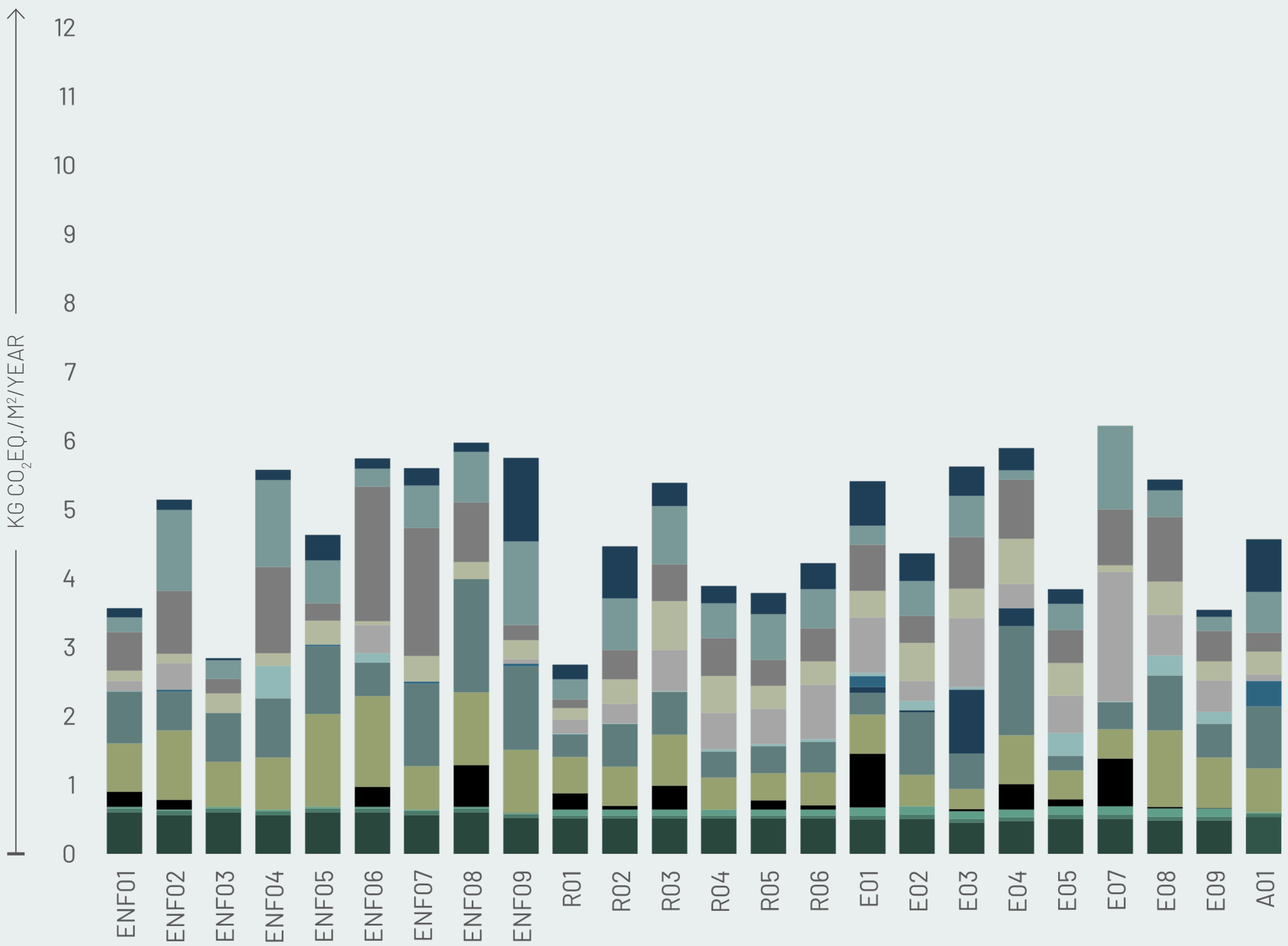


Figure 29: CO_2 accounting: building components
The horizontal axis shows the 24 buildings in the report and the emissions from the various building components. The vertical axis shows the emission of CO_2eq./m²/year.

BUILDING COMPONENTS + OPERATIONAL ENERGY USE

The axis represents the unit kg CO_2eq./m²/year, showing emissions from buildings divided into three categories. Emissions from operational energy use are placed at the top and shaded to illustrate the relationship between emissions from materials and operational use. Case study A01 is not a dwelling and therefore not subject to a median value of operational energy use. Operational energy use appears to be the heaviest item in half of the case studies.

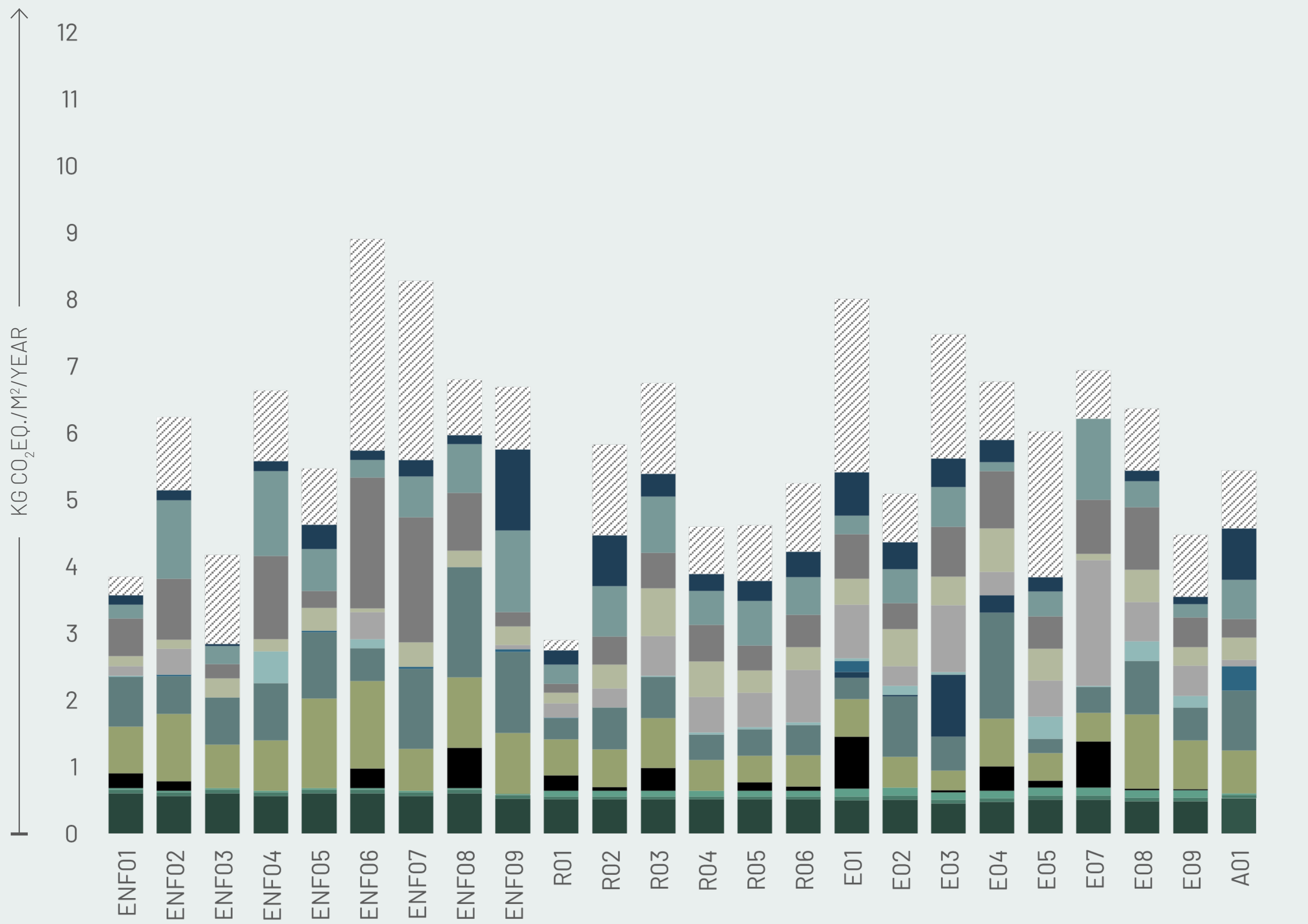


Figure 30: CO_2 accounting: building components including operational use
The horizontal axis shows the 24 buildings in the study and the emissions from the various building components with operational energy use added at the top. The vertical axis shows the emission of CO_2eq./m²/year.

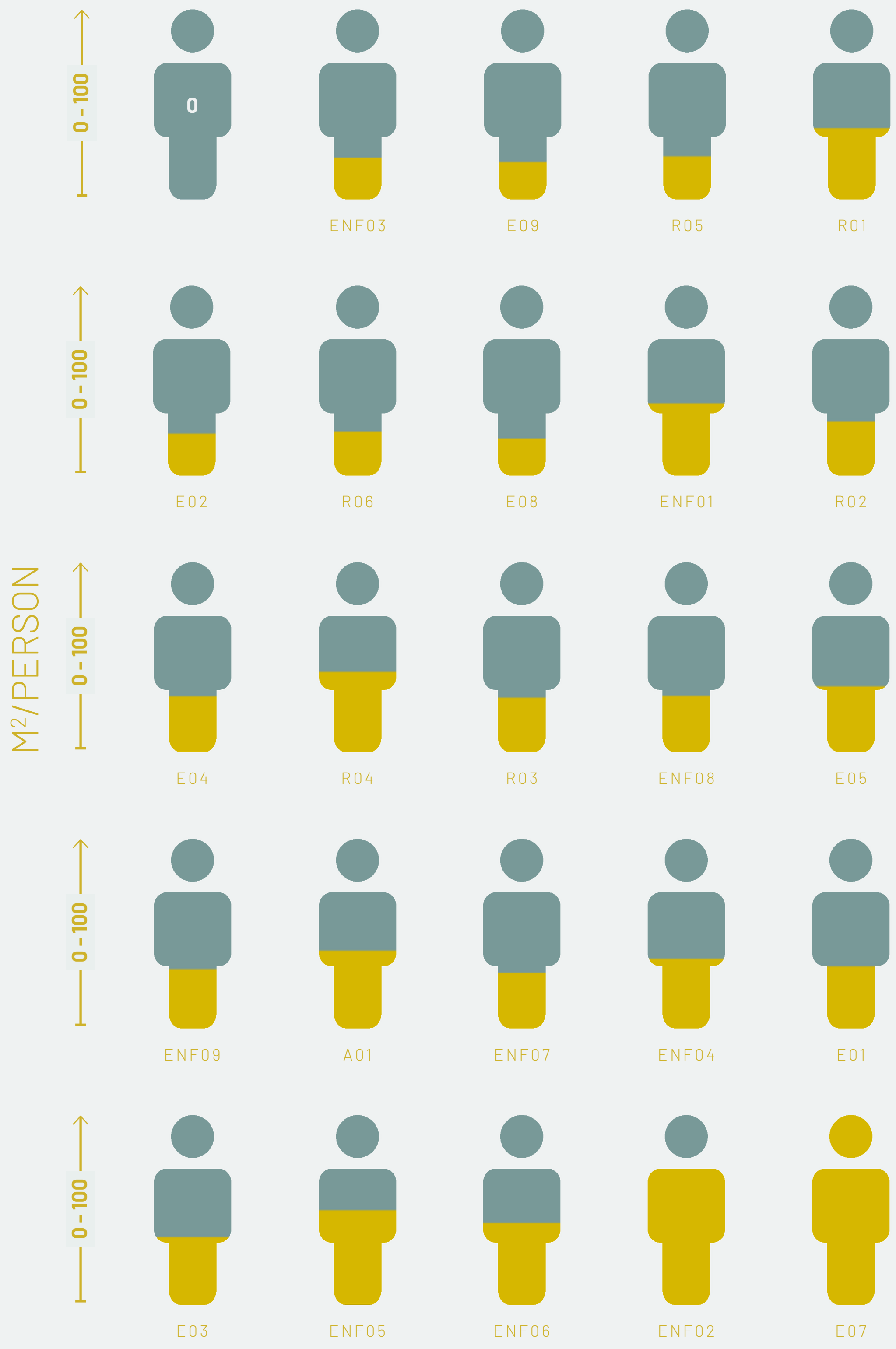
HUMAN SHARE

The green axis represents the unit kg CO_2eq./person/year, and the yellow axis the unit m^2 of floor space/person and looks at the connection between occupant and emissions per occupant. The case studies are sorted according to kg CO_2eq./person/year, starting with the project with the lowest emissions.

HUMAN SHARE

The case collection applies the rule that space per occupant is significant for the emission of CO_2eq./person/year. However, there seems to be no convincing relationship between high space per person and a high rate of emission per person.

It was nevertheless concluded from this analysis that materials have a greater impact on the results of kg CO_2eq./person/year than m^2 of floor space/person.



HUMAN SHARE

The axis represents both the unit kg CO_2eq./person/year and m² of floor space/person. This shows the case collection broken down into typology to facilitate identifying the emission trends and any correlation between the m²/person in the dwelling.

The two case studies with the highest emissions, both in terms of kg CO_2eq./person/year and m²/person are a single-family dwelling and multi-storey housing, respectively. Besides these two case studies, the distribution of m²/person is relatively even across the case collection spectrum, while there is evidence of a great spread in terms of emissions/person.

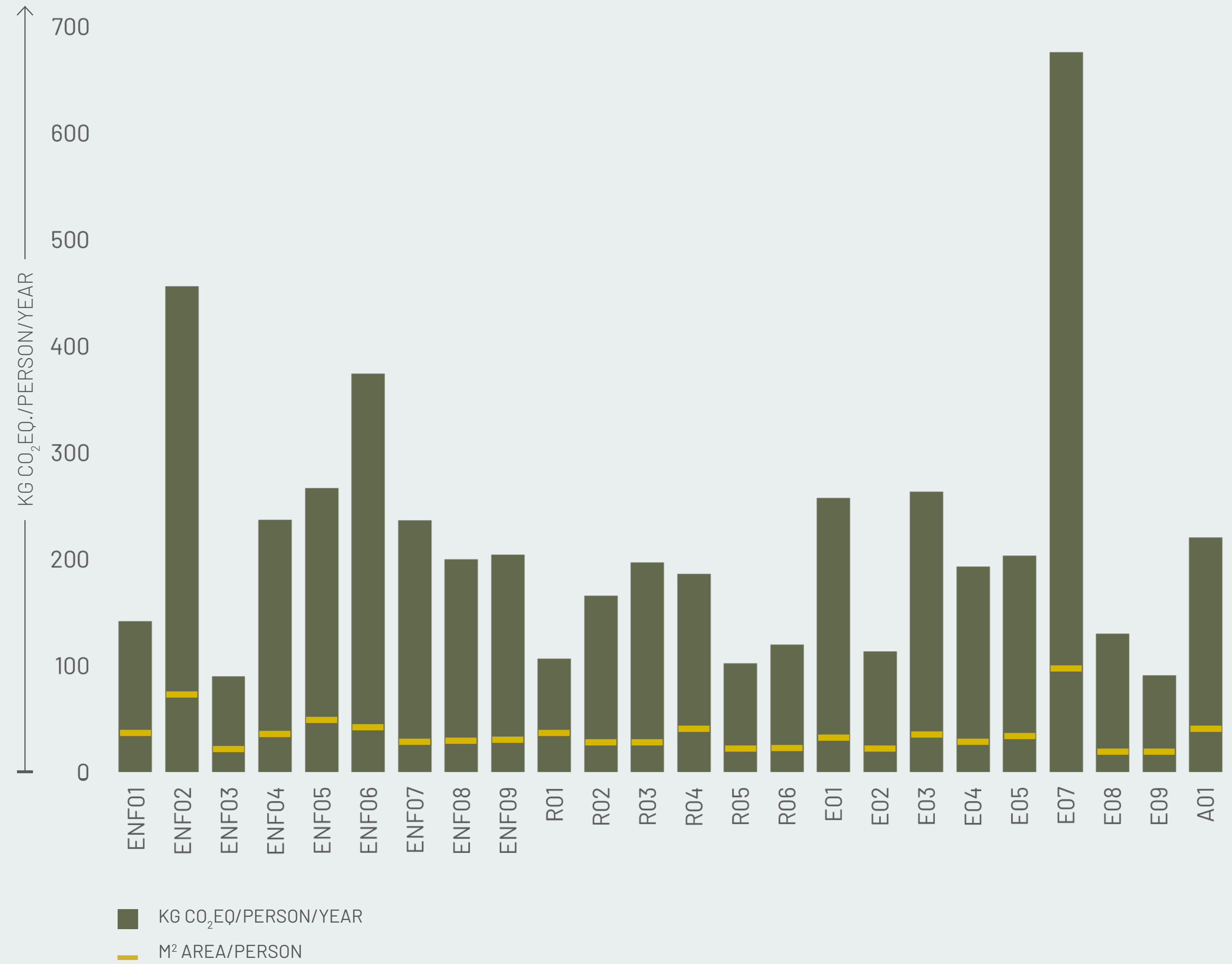


Figure 31: Best practice case emissions of kg CO_2eq./person/year and m²/person

3 SCENARIER: kg CO_2eq./person/year

The basis of this analysis is the case collection housing, where reference area and number of occupants from the 24 case studies are used to demonstrate four variations of emissions/ person. The analysis shows a strong reduction in emissions per person in the best practice case collection compared to a similar dwelling of the same size and number of occupants constructed using conventional materials and methods. The four scenarios are shown as spans subdivided as follows:

The red section indicates the case collection span if the housing were built as conventional housing with emissions totalling 10 kg CO_2eq./m²/year.

The dark blue section shows the actual span of emissions/person in the case collection.

The green section indicates the span of the case collection if the dwellings were to achieve the 4 > 1 planet goal of 2.5 kg CO_2eq./m²/year.

The pale blue section indicates the span of the case collection if the dwellings were to achieve the safe operating space of 0.4 kg CO_2eq./m²/year.

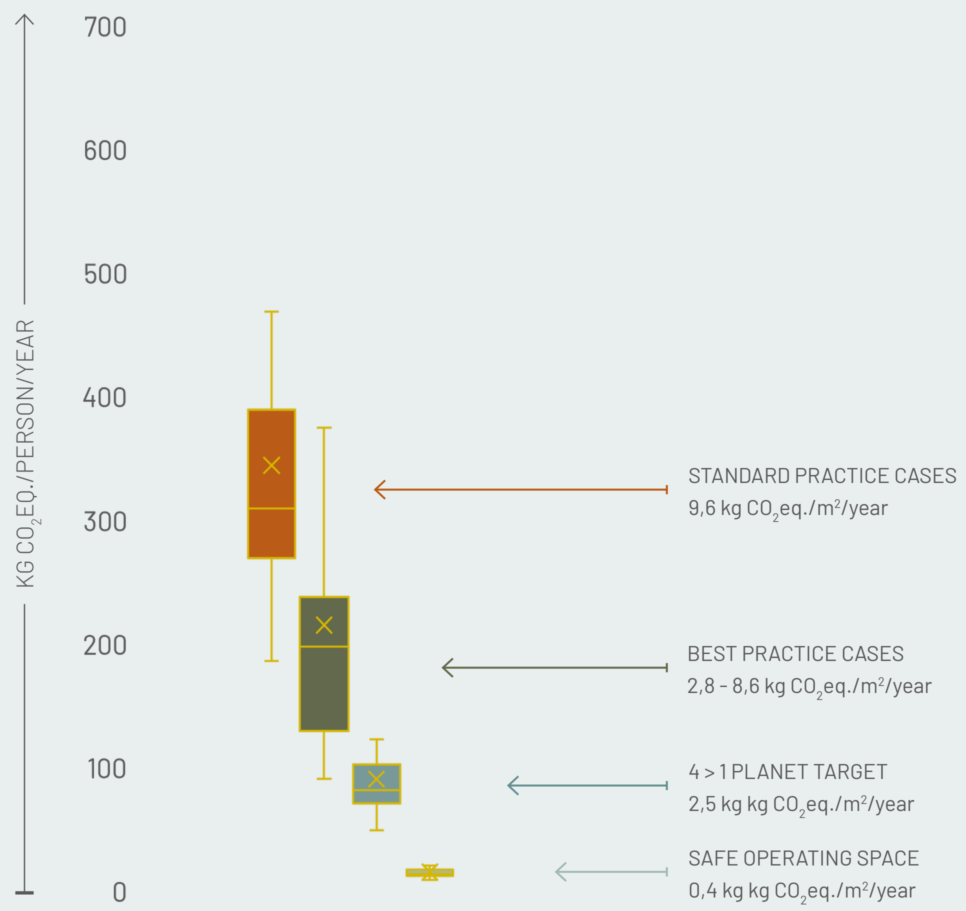


Figure 32: Scenarios for the building's emission of kg CO_2eq./person /year

RATIO / ENVIRONMENTAL IMPACT

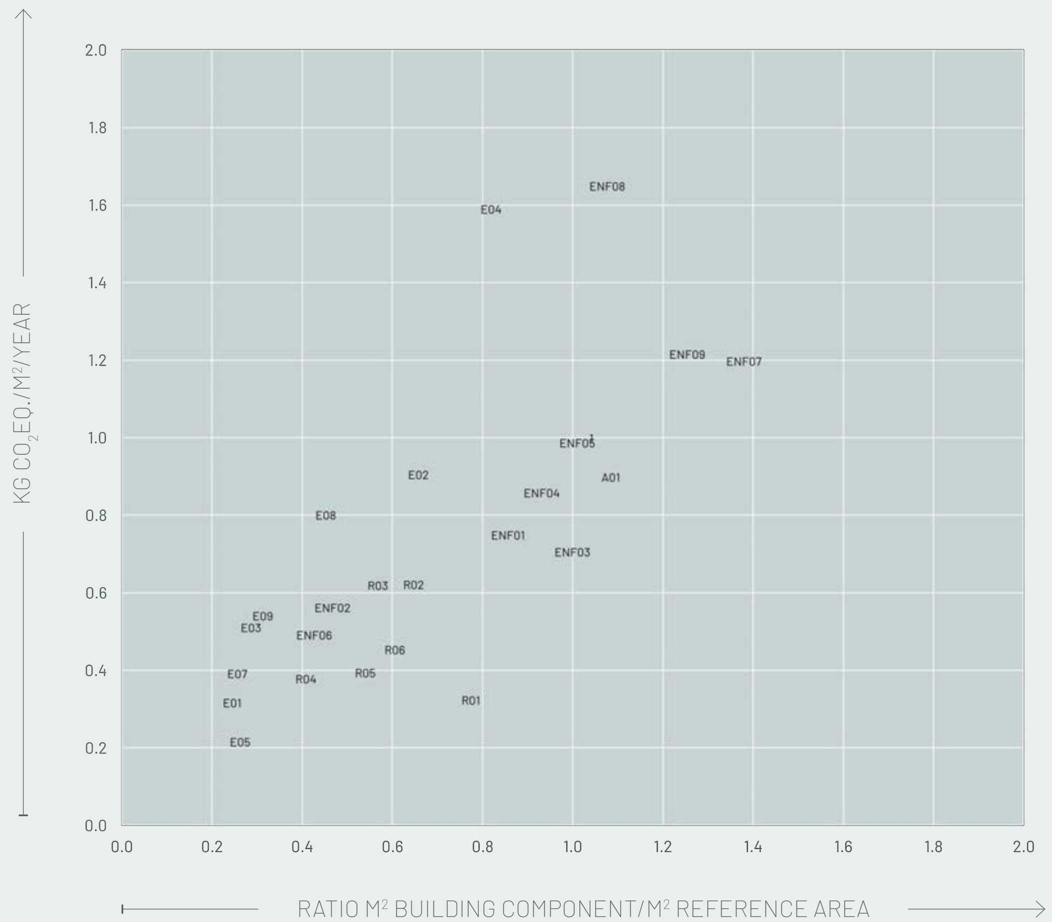
The analysis couples the relationship of the ratio of a building component to its emission to examine the correlation between emissions and occurrence. In this context, ratio is the square metreage of a specific building component spread over the building's reference area, for example, 1 m^2 of exterior wall/1 m^2 of reference area. The selected building components occur in all housing typologies and are traditionally among those with the highest impact. The three diagrams represent roofs, exterior walls, and windows and show the emission of CO_2eq./m^2/year per building component in relation to the m^2 of building component/m^2 of reference area.

The roof shows a wide span of both emissions and ratio, tending to concentrate in the lower left corner of the diagram for multi-storey housing. There is a correlation between ratio and emission, where it is evident that one-storey single-family housing moves towards the centre right of the diagram. This indicates that both material choice and ratio play a decisive role. A few case studies stand out, showing low emissions despite a relatively high ratio.

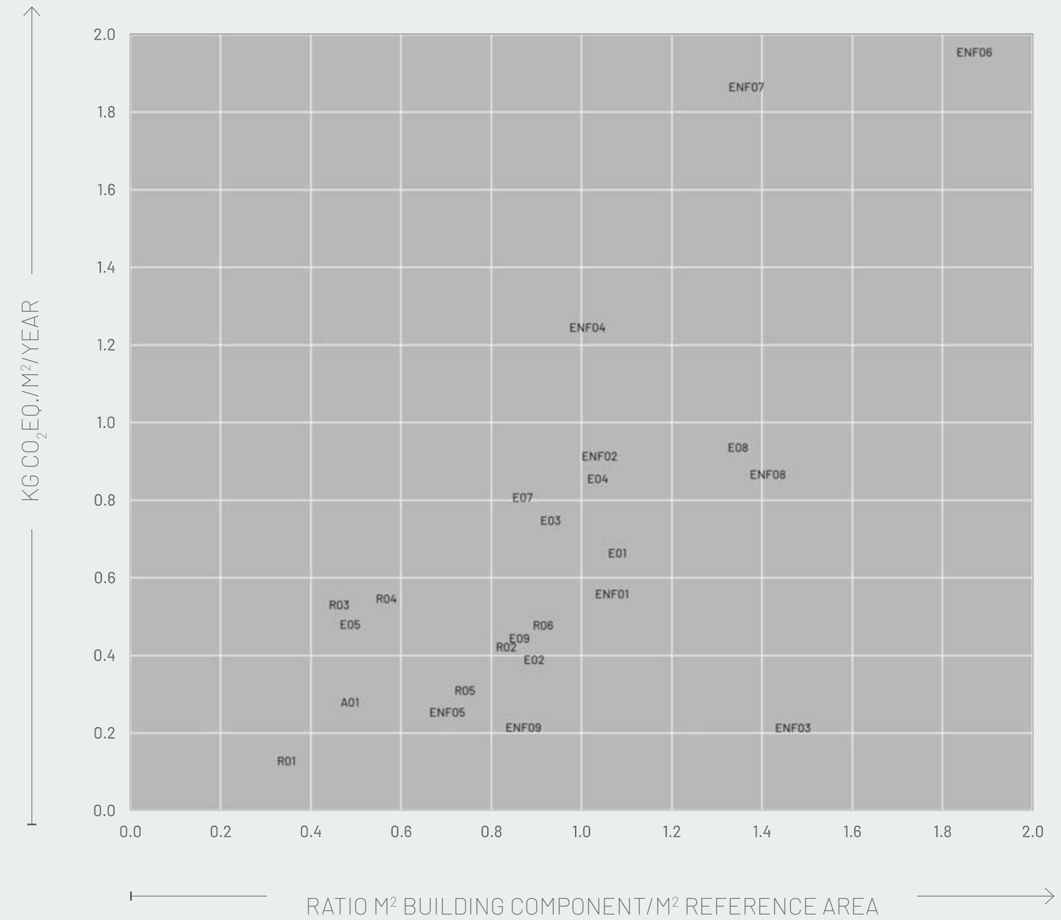
The picture is different for exterior walls, showing a larger span both in terms of emission and ratio. This confirms that material choice is significant for the building component, since it is evident that some exterior walls with relatively low emissions still have a high ratio. In line with the results for the roofs, it is primarily single-family housing that tends to move towards the right side of the diagram.

The pattern for windows differs from that of roofs and exterior walls. There is less variation in the ratio, i.e. the case collection operates with a relatively stable ratio of m^2 of window/m^2 of reference area. The trend line is steeper (with a few outliers), indicating that higher emissions are proportionate with a higher ratio. Further, the scale of environmental impact from windows is the same as that from exterior walls and roofs, despite a lower ratio.

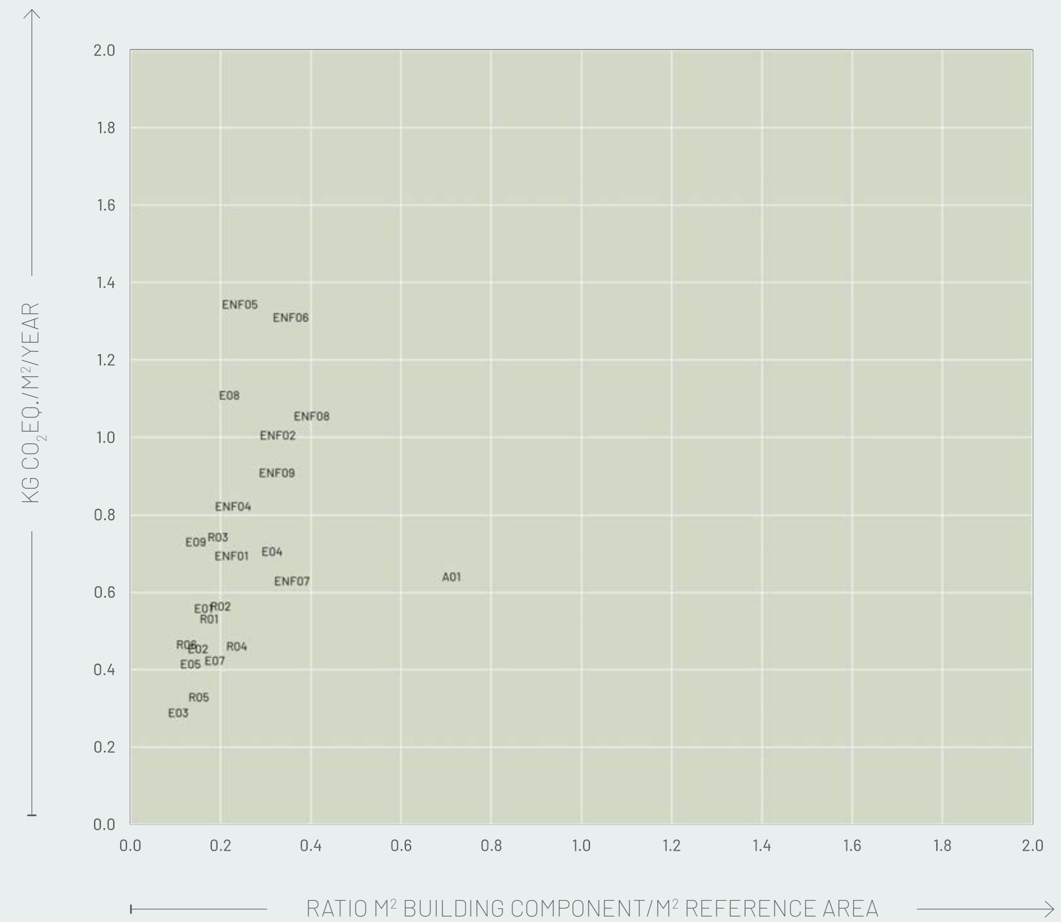
BUILDING COMPONENT: ROOF



BUILDING COMPONENT: EXTERIOR WALL



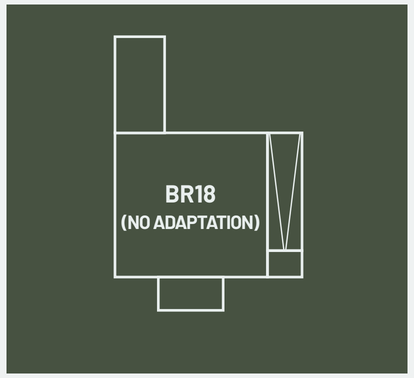
BUILDING COMPONENT: WINDOW, DOOR AND GLASS FACADE



24 CASES

ENF01: Living Places I

Developer:	VELUX
Architect:	EFFEKT
Engineer:	Artelia
Contractor:	Enemærke & Petersen
Year (built):	2023
Floor area:	147 m²
Reference area:	147 m²
Use:	Residential
Occupants:	4
Year (calculated):	2022
Heating:	Heat pump
Solar cells:	Yes



DESCRIPTION

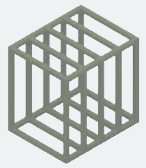
Living Places is a demo project, challenging the idea of "business as usual" with a holistic approach to building, pointing the building trade in new directions for the benefit of both people and the planet. The project is implemented via a strategic partnership, showing that by exclusively making use of existing knowledge and known materials, it is possible to build housing with a better indoor climate and lower carbon footprint than is common practice today. All materials are therefore given careful consideration relative to construction technique and carbon footprint. Further, the design incorporates mechanical seams, facilitating end-of-life dismantling of structures. The collaboration resulted in two prototypes, including Living Places Bolig, designed to house a family of four.

The three-storey building is built on steel screw-pile foundations with glulam wall plates. The grade deck is a light-weight cassette structure in mass wood, insulated with cellulose and covered with particle board.

The house is constructed with facade cassettes and supporting structures in glulam. Exterior walls are insulated with cellulose and wood-fibre material. The facade has timber facing. Rib-deck constructions in mass timber with an integral footfall insulation membrane and plywood, covered with fibre gypsum boards and wooden flooring, respectively. Interior walls are light-weight timber-framed walls with wood-fibre insulation, covered with tongue-and-groove plywood and fibre gypsum boards, eliminating the need for filler.

The roof is a cassette structure with cellulose insulation covered with zinc-magnesium-coated steel sheeting with roof lights. Where photovoltaic modules are fitted, the underlying roofing material is bituminous felt.

The three-bedroom house is 147 m². With four occupants, this gives approx. 37 m²/person, which is an average for the case collection.



Timber frame

3 storeys

ENF01: Living Places I

3,85 kg CO_2eq./m²/year

Figure ENF01.1: Emissions of kg CO_2eq./m²/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO_2eq./m²/year in single-family housing in the case collection.

26.229 kg CO_2eq.

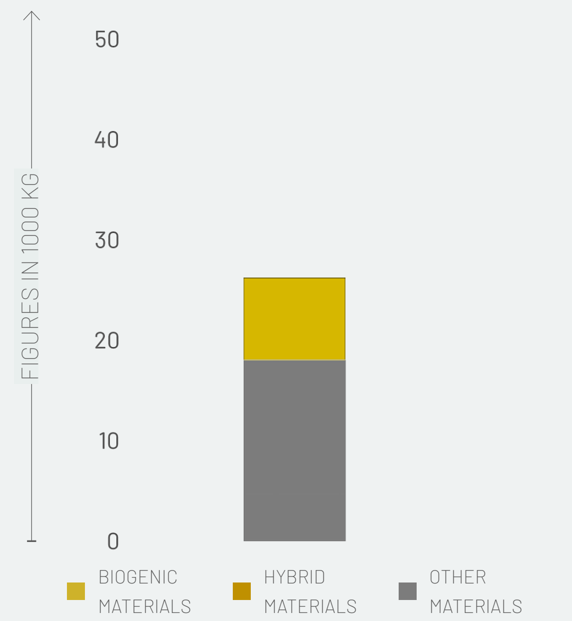


Figure ENF01.2: Total emission of kg CO_2eq.
The stacked bar chart shows the overall emission of kg CO_2eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

142 kg CO_2eq./person/year

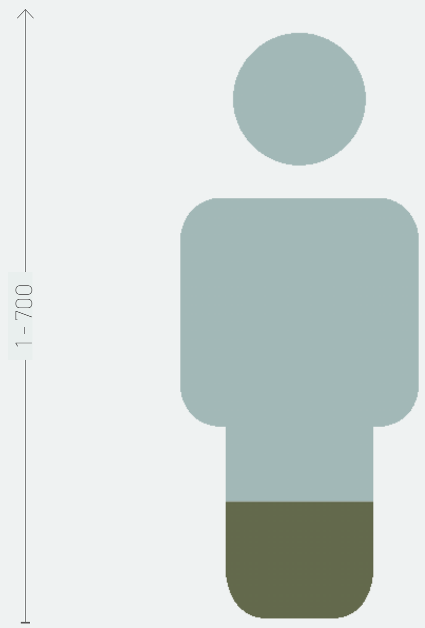


Figure ENF01.3: Emissions of kg CO_2eq./person/year
The span of the vertical axis is 1 to 700 kg CO_2eq./person/year

37 m²/person

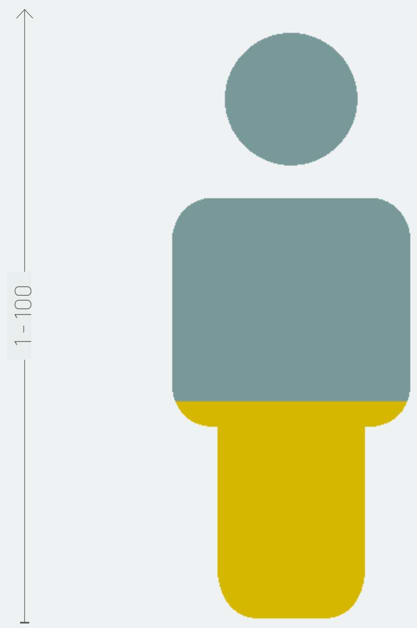


Figure ENF01.4: m²/person
The span of the vertical axis is 1 to 100 m²/person

ENF01: Living Places I

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m²/year.

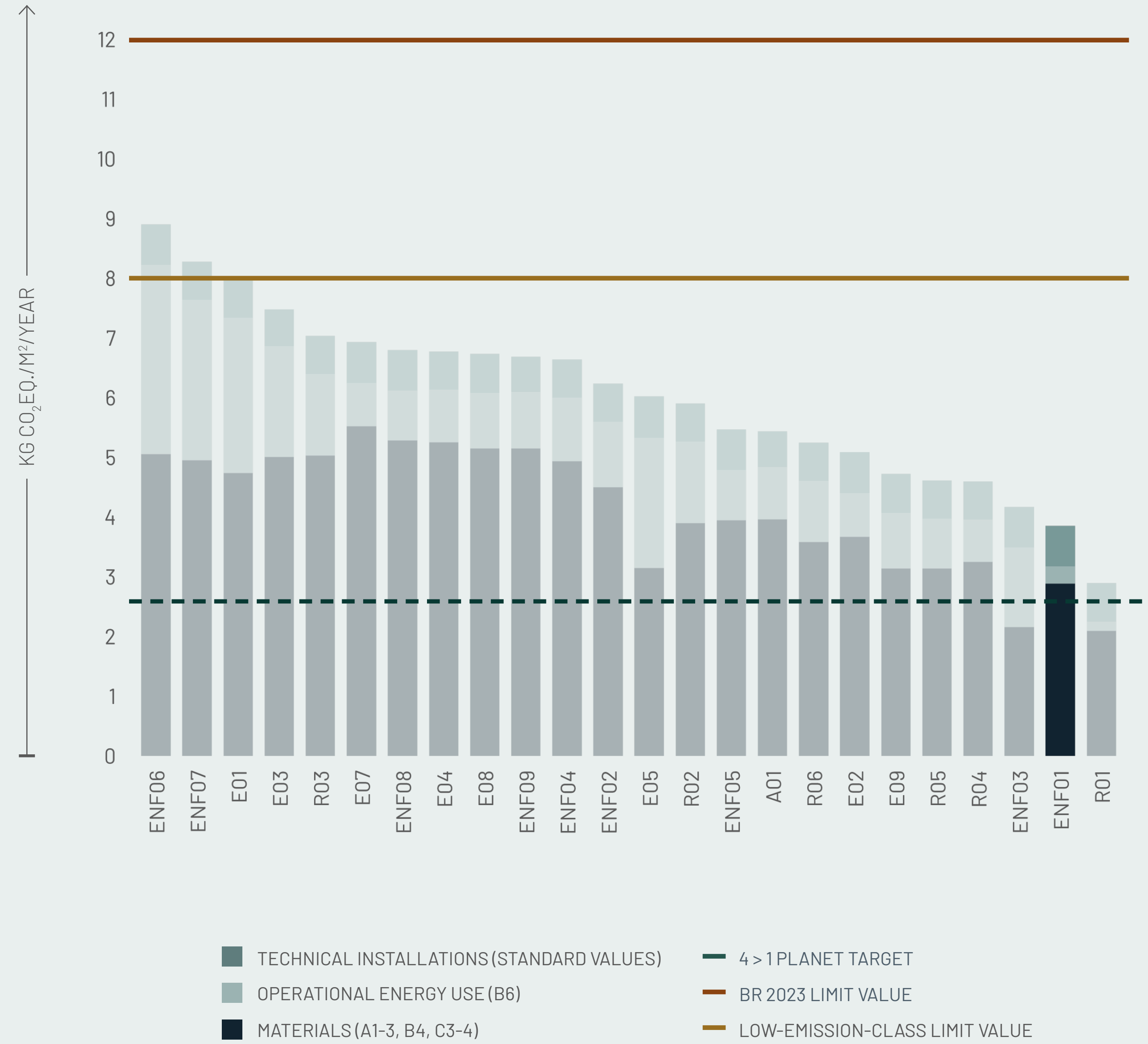


Figure ENF01.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m²/year. The horizontal axis shows the 24 best practice cases.

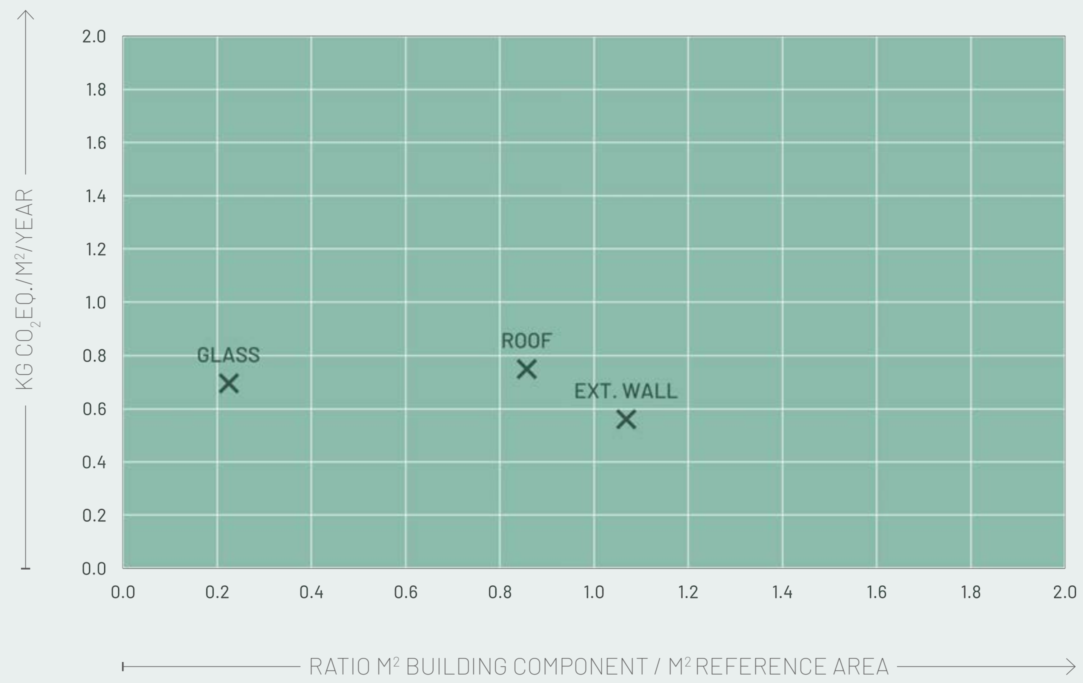
ENF01: Living Places I

ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in CO_2eq./m²/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is well within the fastest reduction rate: the 83% likelihood scenario.

Figure ENF01.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq./m²/year, and the 'safe operating space'.

RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS



ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

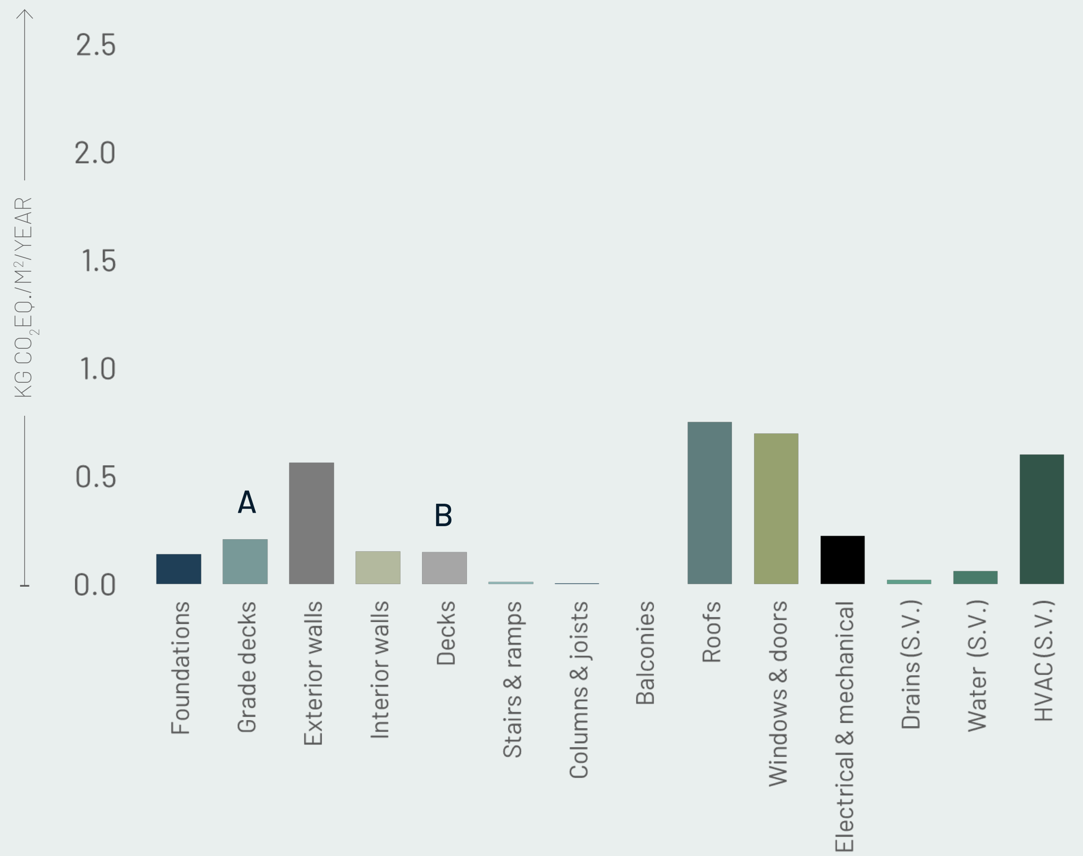


Figure ENF01.7: CO_2 accounting for building components
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades, electrical and mechanical systems, and technical installations (standard values).

SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

Figure ENF01.8:
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

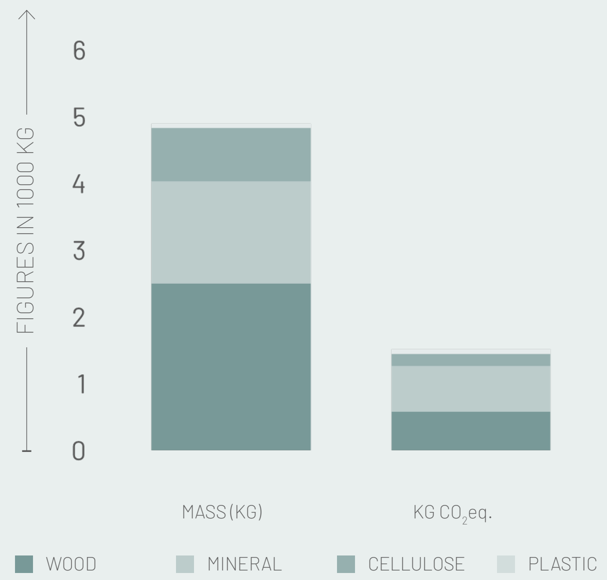
The vertical axis shows the figure in kilos (1000), i.e. the span is 0–50.000 kg.

The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total CO_2eq grouped similarly.

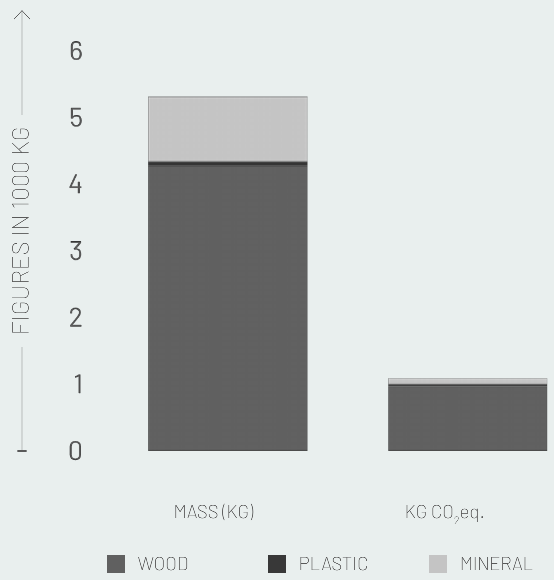
BIOGENIC MATERIALS · HYBRID MATERIALS · OTHER MATERIALS

MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG CO_2EQ.



A. GRADE DECK

Timber flooring
Insulation membrane
Particle board
Timber battens + cellulose insulation
Vapour barrier
Timber cassettes + cellulose insulation
Fibre cement



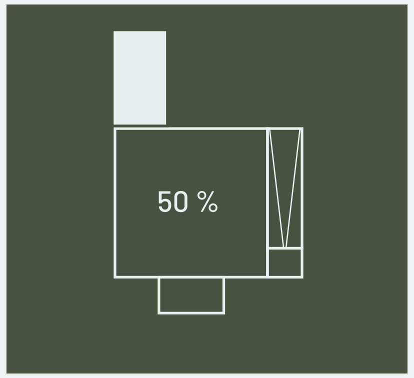
B. DECK

Timber flooring
Insulation membrane
Fibre gypsum boards
Two-layer plywood

ENF02: Sunlighthouse

Developer: VELUX
Architect: HEIN-TROY Architekten
Engineer: Peter Holzer

Year (built): 2010
Floor area: 275 m²
Reference area: 292 m²
Use: Residential
Occupants: 4
Year (calculated): 2022
Heating: Heat pump
Solar cells: Yes



DESCRIPTION

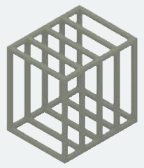
Sunlighthouse is an international case study from 2010 and thus the oldest study in the best practice case collection. The project is Austria's first carbon-neutral single-family dwelling whose sloped roof and other architectural features fully exploit the sunlight for maximum daylight and solar power. The dwelling is expected to become carbon-neutral over its life cycle, as the annual energy production from photovoltaic modules, heat pumps, solar power, and other renewable energy sources exceed annual requirements. The photovoltaic modules and collectors generate more energy than used by the household, which means that the dwelling will have generated the same amount of pure energy used during construction.

The three-storey building is built on continuous concrete foundations. The grade deck consists of concrete insulated with EPS.

There is a basement of concrete structures insulated with EPS. From the ground floor, the supporting structures are mass-timber and CLT with cellulose and wood-fibre insulation. Interior surfaces are covered with gypsum boards.

The roof is a timber-frame structure with cellulose insulation covered with photovoltaic modules.

The two-bedroom house is 275 m². With four occupants, this gives approx. 69 m²/person, which is on the high side in the case collection.



Timber frame

3 storeys

ENF02: Sunlighthouse

6,24 kg CO_2eq./m²/year

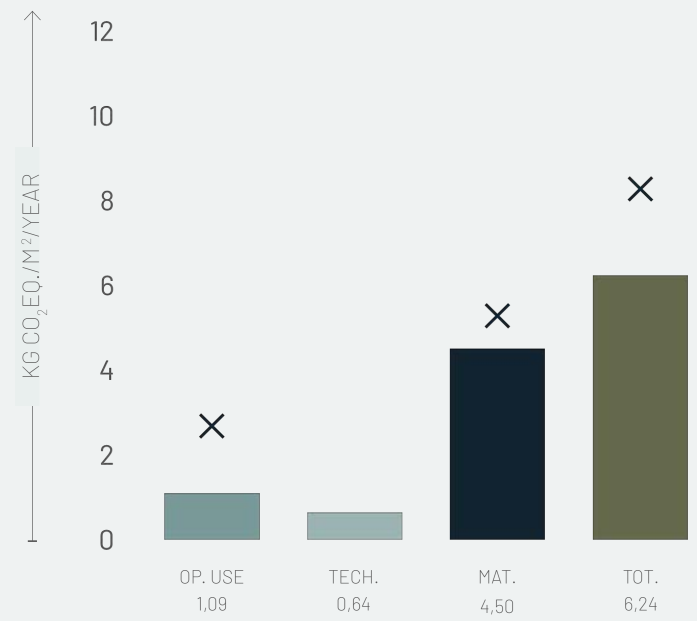


Figure ENF02.1: Emissions of kg CO_2eq./m²/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO_2eq./m² /year in single-family housing in the case collection.

75.183 kg CO_2eq.

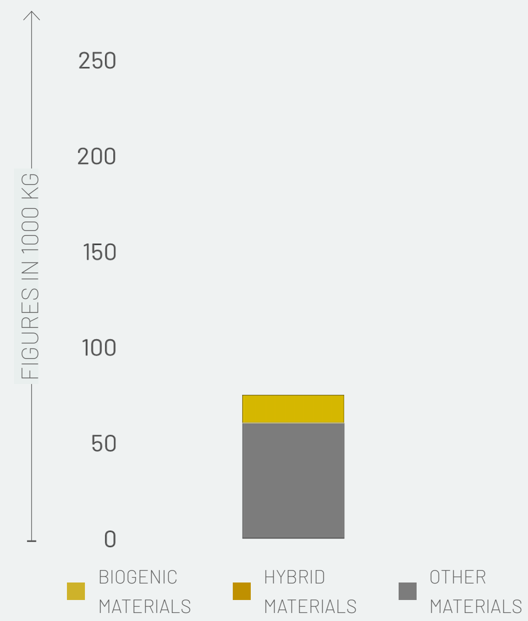


Figure ENF02.2: Total emission of kg CO_2eq.
The stacked bar chart shows the overall emission of kg CO_2eq. in the case study grouped into the three material categories: other, hybrids, and biogenic.

456 kg CO_2eq./person/year

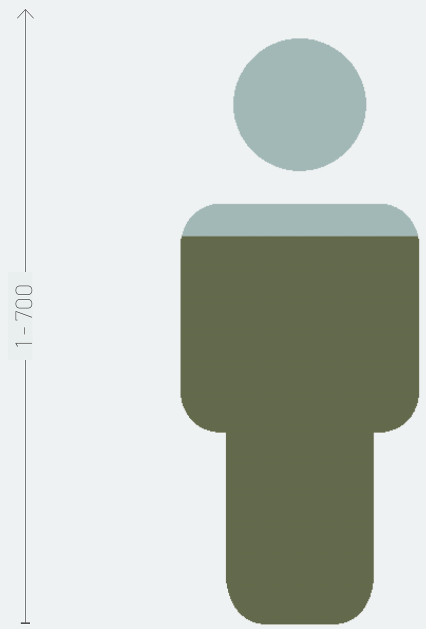


Figure ENF02.3: Emissions of kg CO_2eq./person/year
The span of the vertical axis is 1 to 700 kg CO_2eq./person/year

69 m²/person

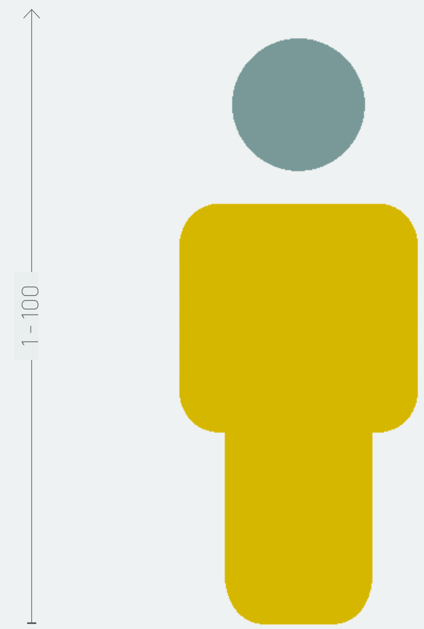


Figure ENF02.4: m²/person
The span of the vertical axis is 1 to 100 m²/person

ENF02: Sunlighthouse

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m²/year.

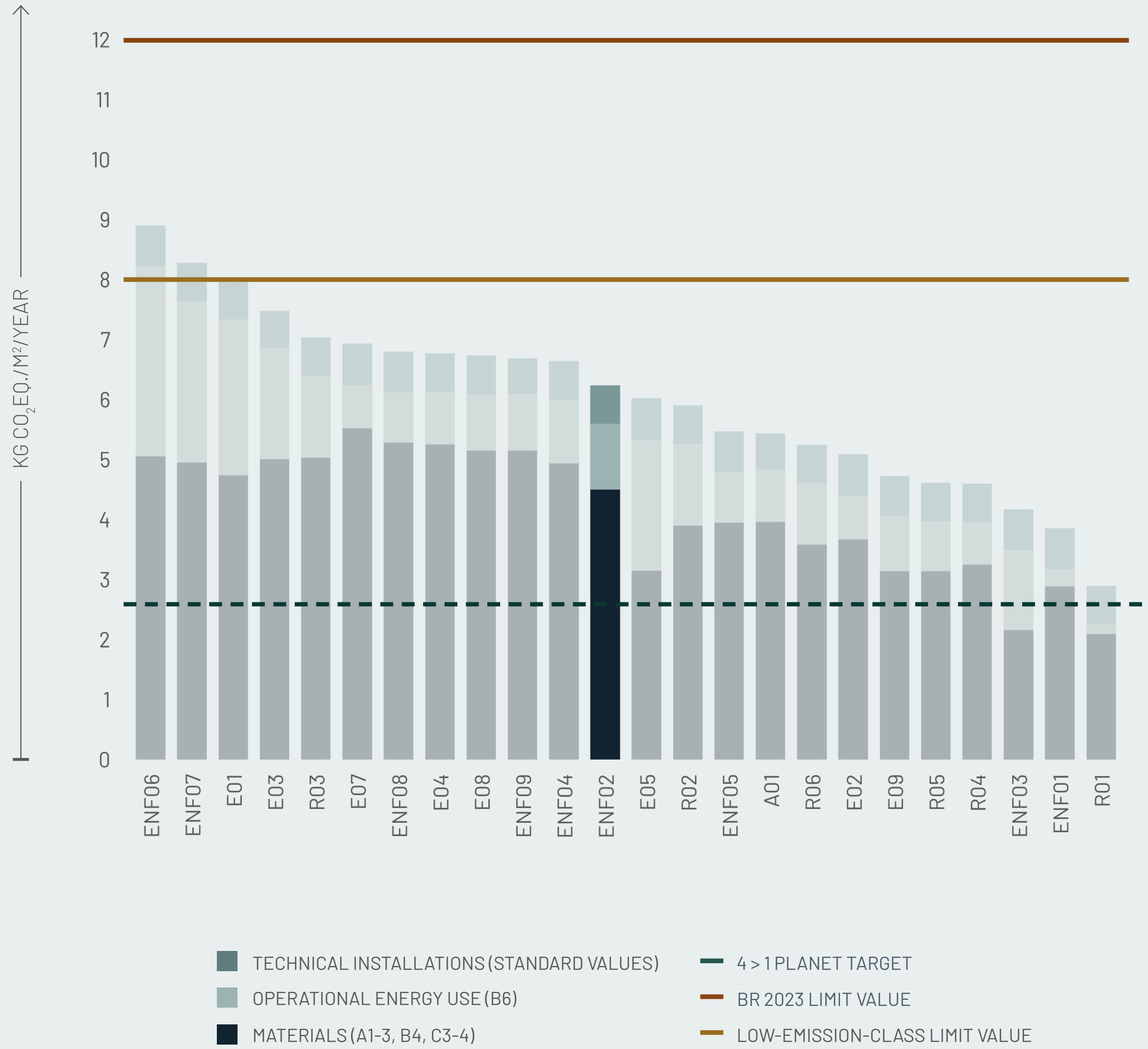


Figure ENF02.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m²/year. The horizontal axis shows the 24 best practice cases.

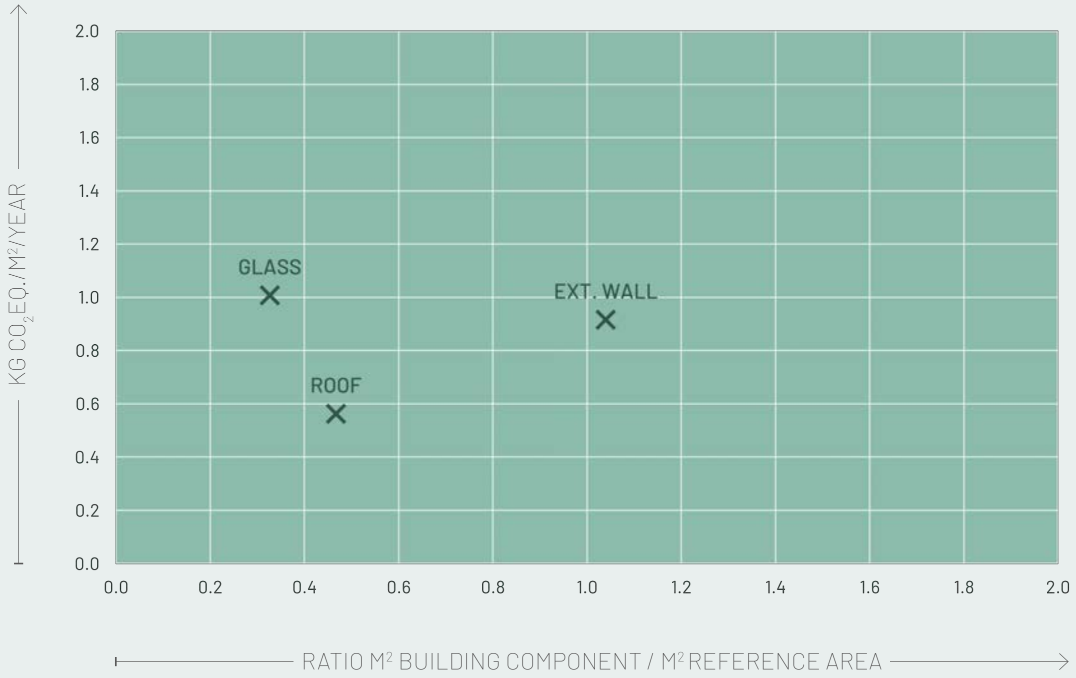
ENF02: Sunlighthouse

ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in CO_2eq./m²/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is well within the fastest reduction rate: the 83% likelihood scenario.

Figure ENF02.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq./m²/year, and the 'safe operating space'.

RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS



ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

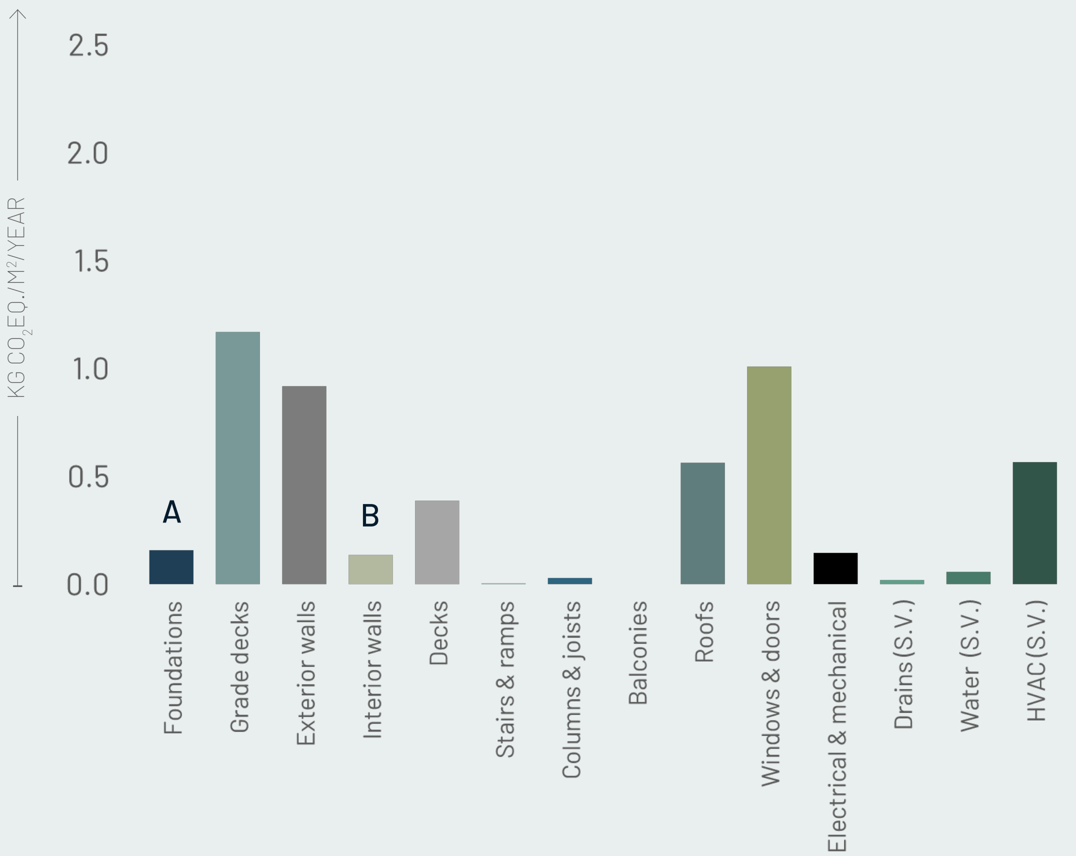


Figure ENF02.7: CO_2 accounting for building components
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades, electrical and mechanical systems, and technical installations (standard values).

ENF02: Sunlighthouse

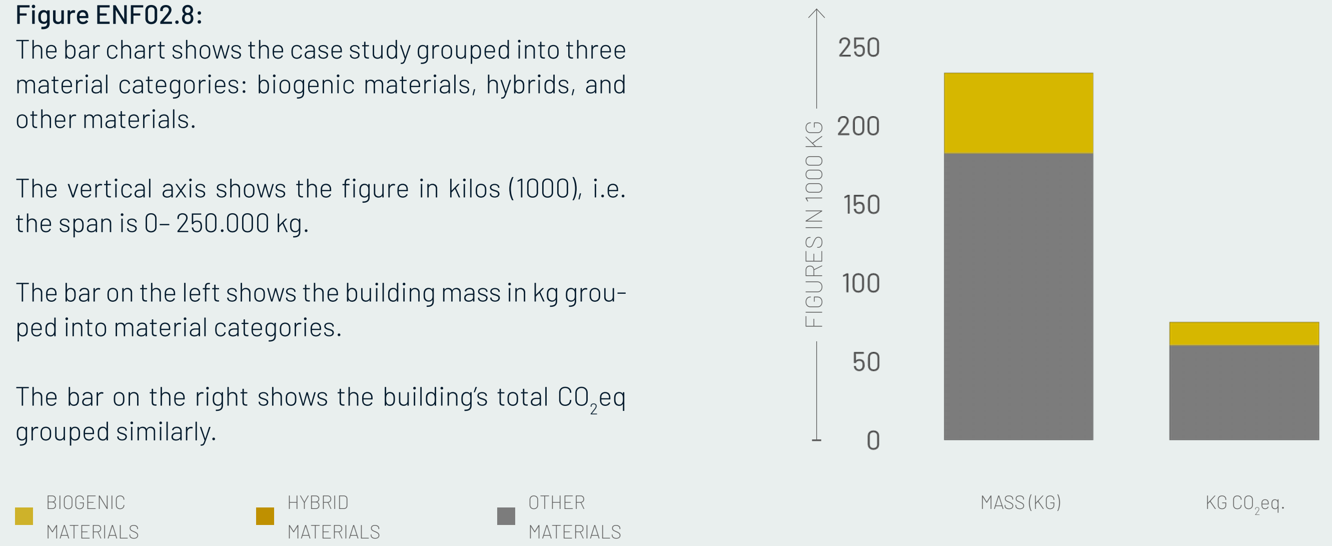
SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

Figure ENF02.8:
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

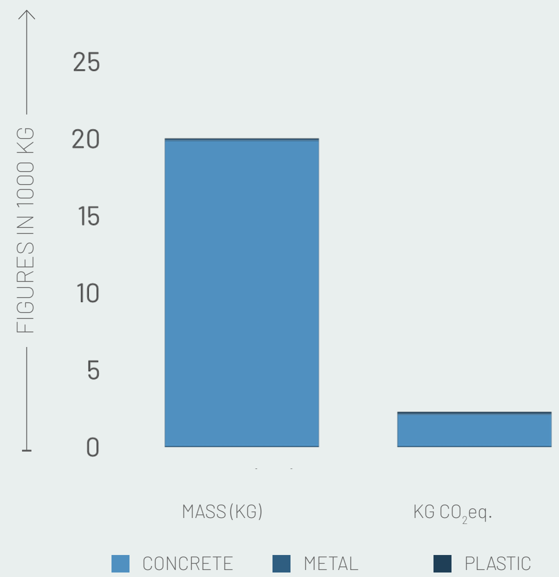
The vertical axis shows the figure in kilos (1000), i.e. the span is 0- 250.000 kg.

The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total CO_2eq grouped similarly.

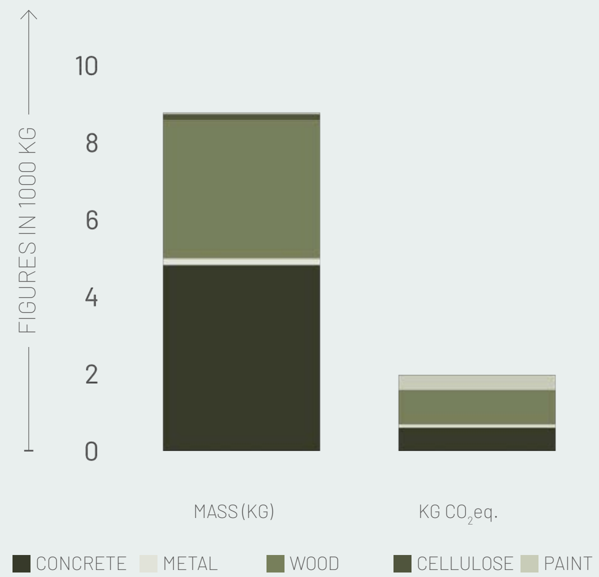


MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG CO_2EQ.



A. FOUNDATION

Reinforced concrete
EPS insulation



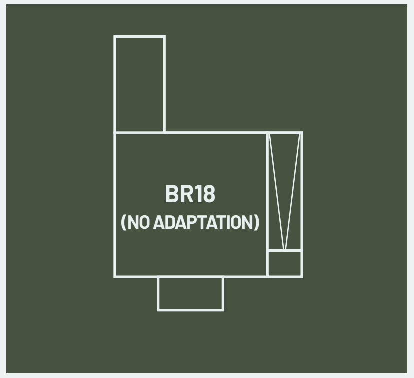
B. INTERIOR WALL

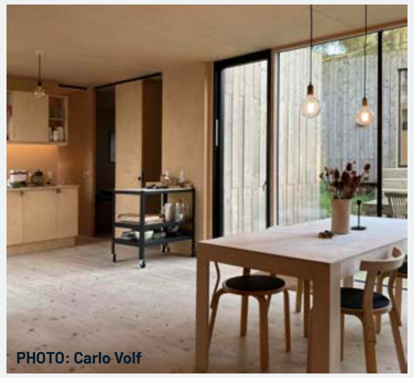
Timber frame
Cellulose insulation Plywood
Timber cladding

ENF03: Ecohousing

Developer: Carlo Volf
Architect: KM Byg Montage m.fl.
Engineer:
Contractor:

Year (built): 2021
Floor area: 86 m²
Reference area: 86 m²
Use: Summer house
Occupants: 4
Year (calculated): 2022
Heating: Electric & wood stove
Solar cells: No





DESCRIPTION

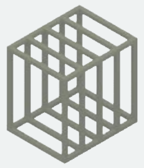
EcoHousing is an experimental project where construction principles and material choice are governed by their CO_2-storage properties. Consequently, the house is constructed in bio-based materials, except for foundations, bituminous felt, windows, and plumbing and heating components.

The one-storey building is built on screw-pile foundations dimensioned for sandy subsoil to obtain a minimalistic construction. The grade deck is a timber-frame construction with eelgrass and wood-fibre insulation.

Generally, the house is constructed with supporting structures in timber with eelgrass insulation. Creating a healthy indoor climate and avoid vapour barriers was important, so the moisture-absorbent properties of primary materials were a special focal point. Eelgrass regulates the temperature in the house by keeping it low during the summer months, however, considerable time is required to warm up the house in the winter months.

Interior and exterior surfaces are untreated timber, and the windows have a low iron content and are oriented to minimise high indoor temperatures. Bituminous felt roof covering.

The three-bedroom house is 86 m². With four occupants, this gives approx. 22 m²/person, which is on the low side in the case collection.



Timber frame

1 storey

ENF03: Ecohousing

4,17 kg CO_2eq./m²/year

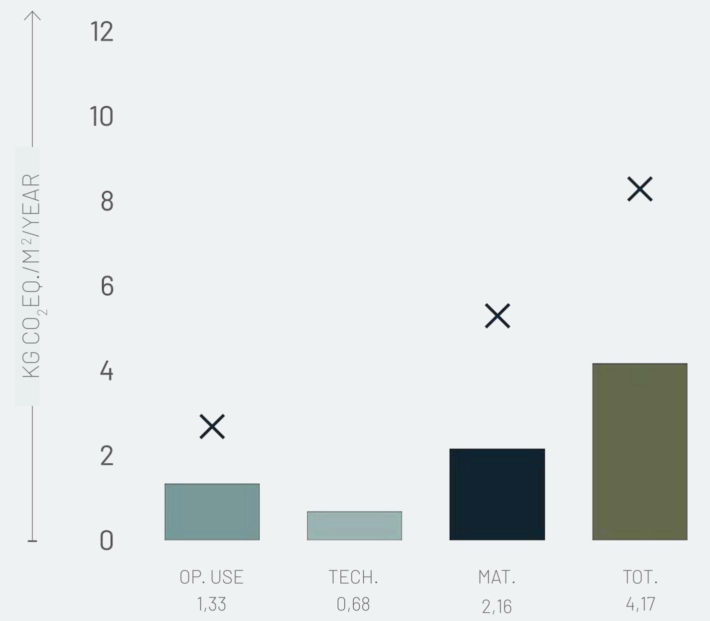


Figure ENF03.1: Emissions of kg CO_2eq./m²/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO_2eq./m²/year in single-family housing in the case collection.

12.209 kg CO_2eq.

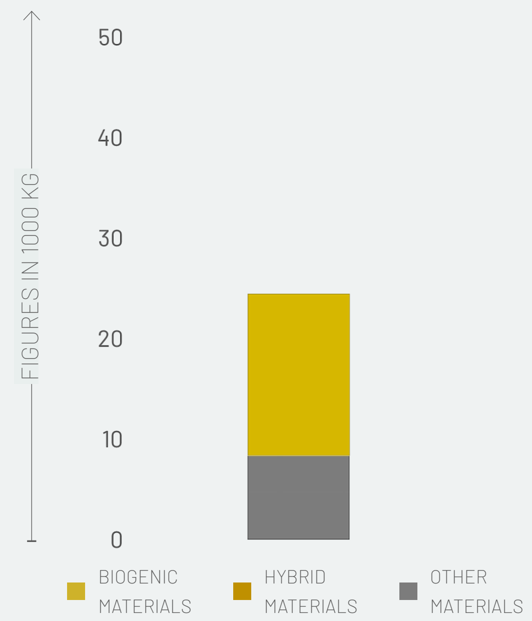


Figure ENF03.2: Total emission of kg CO_2eq.
The stacked bar chart shows the overall emission of kg CO_2eq. in the case study grouped into the three material categories: other, hybrids, and biogenic.

90 kg CO_2 eq./person/year

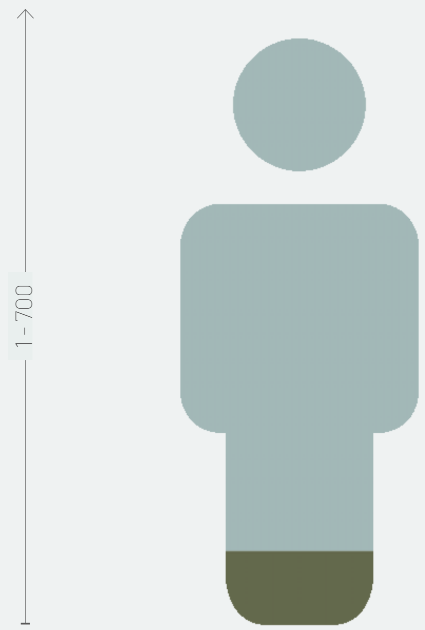


Figure ENF03.3: Emissions of kg CO_2eq./person/year
The span of the vertical axis is 1 to 700 kg CO_2eq./person/year

22 m²/person

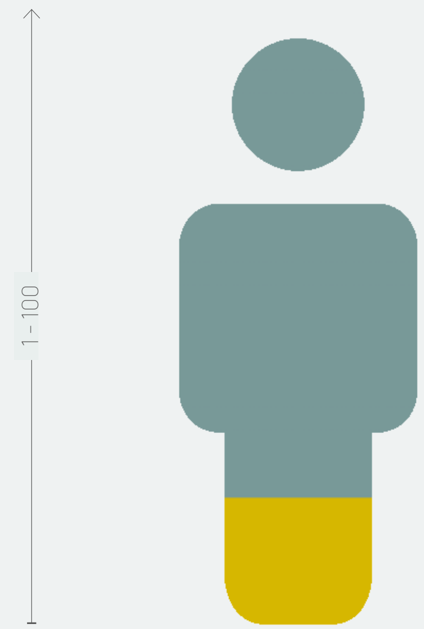


Figure ENF03.4: m²/person
The span of the vertical axis is 1 to 100 m²/person

ENF03: Ecohousing

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m²/year.

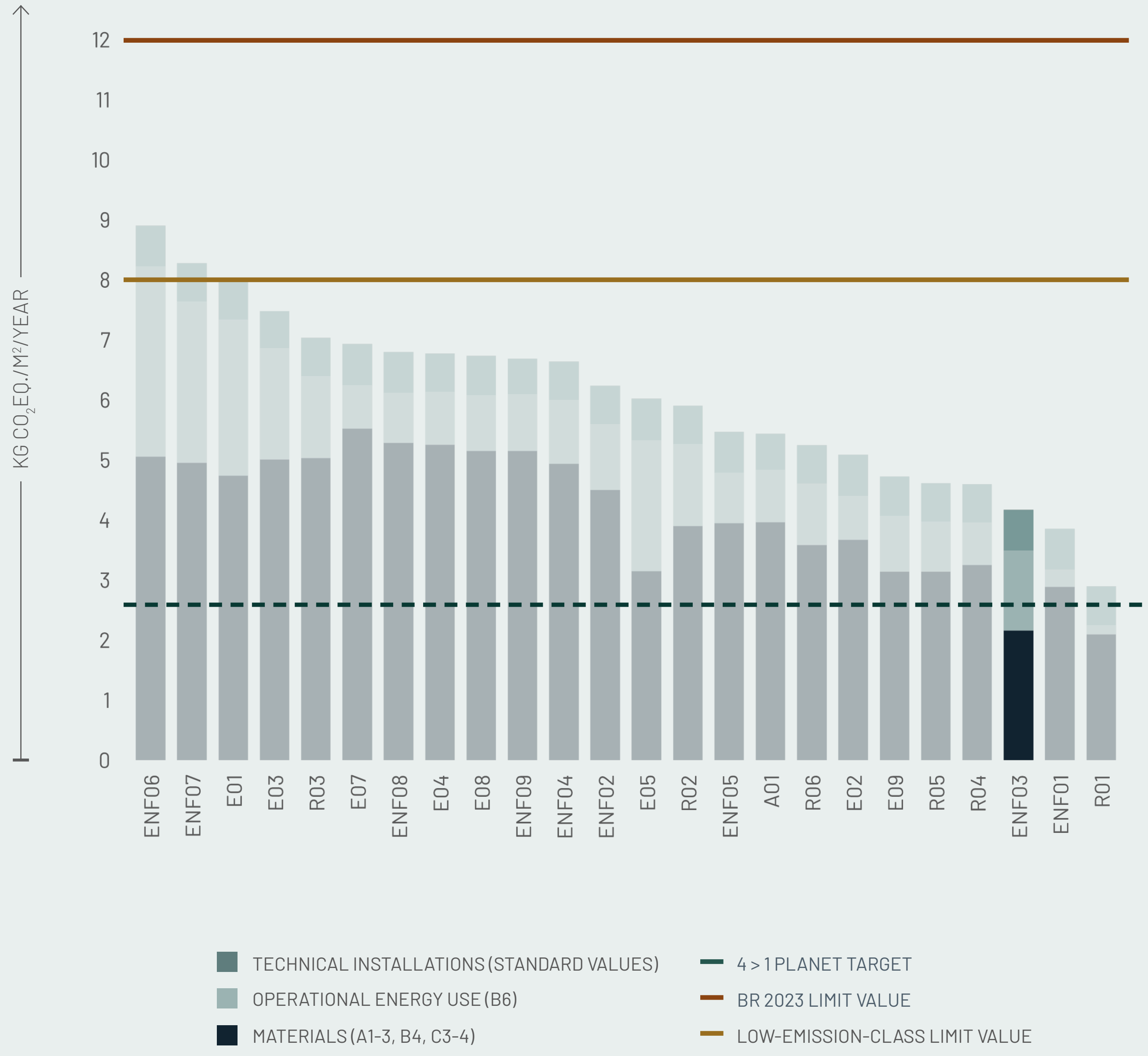


Figure ENF03.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m²/year. The horizontal axis shows the 24 best practice cases.

ENF03: Ecohousing

ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in CO_2eq./m²/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is well within the fastest reduction rate: the 83% likelihood scenario.

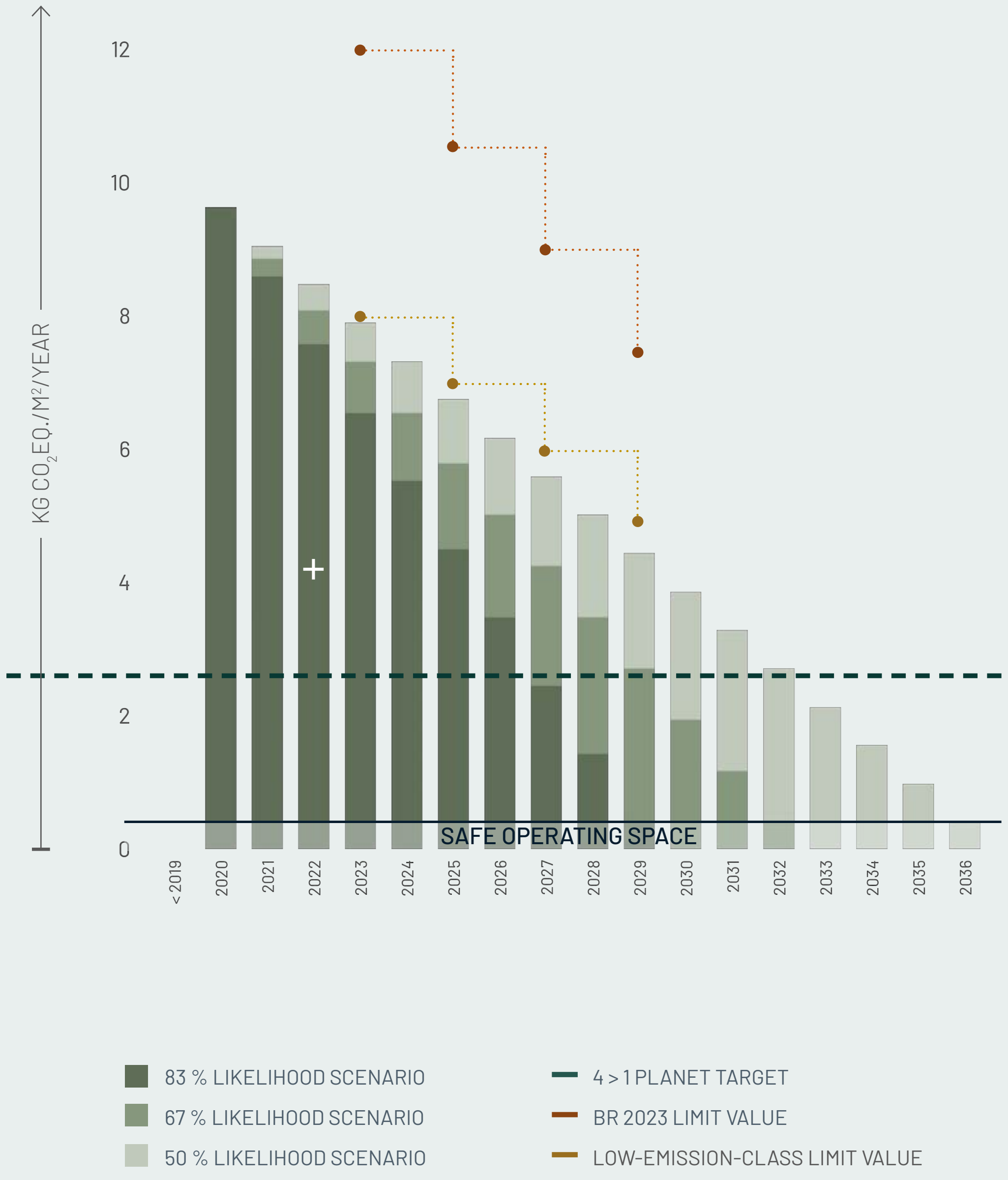
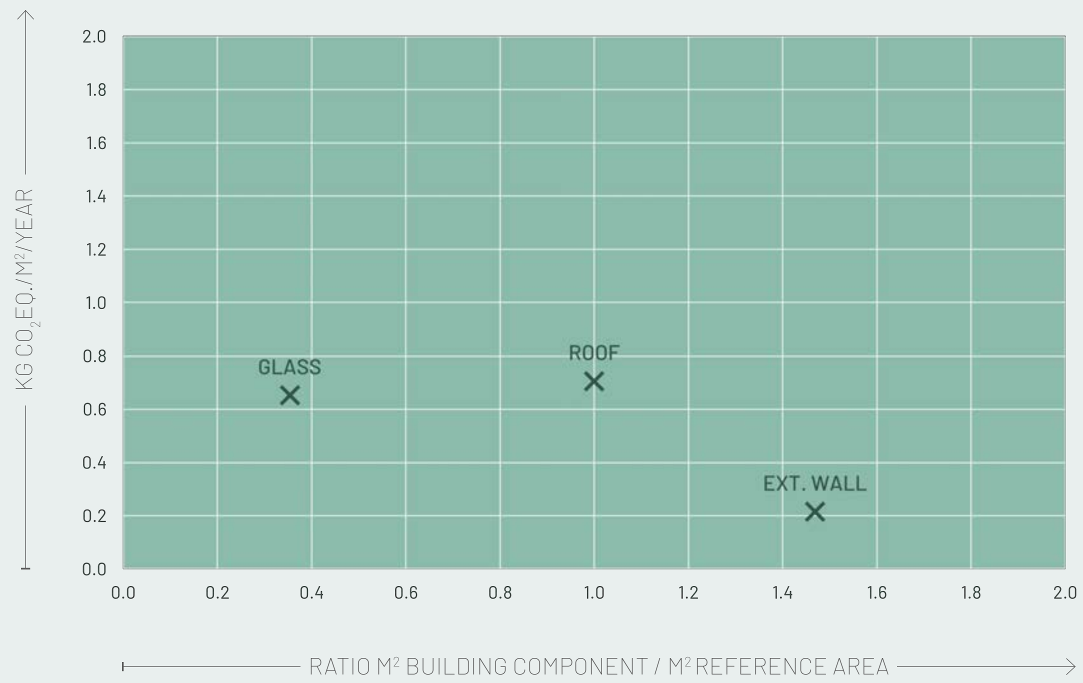


Figure ENF03.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq./m²/year, and the 'safe operating space'.

RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS



ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

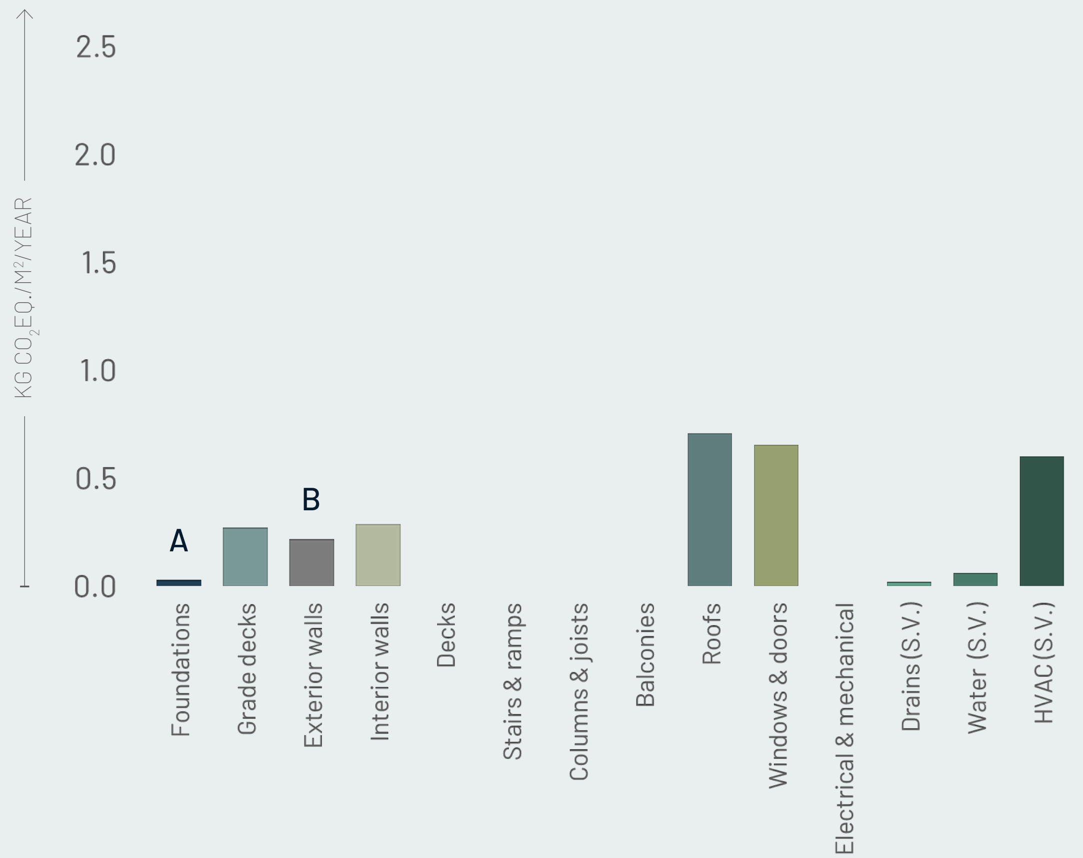


Figure ENF03.7: CO_2 accounting for building components
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades, electrical and mechanical systems, and technical installations (standard values).

ENF03: Ecohousing

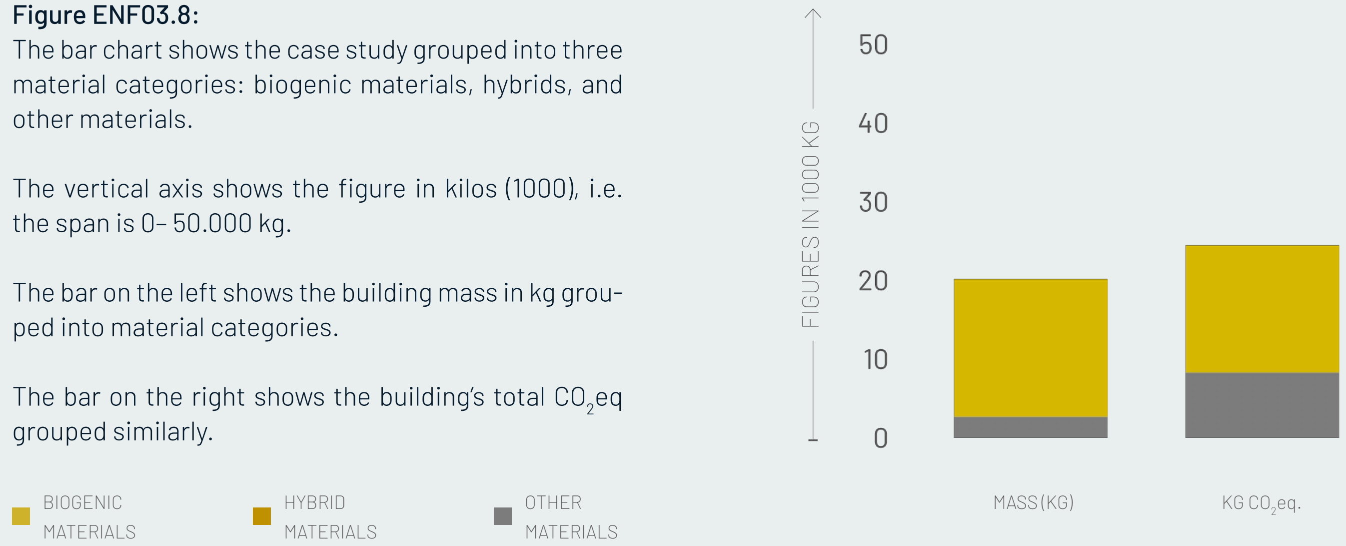
SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

Figure ENF03.8:
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

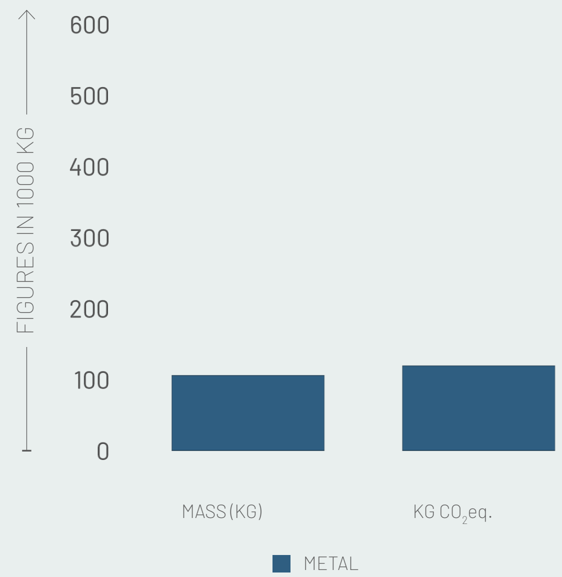
The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

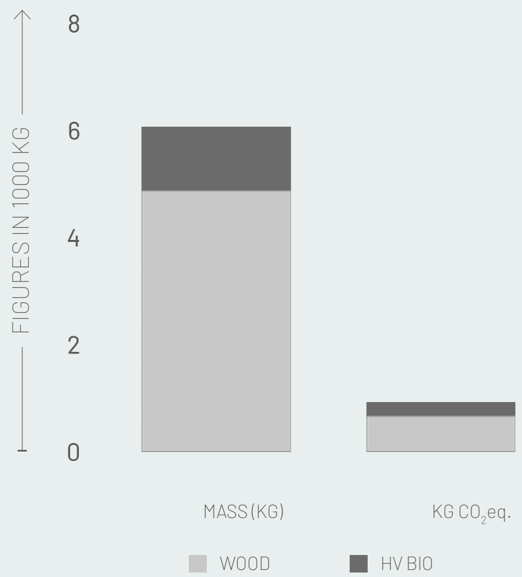
The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total CO_2eq grouped similarly.



MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG CO_2EQ.





A. FOUNDATION

Galvanised steel screws

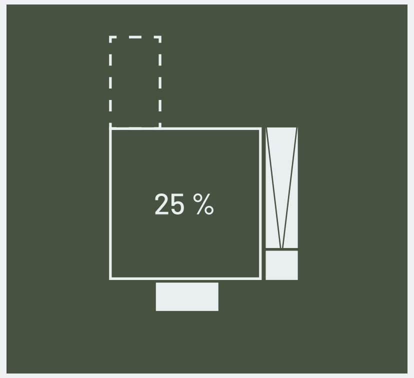
B. EXTERIOR WALL

Wooden cladding
Timber jambs
Wind barrier
Timber-framed cassettes
Eelgrass insulation
Plywood

ENF04: Klimakassen

Developer: Fabulas
Architect: Signatur Arkitekter
Engineer: ABC Rådgivende Ingeniører
Contractor: Scandi Byg

Year (built): 2022
Floor area: 86 m²
Reference area: 86 m²
Use: Residential
Occupants: 4
Year (calculated): 2022
Heating: Heat pump
Solar cells: No



DESCRIPTION

Klimakassen is a prototype of a prefabricated, modular, and system-built housing concept adapted to climate changes. The Product stage took place at a factory, which is likely to help reduce the consumption of building materials and resources on the building site.

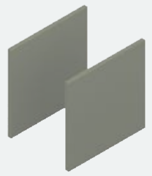
The one-storey building is built on screw-pile foundations and encircled by grade-covering timber decking. The grade deck is a prefabricated modular timber construction with blown-in wood-fibre insulation.

The house is constructed with supporting structures in timber with wood-fibre insulation. A special focal point is the building's indoor climate, and a vapour retarder of OSB sheeting was installed instead of a moisture barrier. Further, the combination of ventilator windows and an air-source heat pump is tested to obtain an optimally ventilated indoor climate with less particle pollution.

Sedum roof (green roof) and facades with slate and brick-tile facing. Interior surfaces are clad with reinforced gypsum boards.

In accordance with the BR18 (2023) area adaptation, 25% of the grade-covering decking and outdoor access stairs is included.

The one-bedroom house is 71.4 m². With four occupants, this gives approx. 36 m²/person, which is average for the case collection.


Sheeting


1 storey

ENF04: Klimakassen

6,64 kg CO_2eq./m²/year

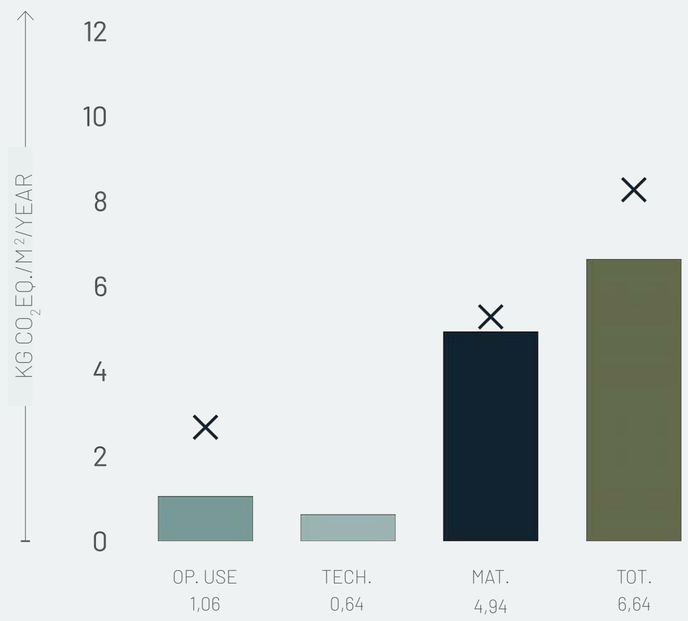


Figure ENF04.1: Emissions of kg CO_2eq./m²/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO_2eq./m²/year in single-family housing in the case collection.

19.908 kg CO_2eq.

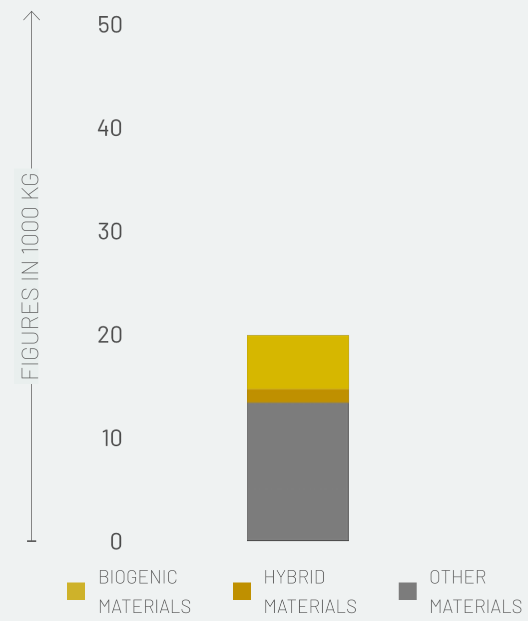


Figure ENF04.2: Total emission of kg CO_2eq.
The stacked bar chart shows the overall emission of kg CO_2eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

237 kg CO_2eq./person/year

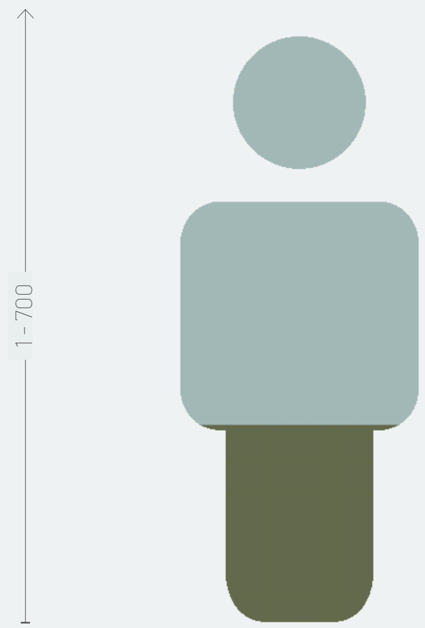


Figure ENF04.3: Emissions of kg CO_2eq./person/year
The span of the vertical axis is 1 to 700 kg CO_2eq./person /year

36 m²/person

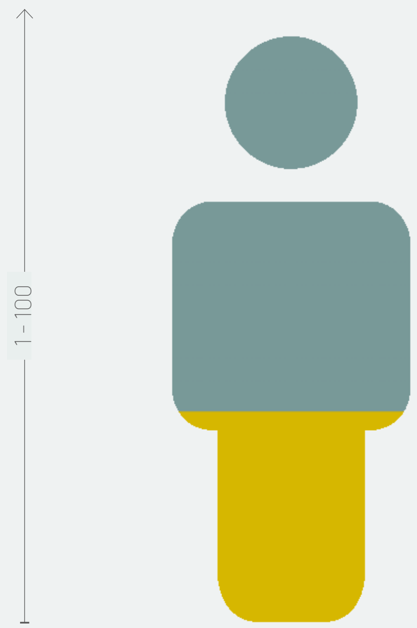


Figure ENF04.4: m²/person
The span of the vertical axis is 1 to 100 m²/person

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m²/year.

Figure ENF04.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m²/year. The horizontal axis shows the 24 best practice cases.

ENF04: Klimakassen

ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in CO_2eq./m²/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is well within the fastest reduction rate: the 83% likelihood scenario.

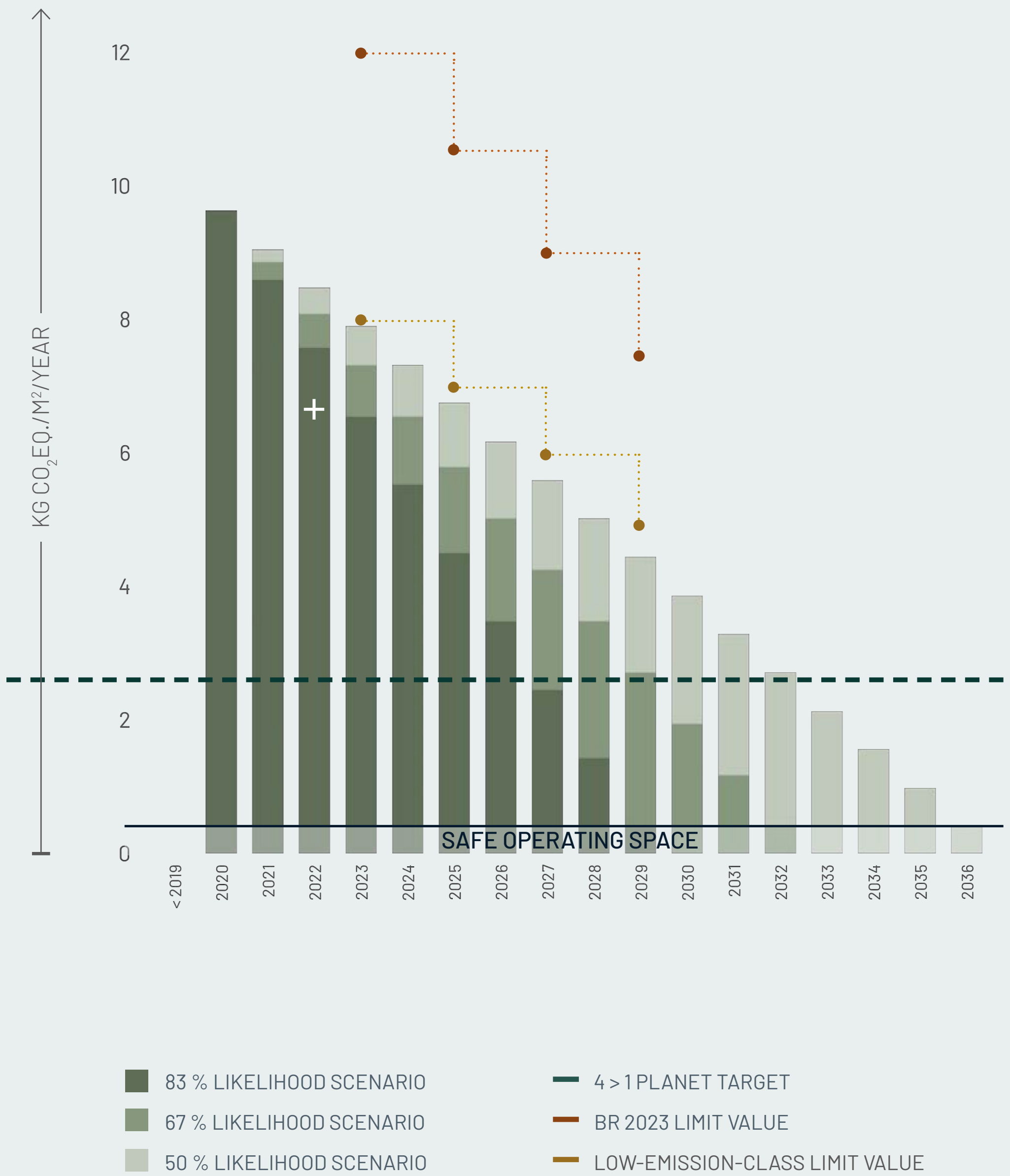
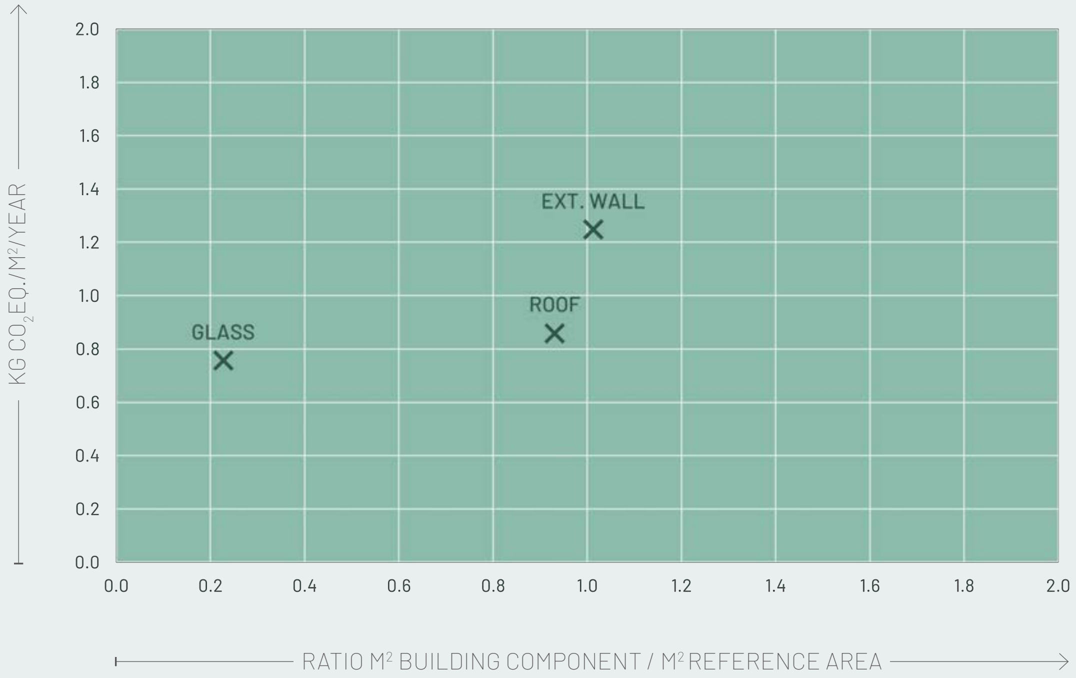


Figure ENF04.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq./m²/year, and the 'safe operating space'.

RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS



ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

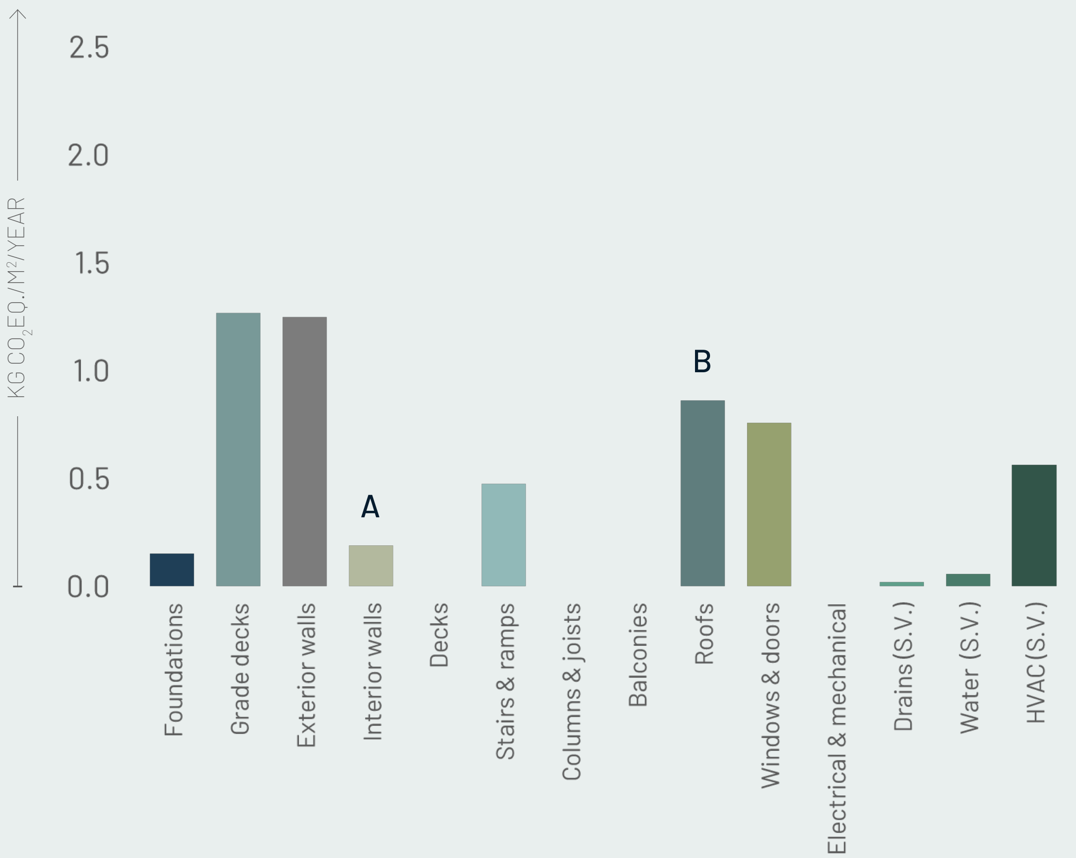


Figure ENF04.7: CO_2 accounting for building components
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades, electrical and mechanical systems, and technical installations (standard values).

ENF04: Klimakassen

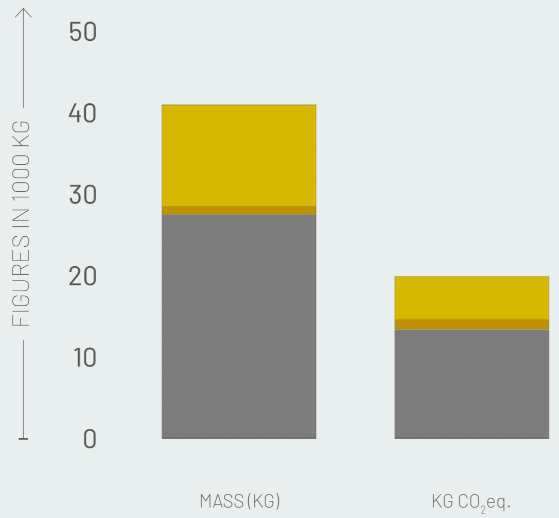
SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

Figure ENF04.8:
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

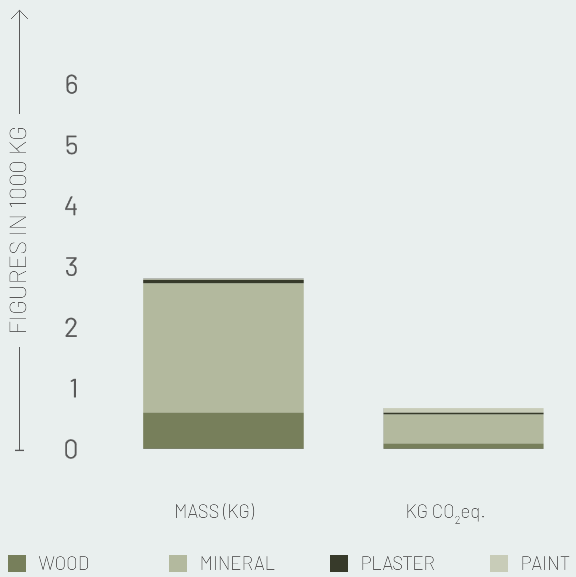
The bar on the left shows the building mass in kg grouped into material categories.

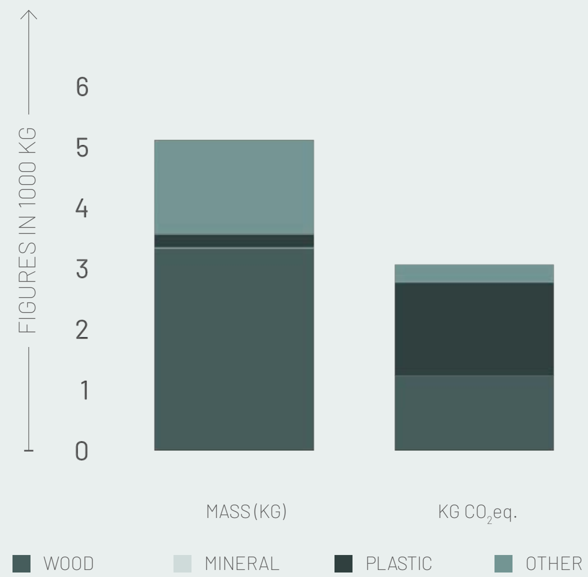
The bar on the right shows the building's total CO_2eq grouped similarly.



BIOGENIC MATERIALS | HYBRID MATERIALS | OTHER MATERIALS

MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG CO_2EQ.





A. INTERIOR WALL

Timber cassettes
Loose-fill wood-fibre insulation
Fibre gypsum boards
Filler and paint

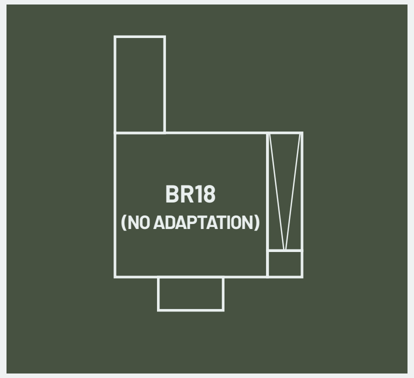
B. ROOF

Sedum roof
Bituminous felt
Plywood
Timber battens
Moisture barrier
Loose-fill wood-fibre insulation
OSB sheeting
Timber I-beams
Lathing
Cement-bonded wood wool panels

ENF05: Snoezelhuset

Developer: Helsingør municipality
Architect: CoreHome
Engineer: KART Rådgivende Ingeniører
Contractor: Canbyg

Year (built): 2022
Floor area: 195 m²
Reference area: 195 m²
Use: Institution (calc. as home)
Occupants: 4
Year (calculated): 2022
Heating: Heat pump
Solar cells: No



DESCRIPTION

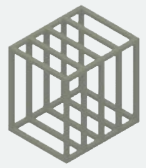
Snoezelhuset is a house appealing to the senses, built in bio-based renewable products by Helsingør Municipality. The house is designed as a single-family home but is used in a public context by one or two users plus their carers a couple of hours every day. In view of the use made of the building, extra fire-safety measures are in place.

The one-storey building is built on screw-pile foundations. The grade deck is constructed in timber cassettes with wood-fibre insulation and covered with cement particle board facing a vented cavity space. On the upper side, an airtight vapour-retarding sheet and 40 mm wood-fibre sheeting with integral underfloor-heating pipes.

The house is constructed with timber supporting structures with wood-fibre insulation and a wind barrier. A combination of natural vapour retarder and fibre gypsum boards on the inside ensures a vapour-permeable structure. Further, the combination of ventilator windows and an air-source heat pump is tested to obtain an optimally ventilated indoor climate with less particle pollution. Special emphasis has been on avoiding cement-based products and products manufactured using oil and natural gas, instead installing wood-based wet-room sheets, for example.

The roof is a lattice-truss structure with steel-sheet roofing, and the facades are covered with untreated common spruce. Interior surfaces are smoothed over with a natural lime filler and painted.

The three-bedroom house is 195 m². With four occupants, this gives approx. 49 m²/person, which is on the high side in the case collection.



Timber frame

1 storey

ENF05: Snoezelhuset

5,47 kg CO_2eq./m²/year

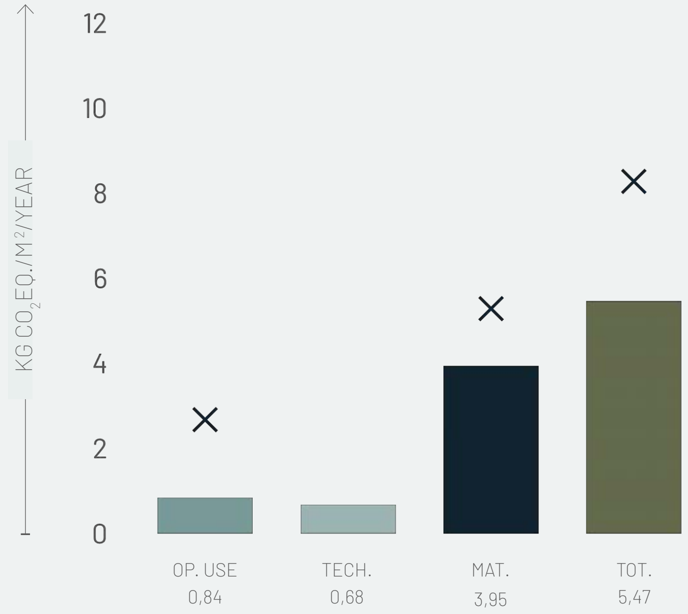


Figure ENF05.1: Emissions of kg CO_2eq./m²/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO_2eq./m²/year in single-family housing in the case collection.

45.107 kg CO_2eq.

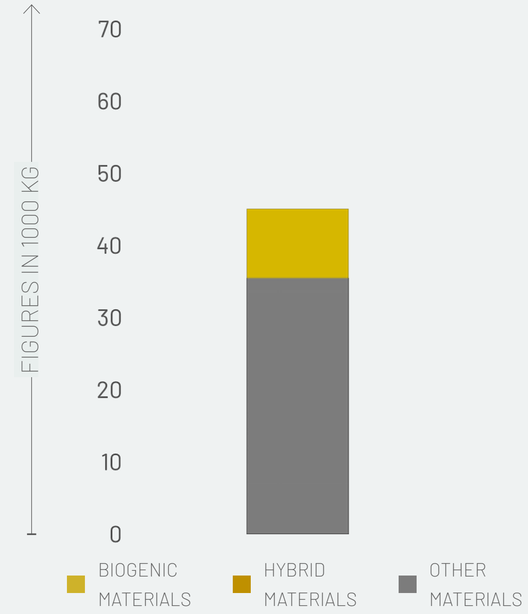


Figure ENF05.2: Total emission of kg CO_2eq.
The stacked bar chart shows the overall emission of kg CO_2-eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

329 kg CO_2eq./person/year

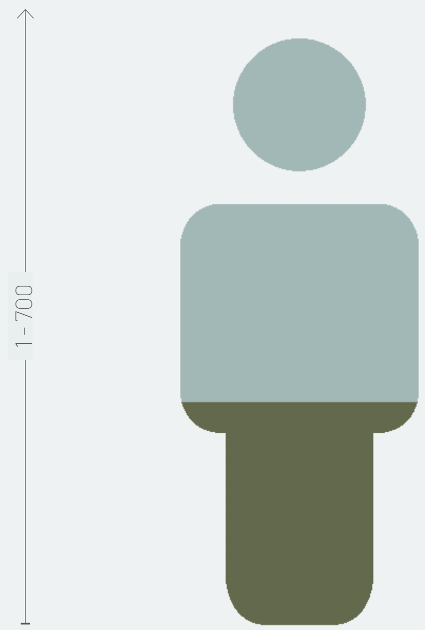


Figure ENF05.3: Emissions of kg COeq./person/year
The span of the vertical axis is 1 to 700 kg CO_2eq./person/year

49 m²/person

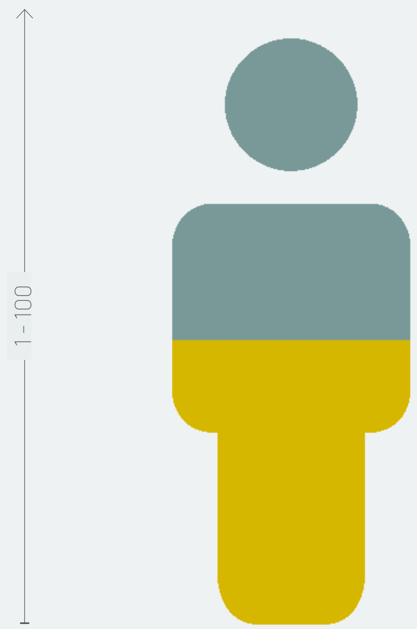


Figure ENF05.4: m²/person
The span of the vertical axis is 1 to 100 m²/person

ENF05: Snoezelhuset

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m²/year.

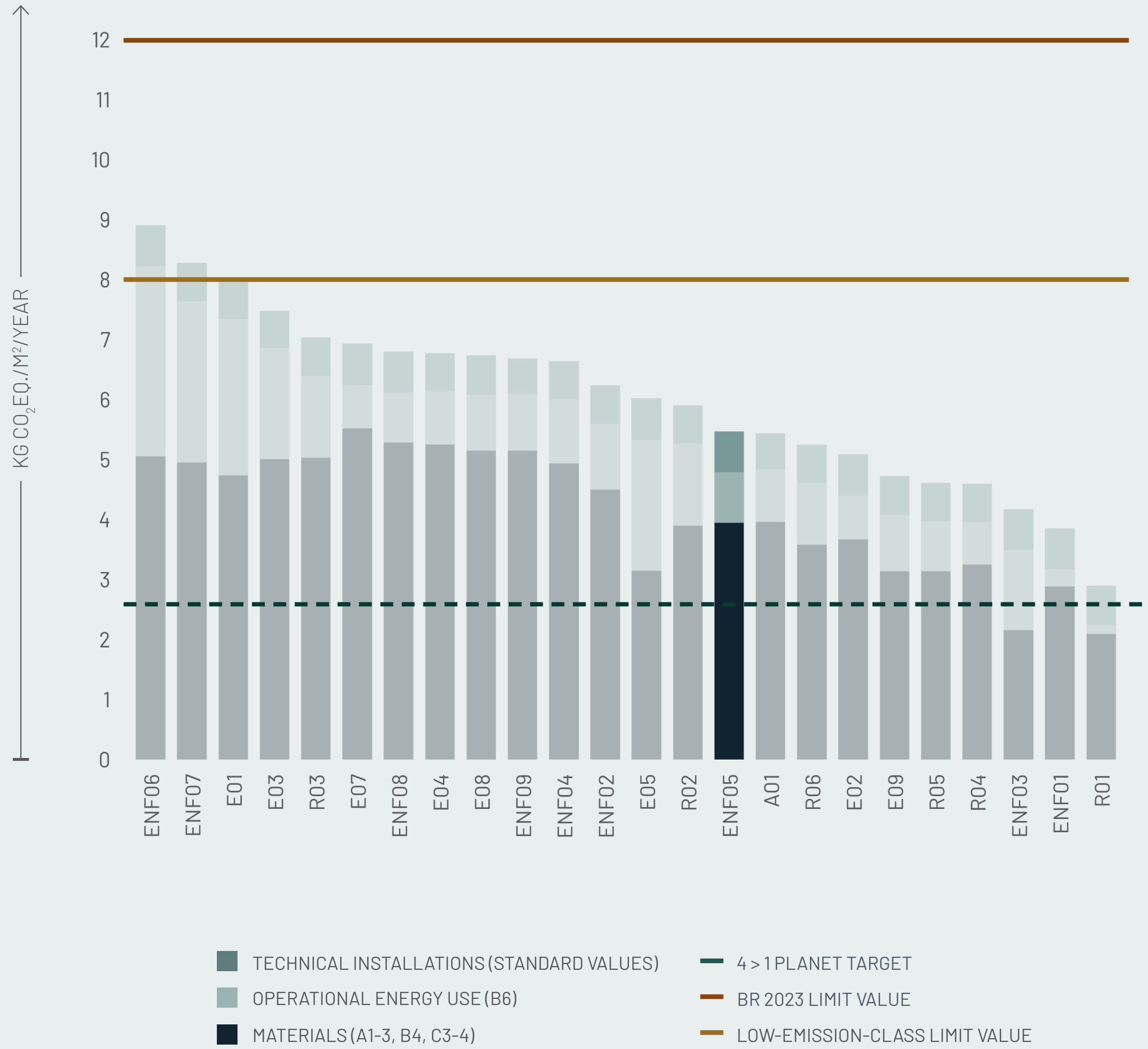


Figure ENF05.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m²/year. The horizontal axis shows the 24 best practice cases.

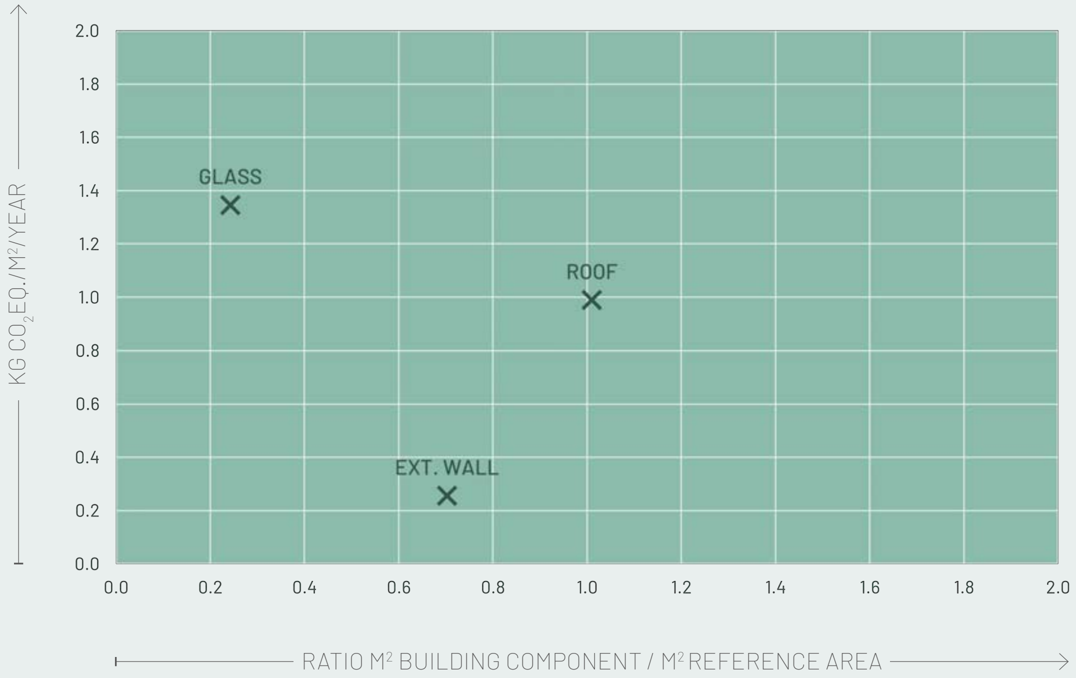
ENF05: Snoezelhuset

ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in CO_2eq./m²/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is well within the fastest reduction rate: the 83% probability scenario.

Figure ENF05.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq./m²/year, and the 'safe operating space'.

RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS



ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

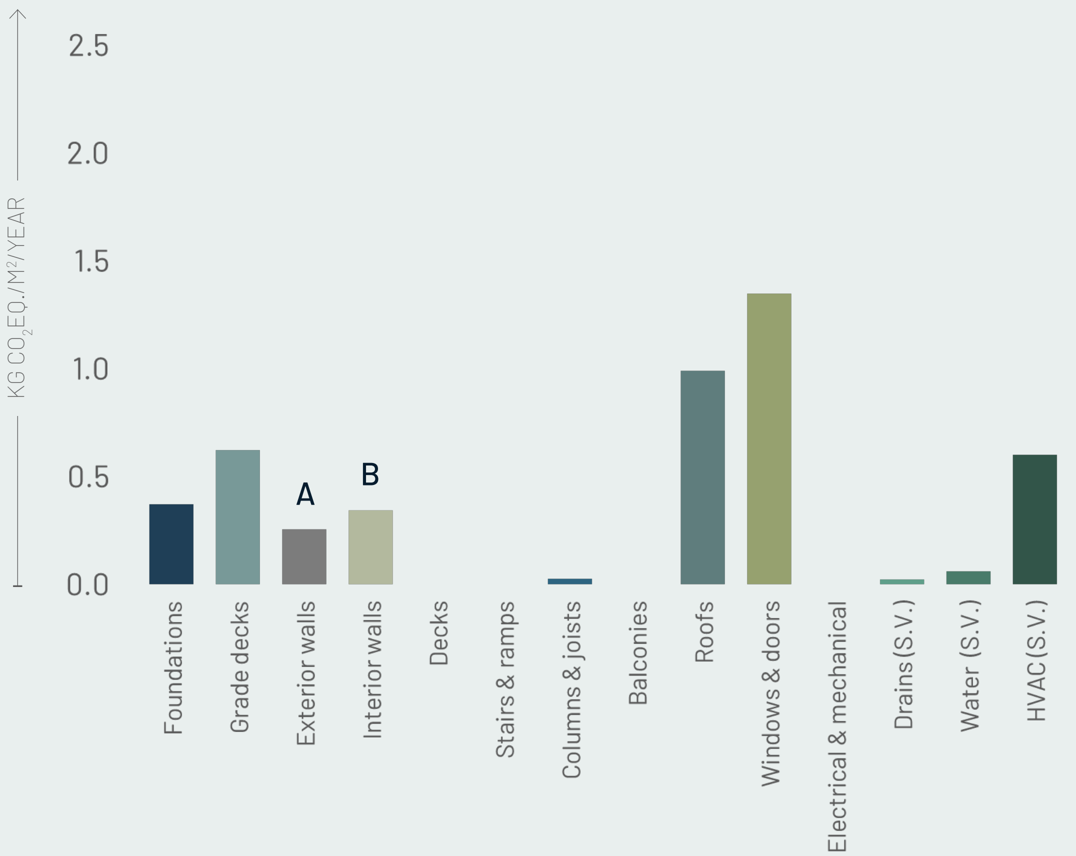


Figure ENF05.7: CO_2 accounting for building components
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades, electrical and mechanical systems, and technical installations (standard values).

ENF05: Snoezelhuset

SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

Figure ENF05.8:
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

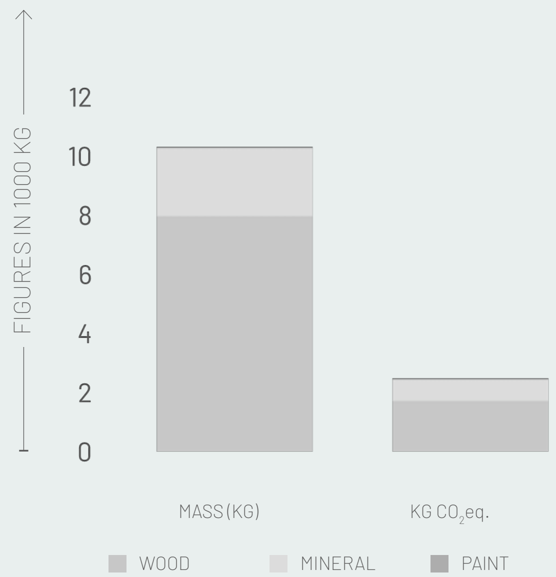
The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 70.000 kg.

The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total CO_2eq grouped similarly.

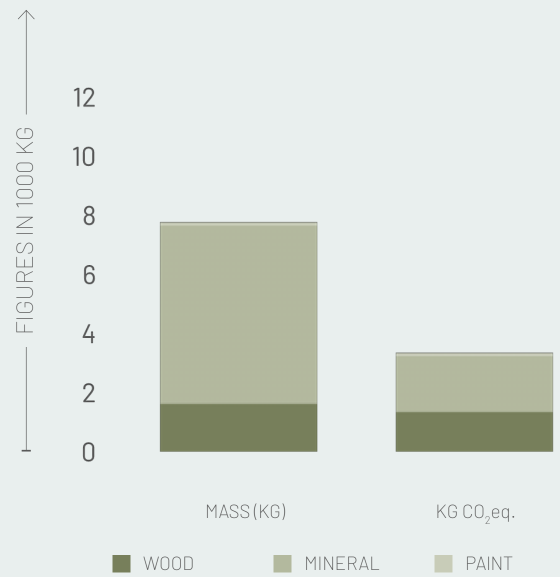
BIOGENIC MATERIALS | HYBRID MATERIALS | OTHER MATERIALS

MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG CO_2EQ.



A. EXTERIOR WALL

Board cladding, common spruce
Transverse lathing
Spacer bars
Timber frame
Loose-fill wood-fibre insulation
OSB sheeting
Fibre gypsum boards
Filler and paint



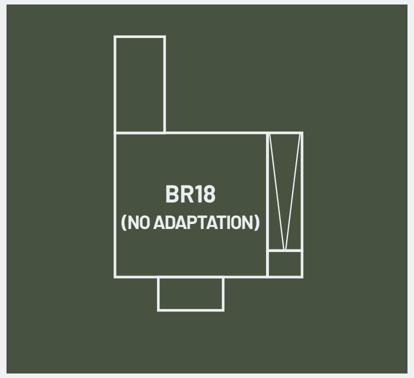
B. INTERIOR WALL

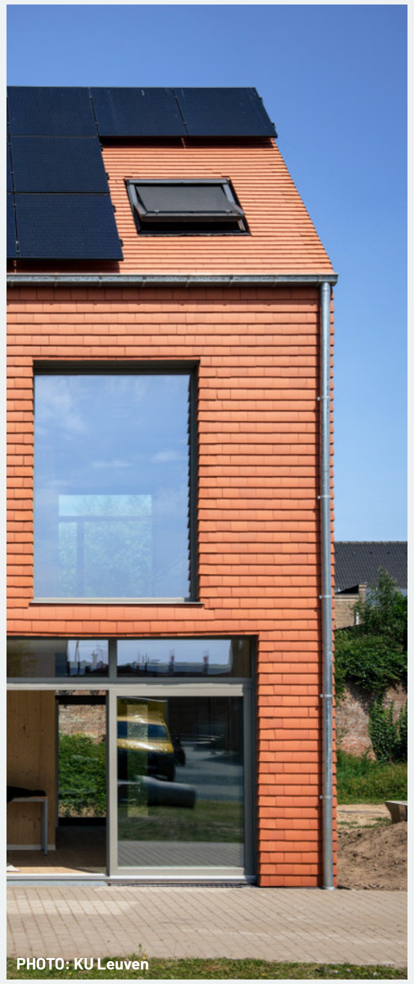
Timber frame
Wood-fibre insulation batts
Fibre gypsum boards
Filler and paint

ENF06: CBCI Living Lab

Developer: KU Leuven
Architect: Paul Lodewijckx
Engineer: Buildup, Studio WLLMS
Contractor: Vanhout

Year (built): 2022
Floor area: 84 m²
Reference area: 84 m²
Use: Residential
Occupants: 2
Year (calculated): 2022
Heating: Heat pump
Solar cells: Yes





DESCRIPTION

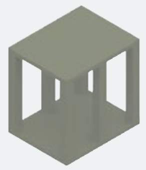
CBCI Living Lab Ghent is an international demo project with special emphasis on a design facilitating dismantling and use of bio-based materials.

The three-storey building is built on screw-pile foundations. The grade deck is constructed as a steel structure with recycled wood particle board insulated with wood-fibre sheeting and granulate cellulose.

The house is constructed with supporting structures in timber and steel with wood-fibre and cellulose insulation. Special emphasis has been on a design that facilitates dismantling at a building and structural level to enable maintenance and replacement of materials separately at their end-of-life stage.

Roof and facades are covered with brick tiles and the two closed gable ends have cork and timber cladding. The service core and interior staircase are constructed in CLT. The interior walls are timber-framed, clad with a layer of gypsum boards, and painted.

The one-bedroom house is 84 m². With two occupants, this gives approx. 42 m²/person, which is on the high side in the case collection.



Hybrid

3 storeys

ENF06: CBCI Living Lab

8,91 kg CO_2eq./m²/year

Figure ENF06.1: Emissions of kg CO_2eq./m²/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO_2eq/m² /year in single-family housing in the case collection. This case study has the highest CO_2eq/m²/year emissions from operational energy use, but since it is an international study, it is not used as reference (X).

24.107 kg CO_2eq.

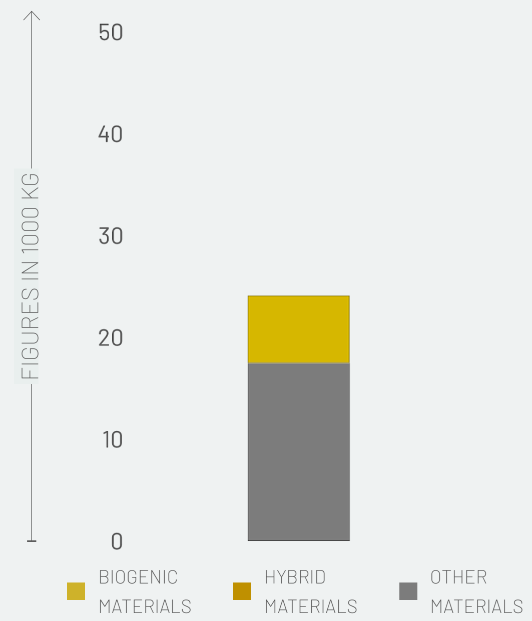


Figure ENF06.2: Total emission of kg CO_2eq.
The stacked bar chart shows the overall emission of kg CO_2eq. in the case study grouped into the three material categories: other, hybrids, and biogenic.

362 kg CO_2eq./person/year

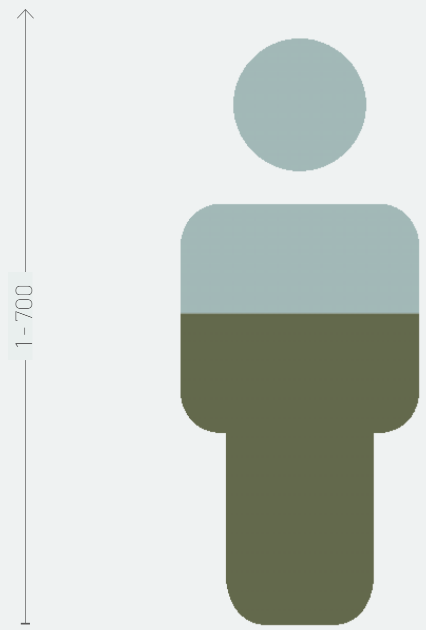


Figure ENF06.3: Emissions of kg CO_2eq./person/year
The span of the vertical axis is 1 to 700 kg CO_2eq./person/year

42 m²/person

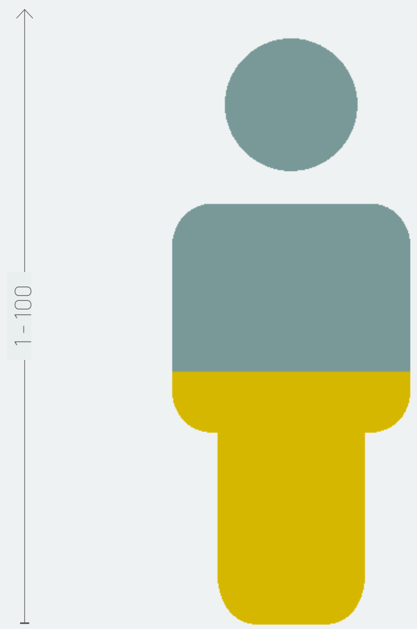


Figure ENF06.4: m²/person
The span of the vertical axis is 1 to 100 m²/person

ENF06: CBCI Living Lab

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m²/year.

Figure ENF06.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m²/year. The horizontal axis shows the 24 best practice cases.

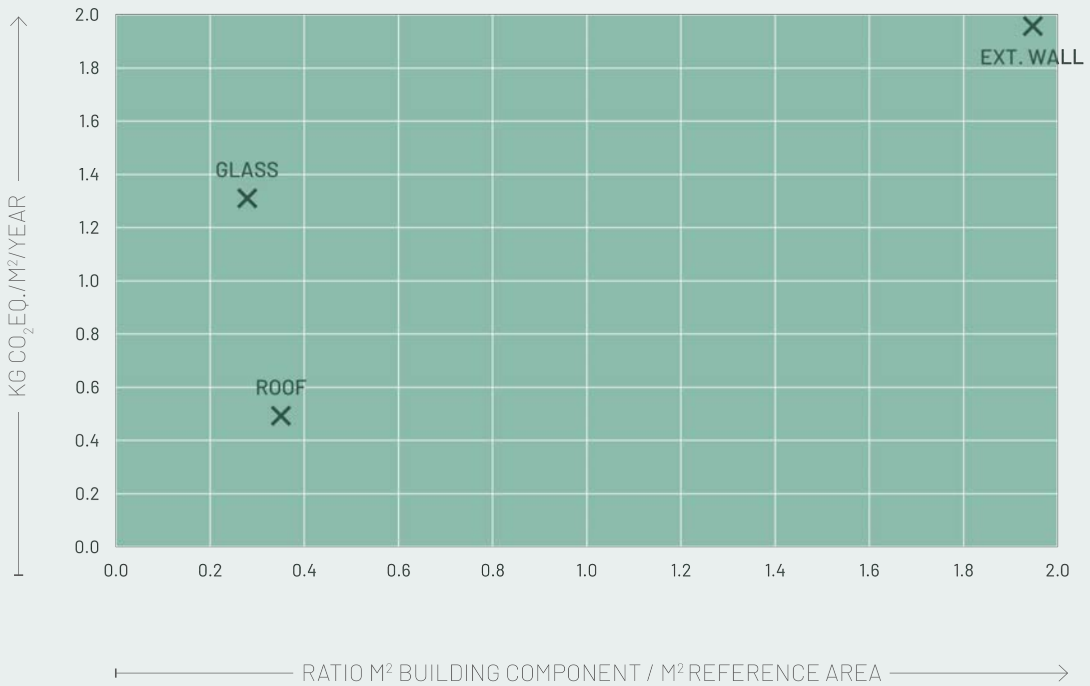
ENF06: CBCI Living Lab

ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in CO_2eq./m²/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is slightly higher than all three likelihood scenarios.

Figure ENF06.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq./m²/year, and the 'safe operating space'.

RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS



ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

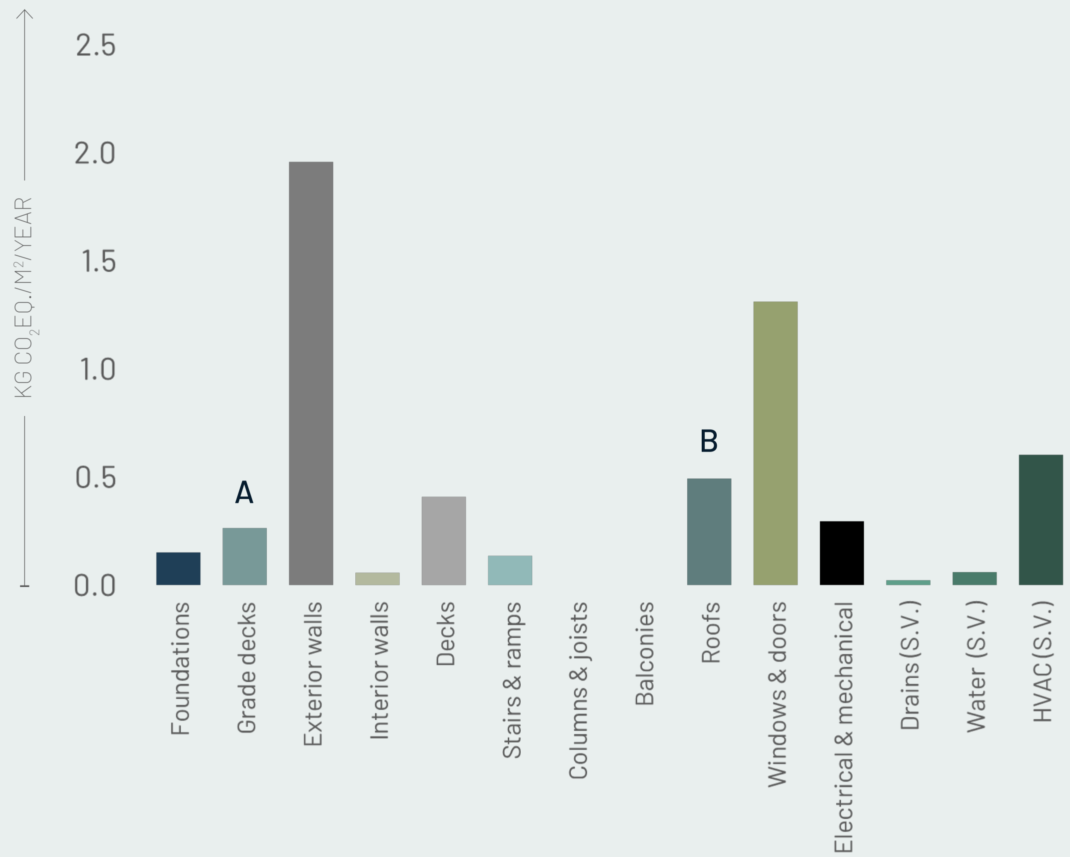


Figure ENF06.7: CO_2 accounting for building components
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades, electrical and mechanical systems, and technical installations (standard values).

ENF06: CBCI Living Lab

SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

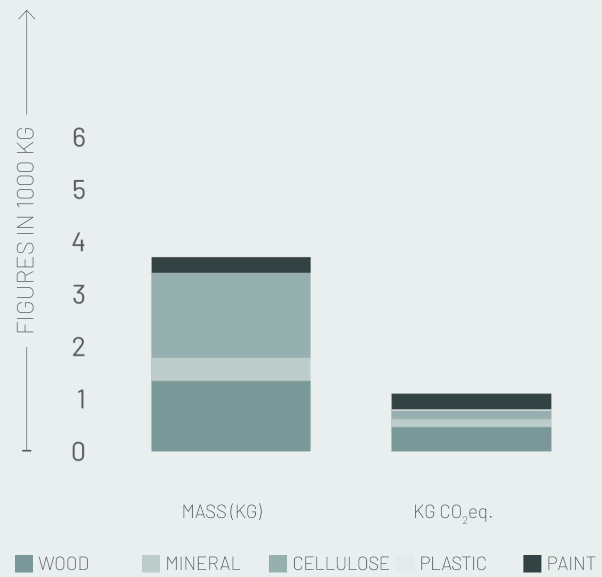
Figure ENF06.8:
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

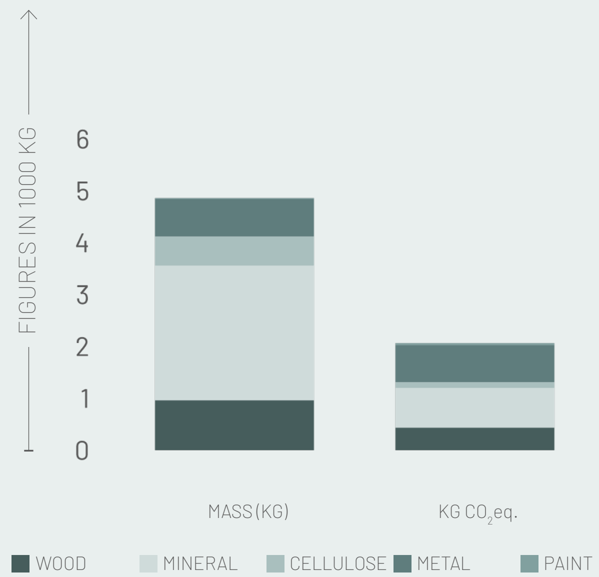
The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total CO_2eq grouped similarly.

MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG CO_2EQ.





A. GRADE DECK

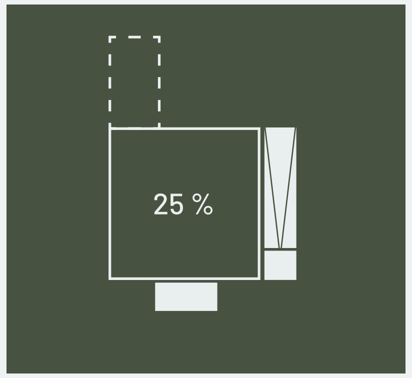
Parquet flooring, wood
Wood-fibre sheet insulation
Wooden strips
Steel frame
Cellulose insulation
Vapour barrier
Particle board (recycled)
Fibre gypsum boards

B. ROOF

Brick tiles
Wood-fibre sheet insulation
Wooden strips
Steel frame
Cellulose insulation
Particle board (recycled)
Fibre gypsum boards
Paint

ENF07: Upcycle House

Developer:	Realdania By & Byg
Architect:	Lendager Group
Engineer:	Artelia
Contractor:	Egen Vinding og Datter
Year (built):	2013
Floor area:	134 m²
Reference area:	143 m²
Use:	Residential
Occupants:	5
Year (calculated):	2022
Heating:	District heating
Solar cells:	No



DESCRIPTION

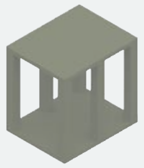
Upcycle House is one of five single-family dwellings collectively known as the MiniCO$_2$ Houses. In this single-family housing project backed by Realdania By & Byg, the common denominator is affordable housing and where emphasis has been on reducing CO$_2$ emissions in various ways. Upcycle House is a project with special focus on the construction phase, i.e. attention has primarily been on reuse and upcycling of materials. In very many ways, the design of Upcycle House is governed by the reuse and upcycling opportunities available, including two 40-foot high-cube containers and wrongly produced windows from other construction projects. During the process, the choice of materials was governed by their CO$_2$- reducing potential, the quality of the reused/upcycled material, and economic aspects.

The one-storey building is built on screw-pile foundations with a light-weight grade deck of sleepers and battens, insulated with recycled polystyrene.

The house is built with supporting structures in timber and steel. The roof and exterior and interior walls are timber-framed structures and reusables from steel containers insulated with cellulose.

The surface cladding is sinus profiles and cardboard-fibre sheeting. The windows are new wrongly produced windows with triple glazing and wooden frames.

The four-bedroom house is 143 m². With five occupants, this gives approx. 29 m²/person, which is on the low side in the case collection.



Hybrid

1 storey

ENF07: Upcycle House

8,31 kg CO$_2$eq./m²/year

Figure ENF07.1: Emissions of kg CO$_2$eq./m²/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO$_2$eq./m²/year in single-family housing in the case collection.

39.951 kg CO$_2$eq.

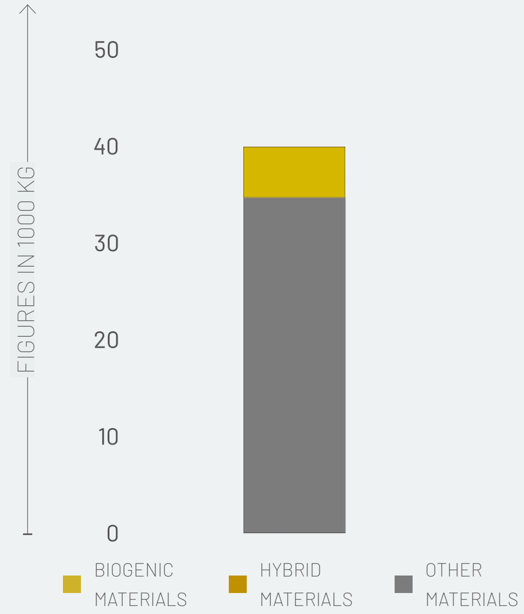


Figure ENF07.2: Total emission of kg CO$_2$eq.
The stacked bar chart shows the overall emission of kg CO$_2$eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

236 kg CO$_2$eq./person/year

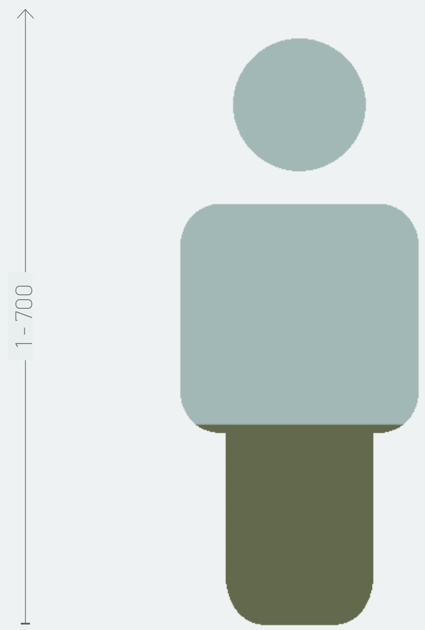


Figure ENF07.3: Emissions of kg CO$_2$eq./person/year
The span of the vertical axis is 1 to 700 kg CO$_2$eq./person/year

29 m²/person

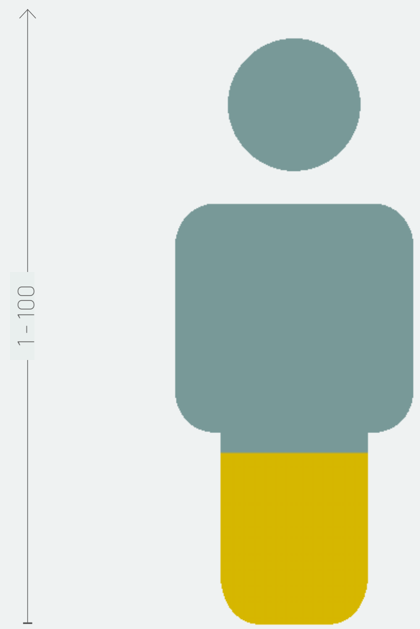


Figure ENF07.4: m²/person
The span of the vertical axis is 1 to 100 m²/person

ENF07: Upcycle House

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m²/year.

Figure ENF07.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m²/year. The horizontal axis shows the 24 best practice cases.

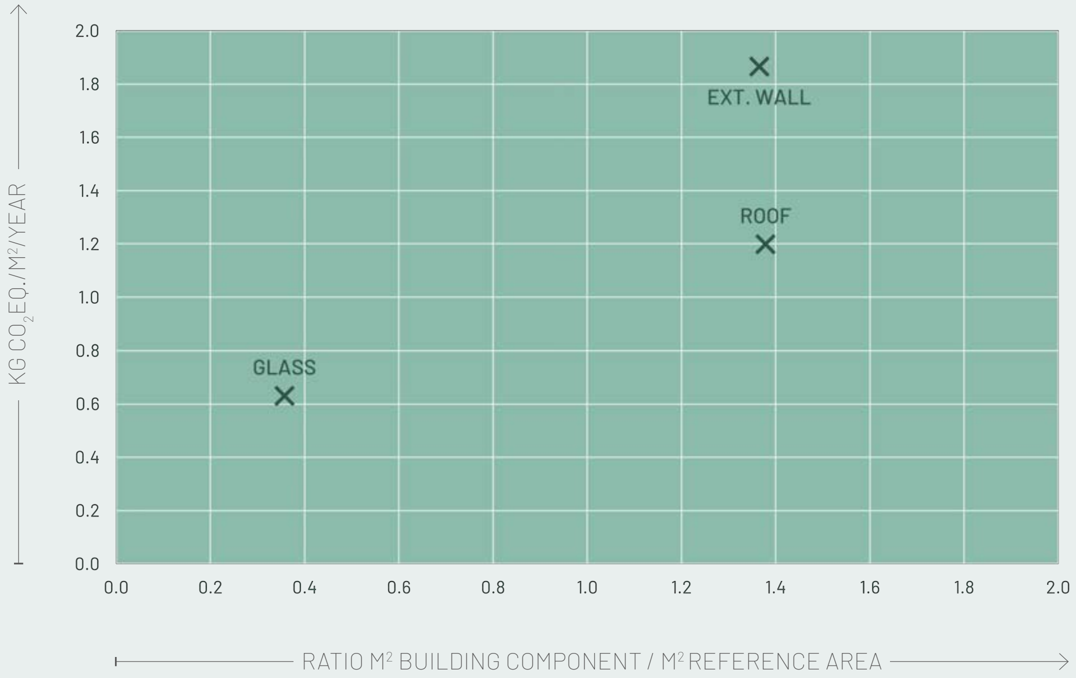
ENF07: Upcycle House

ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in CO_2eq./m²/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is within the slowest reduction rate: the 50% likelihood scenario.

Figure ENF07.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq./m²/year, and the 'safe operating space'.

RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS



ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

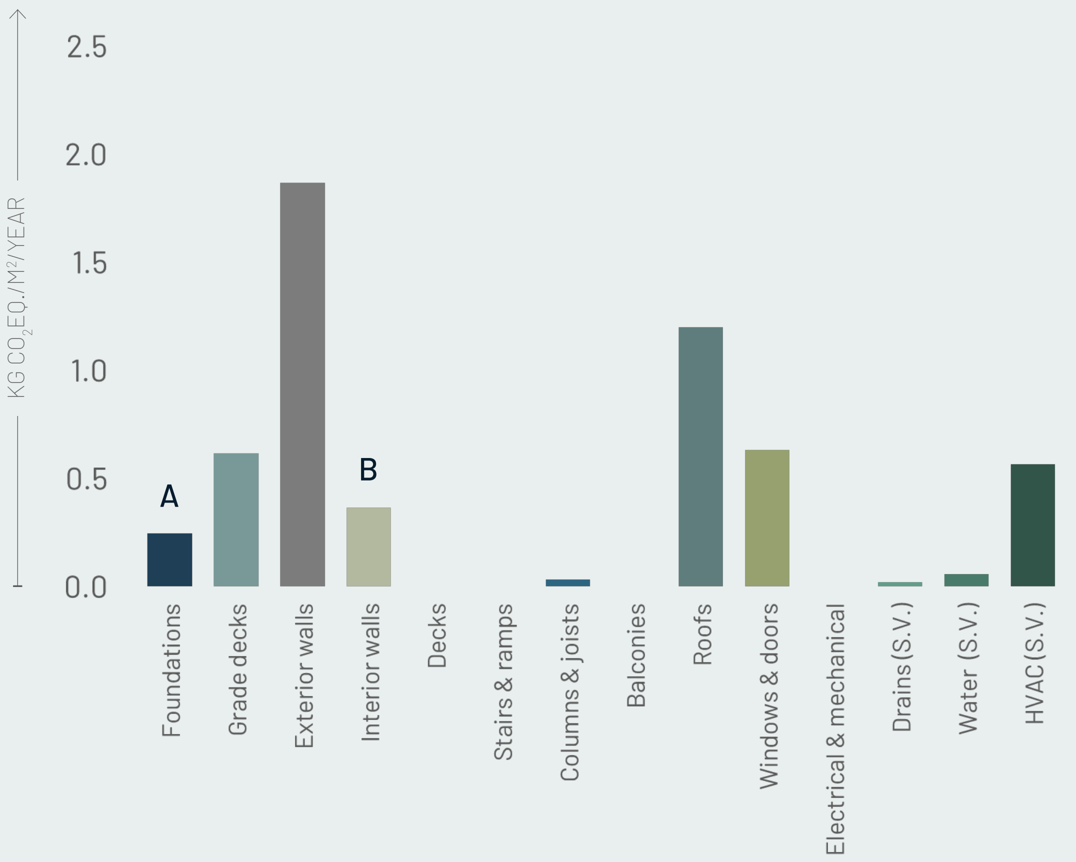


Figure ENF07.7: CO_2 accounting for building components
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades, electrical and mechanical systems, and technical installations (standard values).

ENF07: Upcycle House

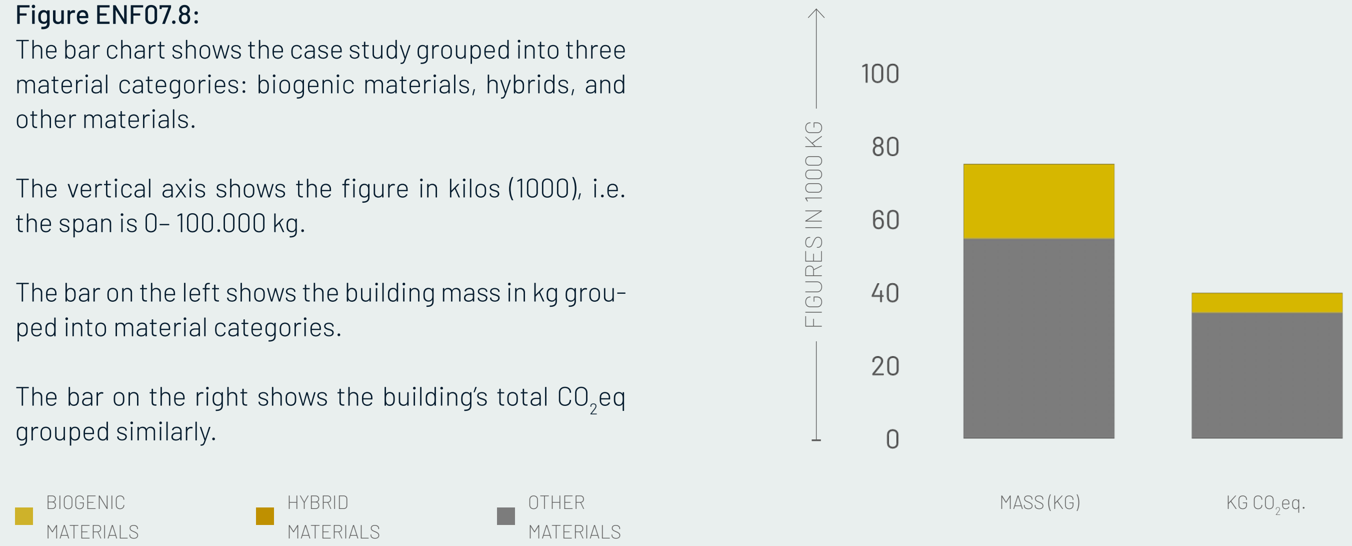
SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

Figure ENF07.8:
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

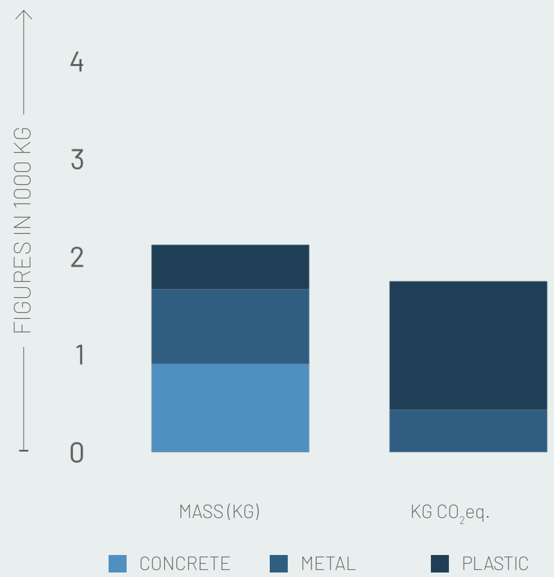
The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 100.000 kg.

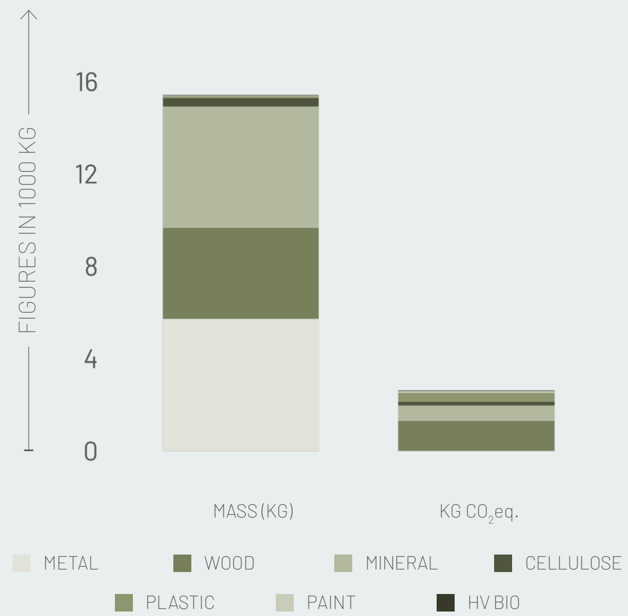
The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total CO_2eq grouped similarly.



MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG CO_2EQ.





A. FOUNDATION

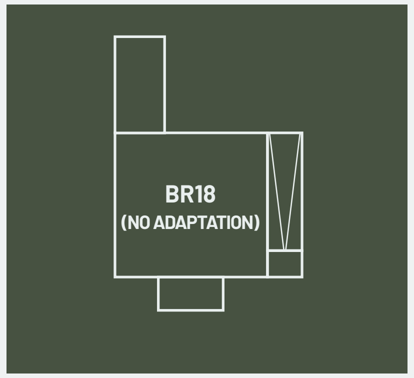
Point foundations, concrete (reuse)
Screw-pile footings, steel (part reuse)

B. INTERIOR WALL

Timber frame
Cellulose insulation
OSB sheeting
Plastic-bricks (recycled PET) with cotton

Developer: JDH-BYG
Architect: Walther Rådgivende Ingeniør
Engineer: JDH-BYG

Year (built): Not built
Floor area: 59 m²
Reference area: 59 m²
Use: Residential
Occupants: 2
Year (calculated): 2022
Heating: Heat pump
Solar cells: Yes



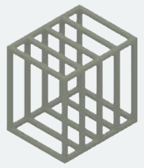
DESCRIPTION

Ecomodul360 is a pilot project with focus on using bio-based and hybrid materials and limiting space consumption. Focus is particularly on natural ventilation with a minimal use of operational energy. The early version of this house was projected with a pitch roof and photovoltaic modules. The finished house has a flat roof without photovoltaic roof modules.

The one-storey house is built on screw-pile foundations and a grade deck structure of I-beams with hard wood-fibre sheets and wood flanges, insulated with wood fibre. Exterior walls are straw-bale panels with timber cladding on the outside and clay plaster on the inside.

Due to its size, there are few interior walls in the house. Those that exist are of timber with wood fibre and clay plaster. The bathroom features painted wet-room wall panels. Wooden window frames and sills with triple-layer energy-efficient glazing. The roof is a timber and steel construction with suspended ceiling and cement-bonded wood wool panels. The roof covering is trapezoidal sheeting of hot-dip galvanised lacquered steel.

The one-bedroom house is 59 m². With two occupants, this gives approx. 29 m²/person, which is on the low side in the case collection.


Timber frame


1 storey

ENF08: Ecomodul360 PIXIE CASE

6,80 kg CO_2eq./m²/year

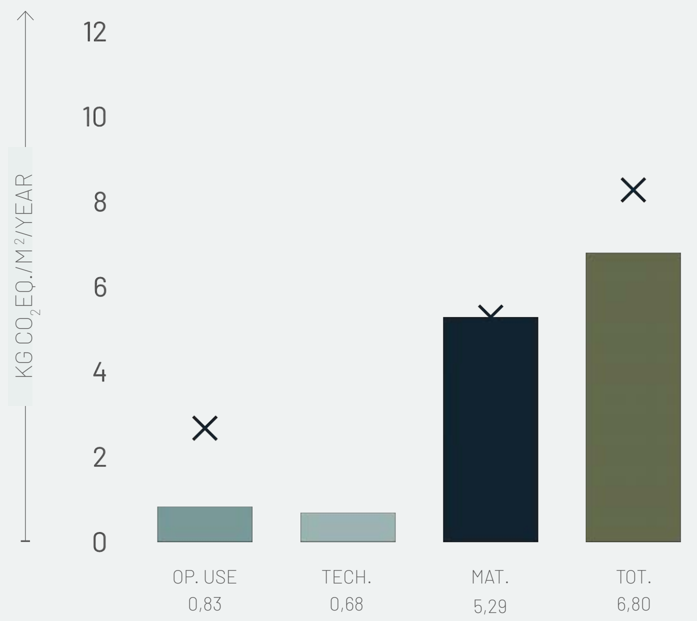


Figure ENF08.1: Emissions of kg CO_2eq./m²/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO_2eq./m²/year in single-family housing in the case collection.

17.545 kg CO_2eq.

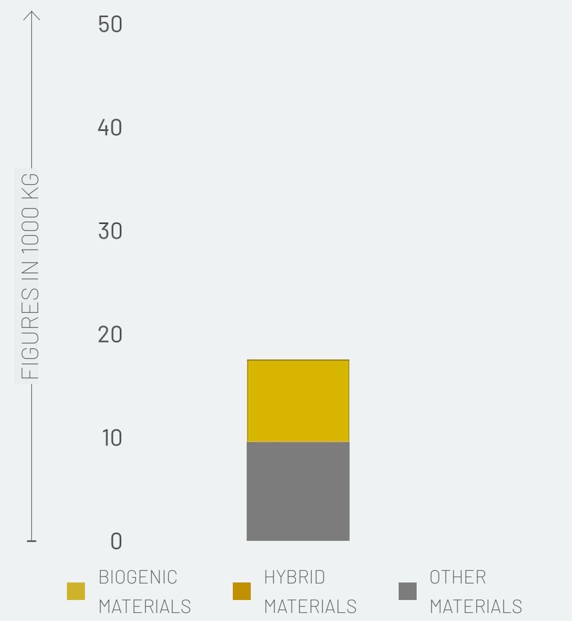


Figure ENF08.2: Total emission of kg CO_2eq.
The stacked bar chart shows the overall emission of kg CO_2eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

200 kg CO_2eq./person /year

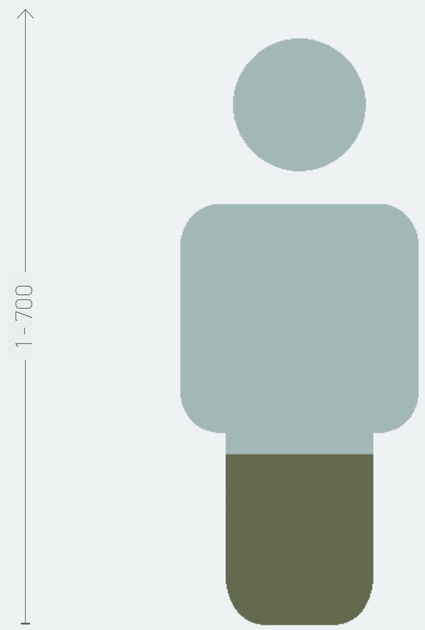


Figure ENF08.3: Emissions of kg CO_2eq./person/year
The span of the vertical axis is 1 to 700 kg CO_2eq./person/year

29 m² / person

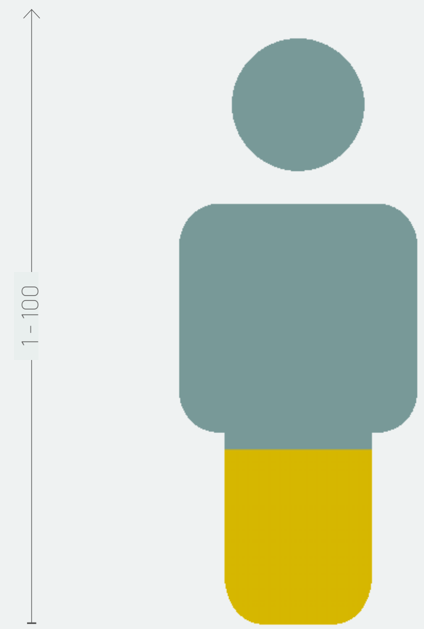


Figure ENF08.4: m²/person
The span of the vertical axis is 1 to 100 m²/person

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m²/year.

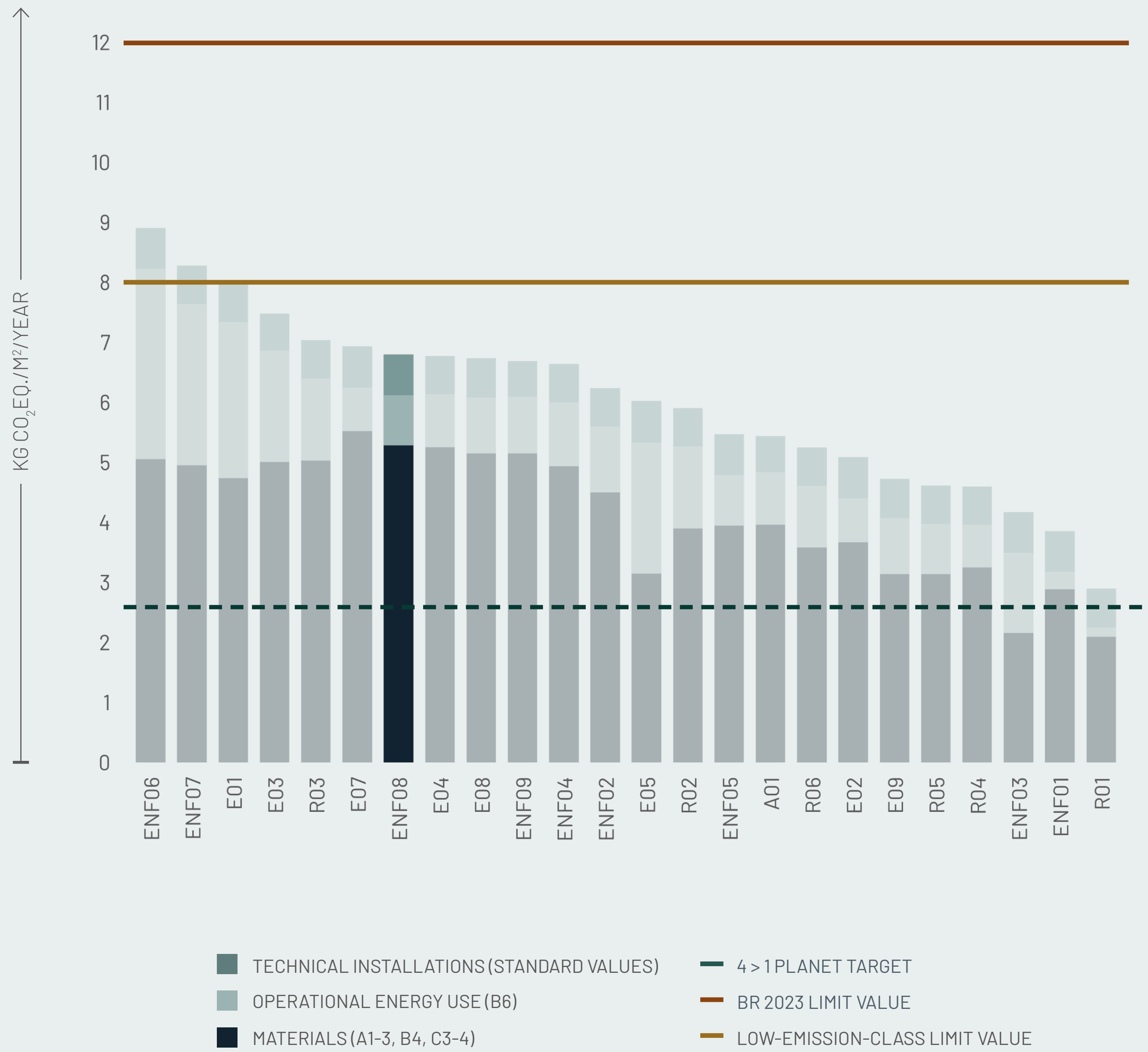


Figure ENF08.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m²/year. The horizontal axis shows the 24 best practice cases.

ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in CO_2eq./m²/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is well within the fastest reduction rate: the 83% likelihood scenario.

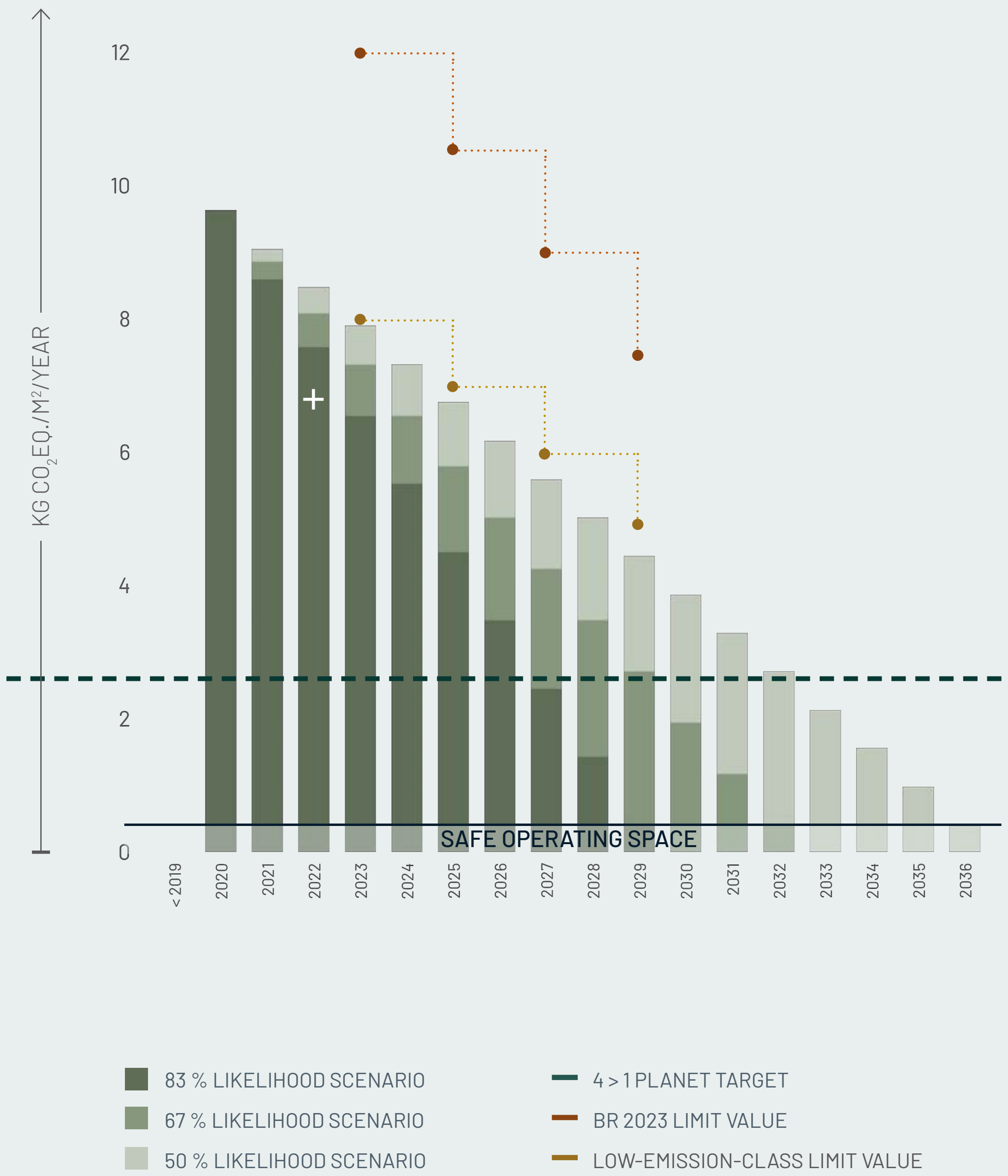
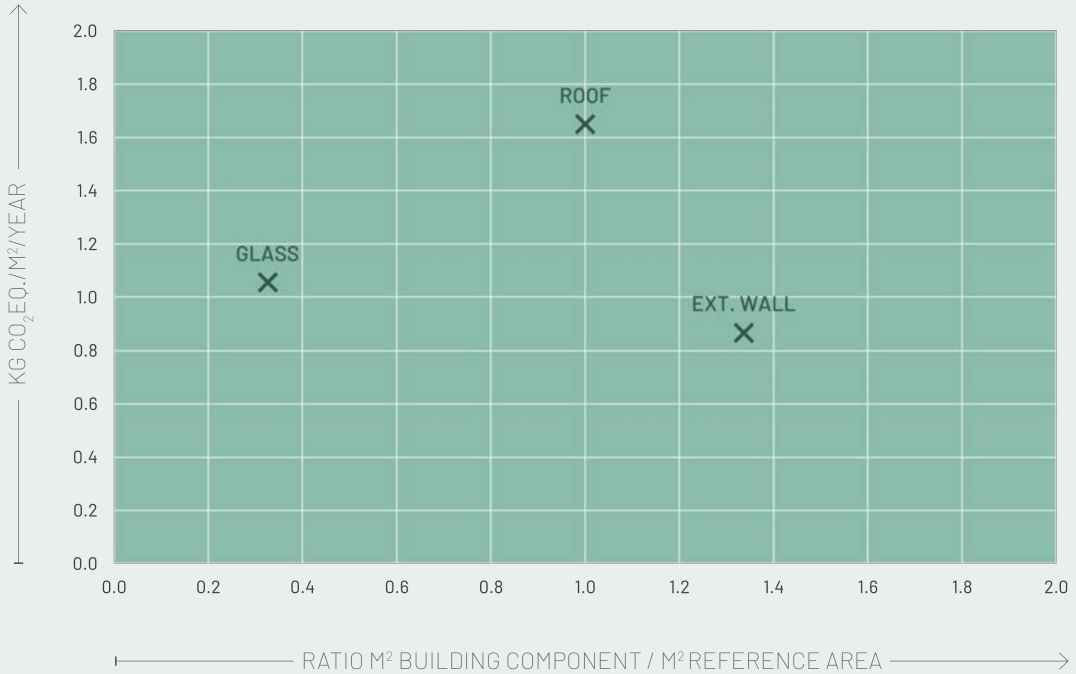


Figure ENF08.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq./m²/year, and the 'safe operating space'.

RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS



ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

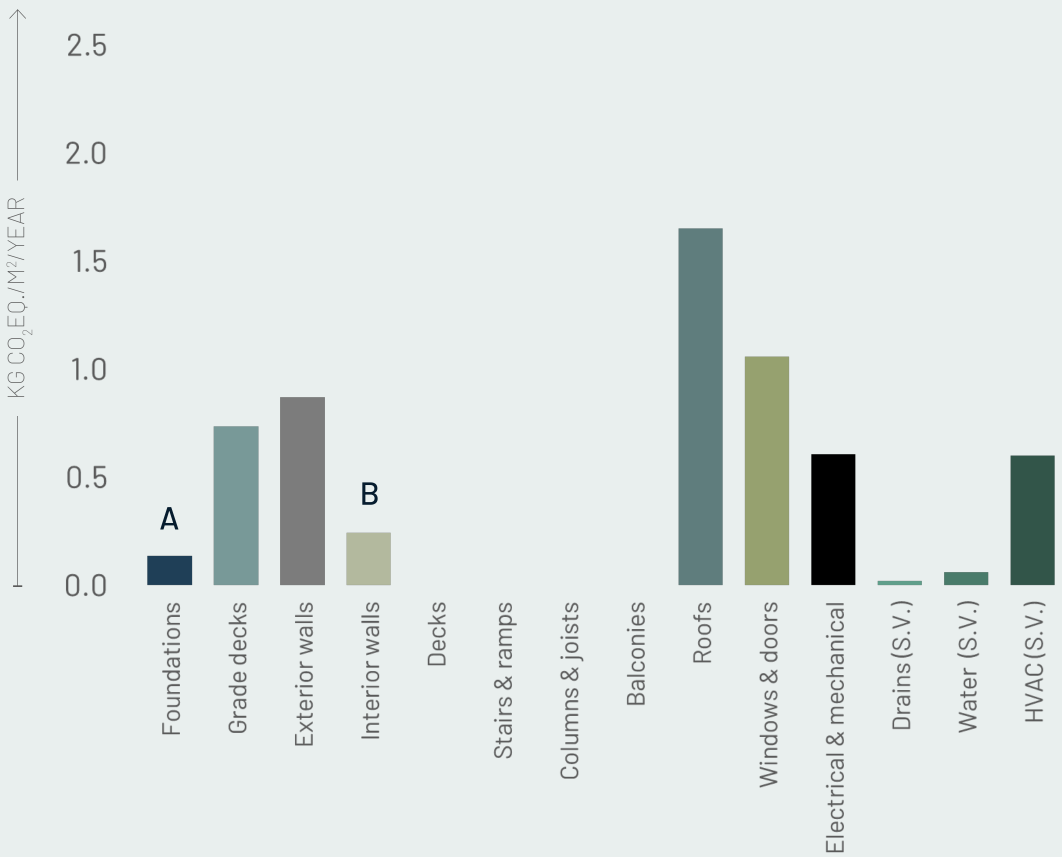


Figure ENF08.7: CO_2 accounting for building components
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades, electrical and mechanical systems, and technical installations (standard values).

ENF08: Ecomodul360 PIXIE CASE

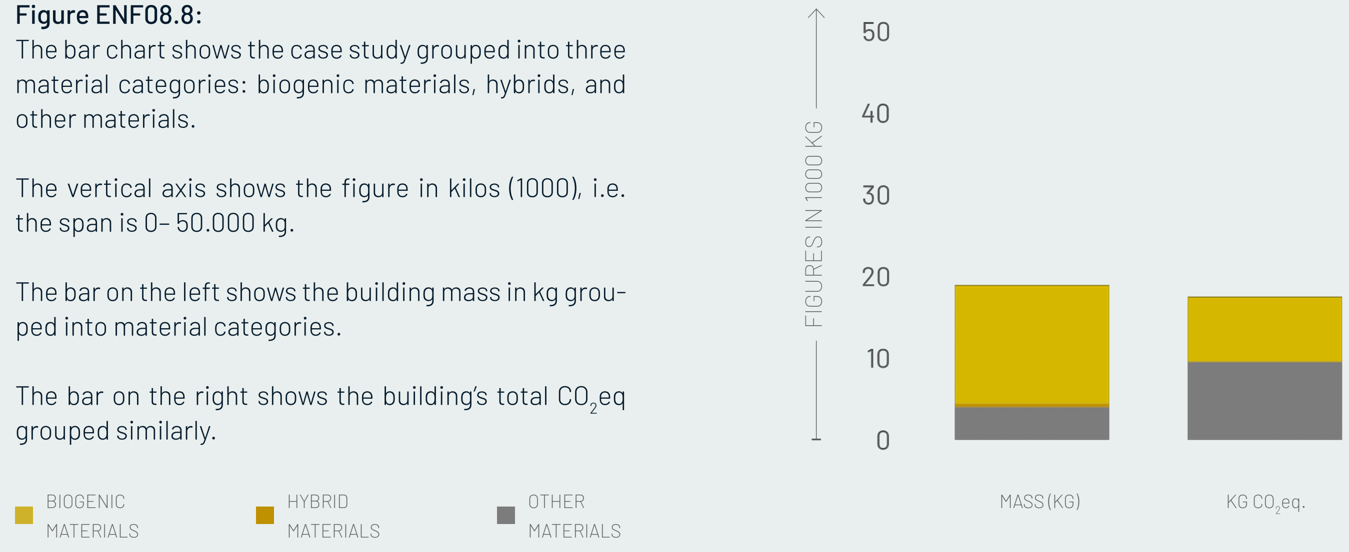
SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

Figure ENF08.8:
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

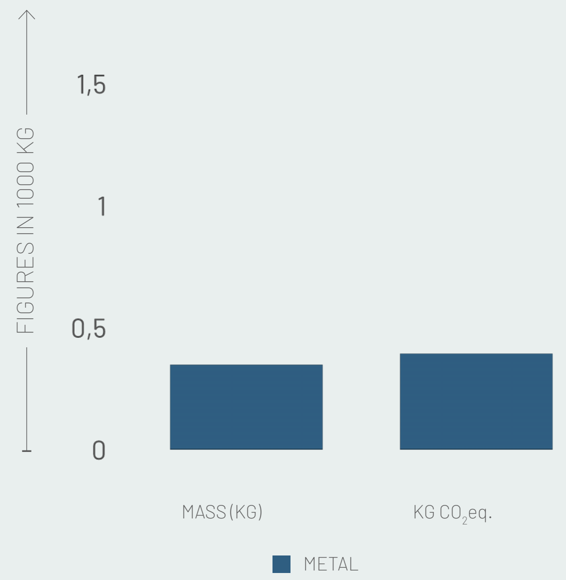
The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total CO_2eq grouped similarly.

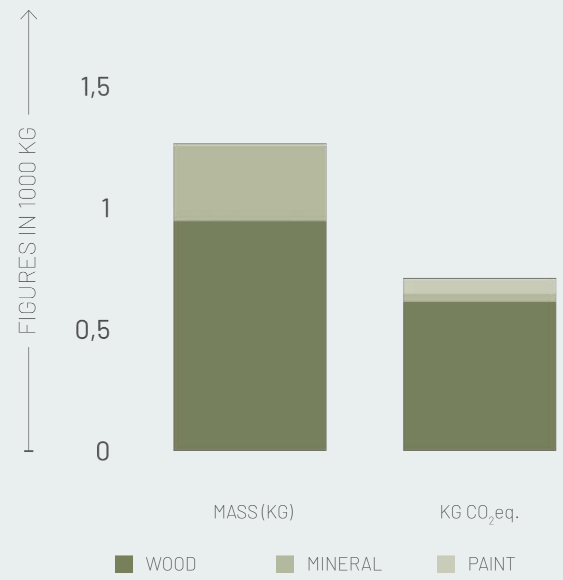


MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG CO_2EQ.



A. FOUNDATION

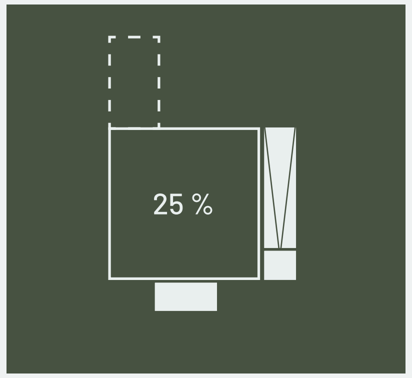
Screw-pile foundations, steel



B. INTERIOR WALL

Timber frame
Wood-fibre sheet insulation
OSB sheeting
Clay plaster
Paint

Developer: Privat
Architect: p a r k + m a r k



Year (built): 2023
Floor area: 122 m²
Reference area: 139 m²
Use: Summer house
Occupants: 4
Year (calculated): 2022
Heating: Heat pump
Solar cells: No

DESCRIPTION

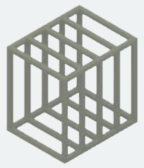
Pramvejen is a project designed and built for a private client, whose concept of a healthy house without materials of toxic or plastic content governed the construction principles and choice of material. The idea was to construct a sustainable house in bio-based materials that would meet the parameters of beautiful architecture with a sharp and simplistic definition along the lines of conventional construction.

This is a one-storey building with an overhead sleeping space built on continuous foundations of lightweight aggregate blocks. The grade deck is constructed in self-compacting concrete and insulated with EPS. The plot stands on a lakeshore, and due to the high groundwater level and generally wet conditions, it was impossible to construct a lightweight grade deck. Foundations are therefore reinforced concrete beams with a grade deck of self-compacting concrete.

The house is constructed with supporting structures in timber with wood-fibre insulation and wind barrier, making it breathable as bio-based materials were used in both the interior and exterior construction. Like the roof, the facade cladding is untreated Danish Douglas fir. Interior surfaces are clad with clay plaster and blockboard with veneer of Douglas fir.

The roof is supported by a single continuous glulam ridge beam from one gable end to the other with a roof overhang. The overhang protects the facade, doors, and windows from direct water impact and acts as a sun shield. Roof runoff is drained directly to a stream via the ground to reduce material consumption, in this case soil-run piping.

The three-bedroom house is 122 m². With four occupants, this gives approx. 31 m²/person, which is on the low side in the case collection.



Timber frame

1 storey

ENF09: Pramvejen PIXIE CASE

6,69 kg CO_2eq./m²/year

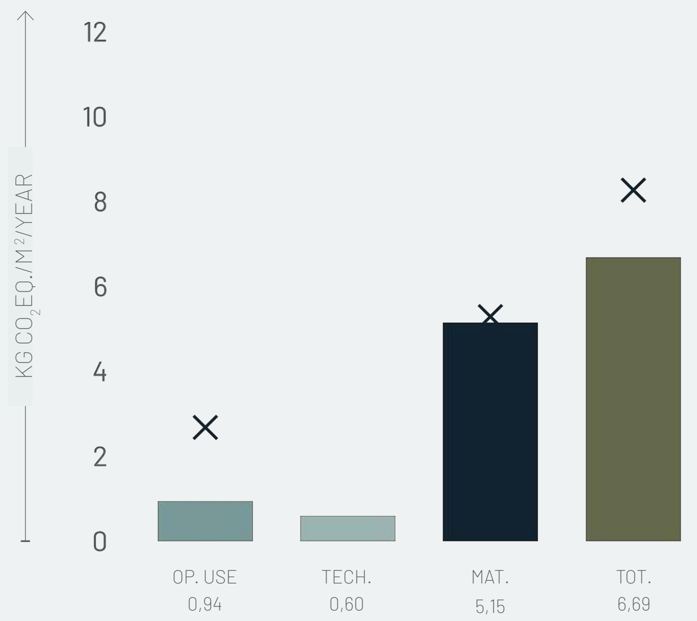


Figure ENF09.1: Emissions of kg CO_2eq./m²/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO_2eq./m²/year in single-family housing in the case collection.

40.005 kg CO_2eq.

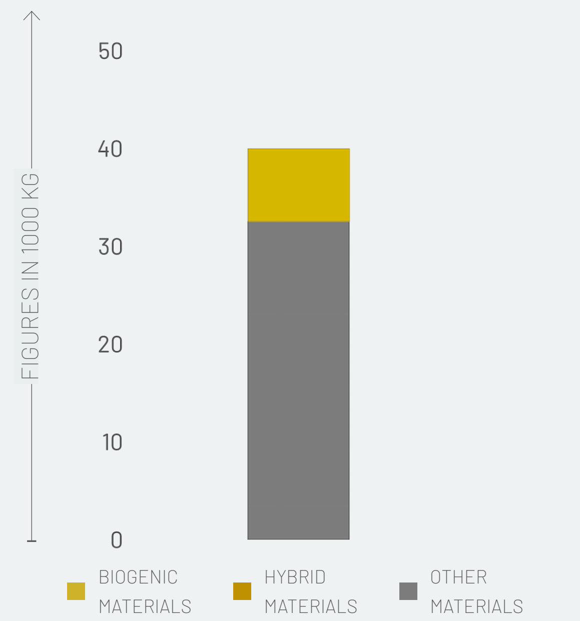


Figure ENF09.2: Total emission of kg CO_2eq.
The stacked bar chart shows the overall emission of kg CO_2eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

204 kg CO_2eq./person/year

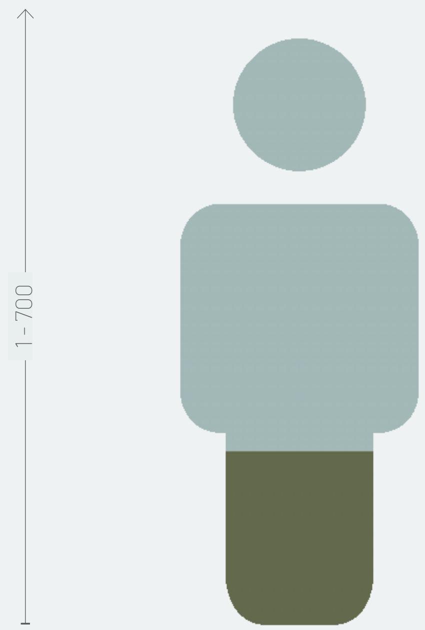


Figure ENF09.3: Emissions of kg CO_2eq./person/year
The span of the vertical axis is 1 to 700 kg CO_2eq./person/year

31 m²/person

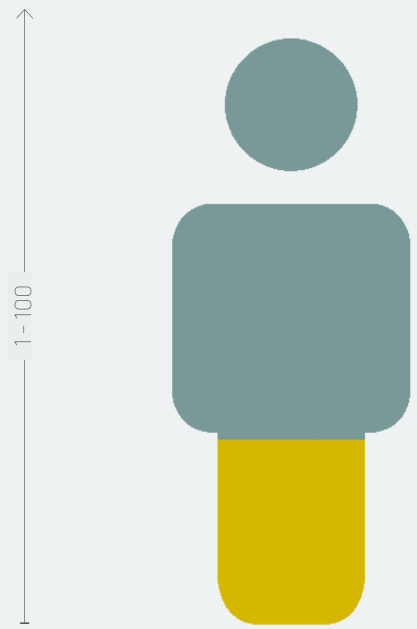


Figure ENF09.4: m²/person
The span of the vertical axis is 1 to 100 m²/person

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m²/year.

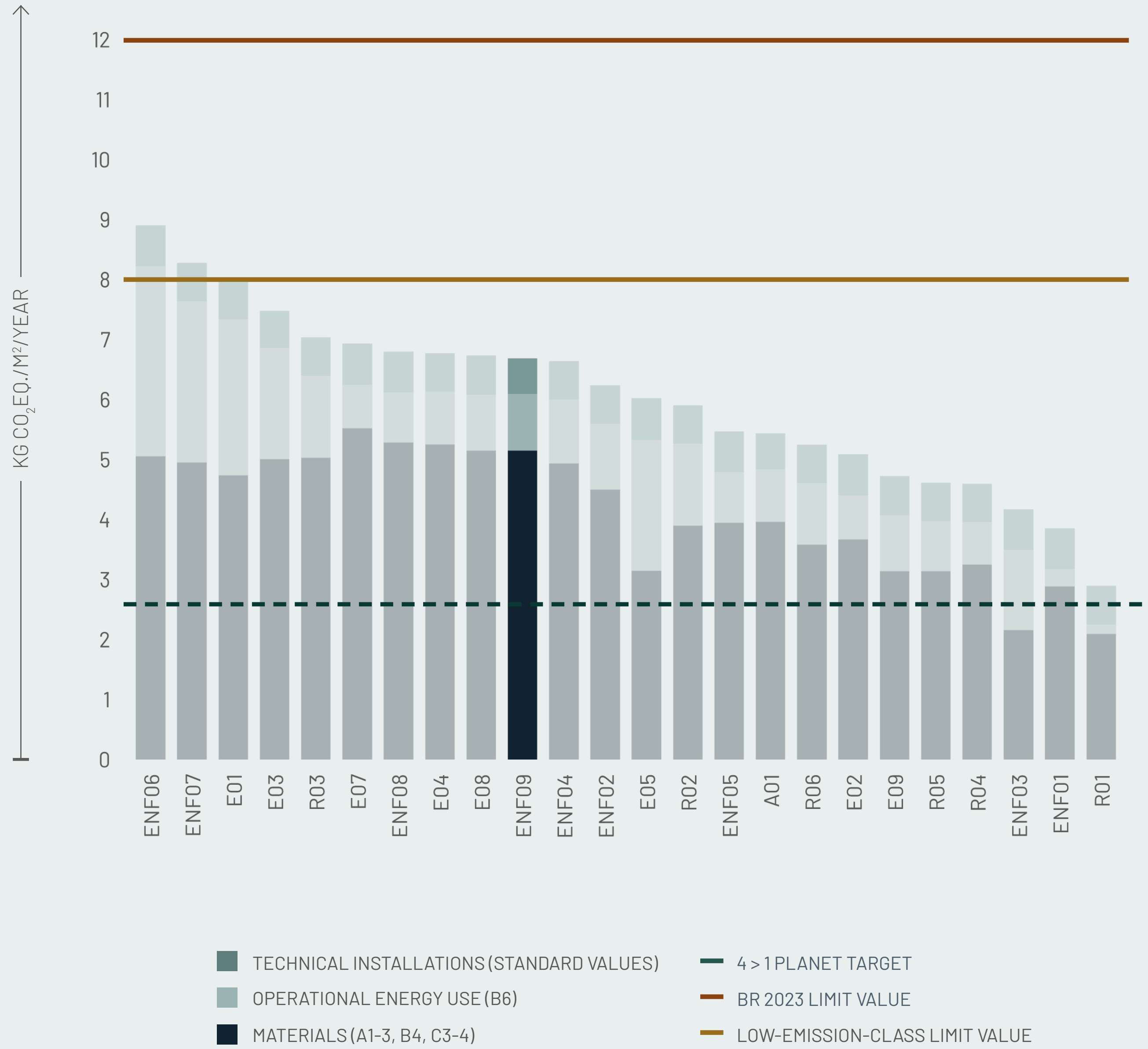


Figure ENF09.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m²/year. The horizontal axis shows the 24 best practice cases.

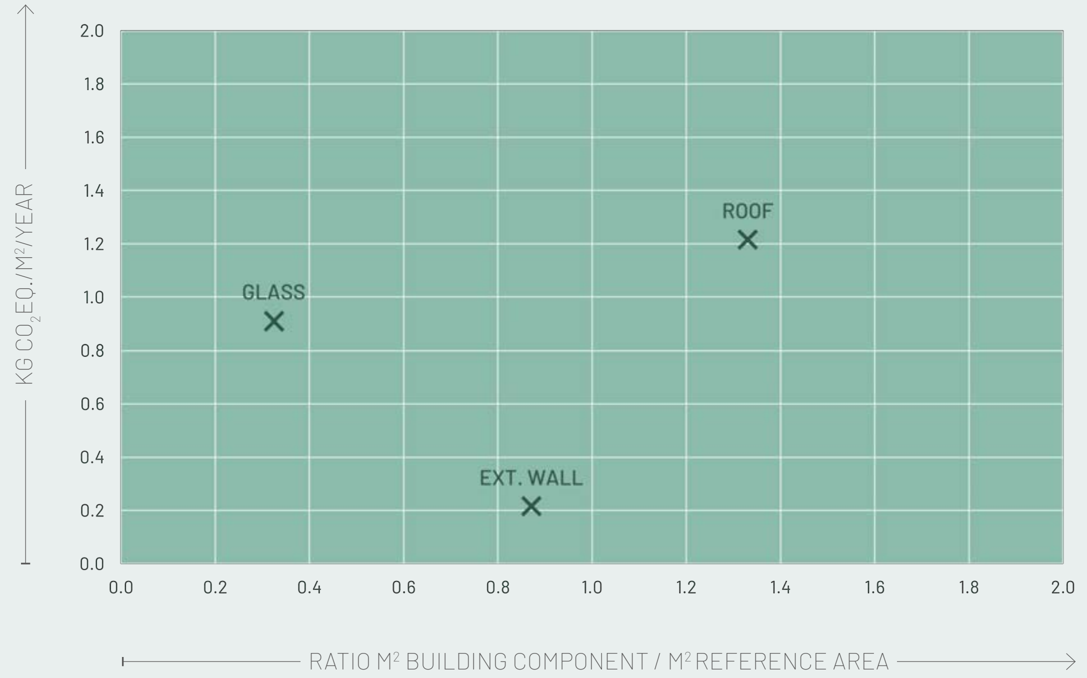
ENF09: Pramvejen PIXIE CASE

ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in CO_2eq./m²/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is well within the fastest reduction rate: the 83% likelihood scenario.

Figure ENF09.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq./m²/year, and the 'safe operating space'.

RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS



ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

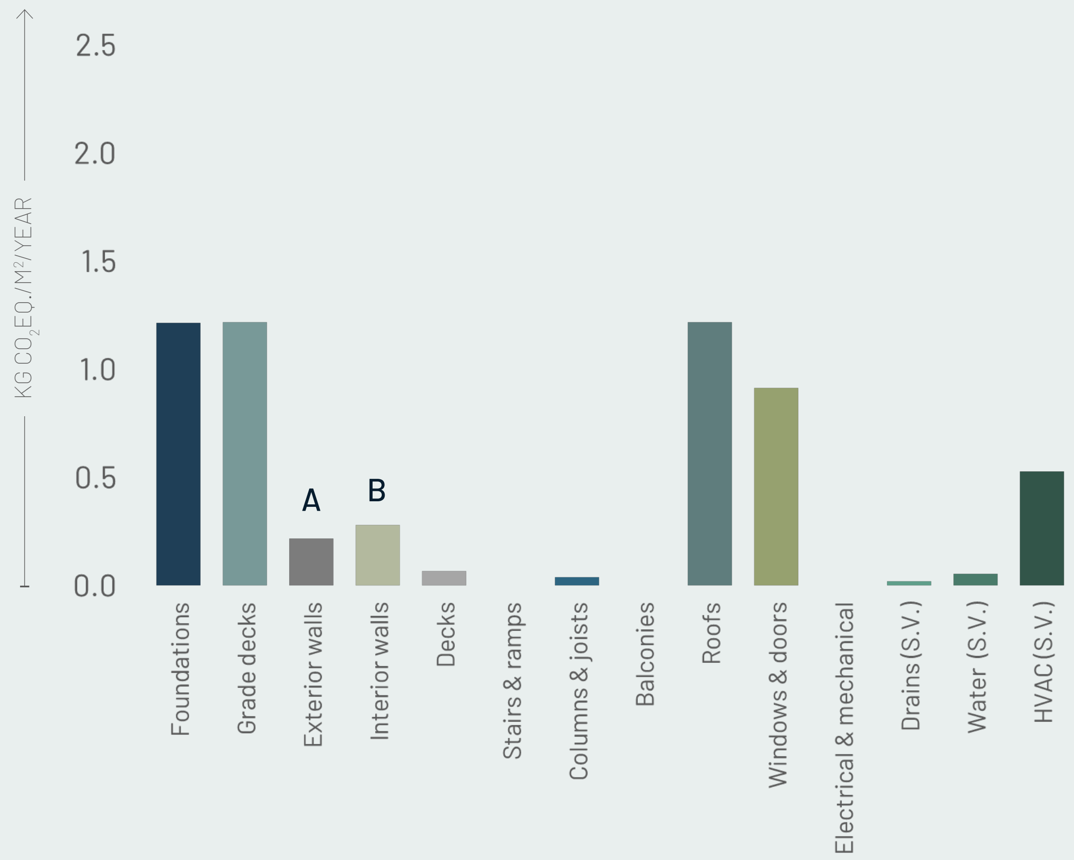


Figure ENF01.9: CO_2 accounting for building components
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades, electrical and mechanical systems, and technical installations (standard values).

SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

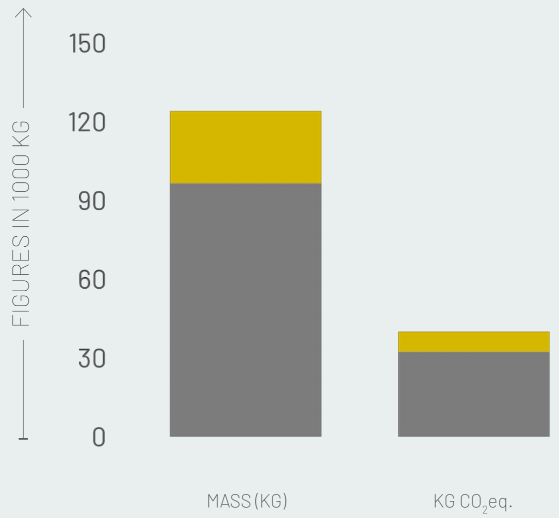
Figure ENF09.8:
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 150.000 kg.

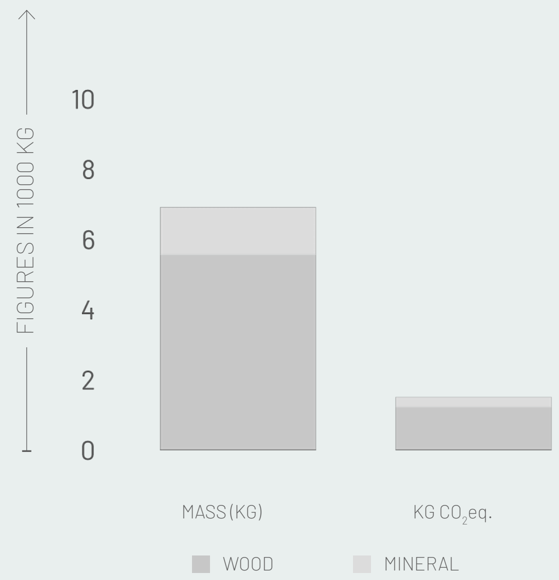
The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total CO_2eq grouped similarly.

BIOGENIC MATERIALS | HYBRID MATERIALS | OTHER MATERIALS

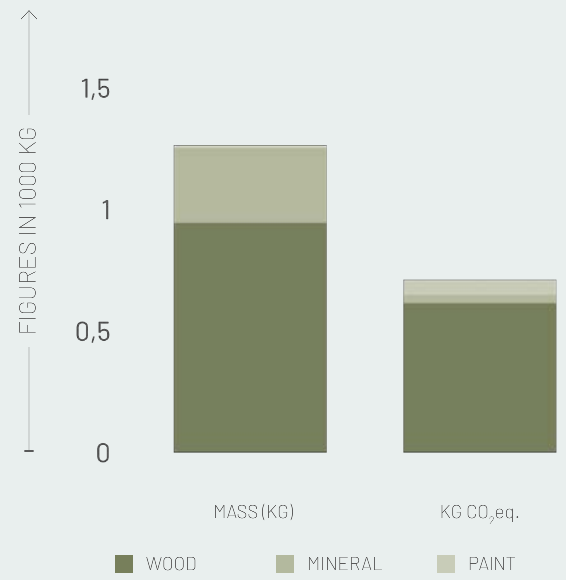


MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG CO_2EQ.



A. EXTERIOR WALL

Board cladding, untreated timber
Wooden strips
Wind barrier, wood-fibre sheeting
OSB sheeting
Wooden strips
Wood-fibre sheet insulation
Fibre gypsum boards
Clay plaster

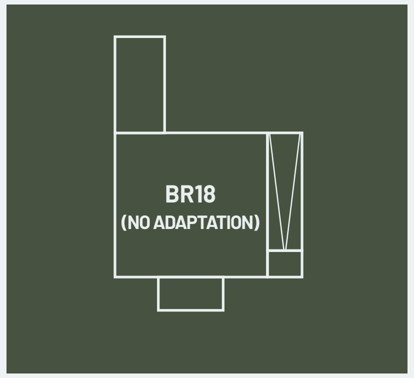


B. INTERIOR WALL

Timber frame
Wood-fibre sheet insulation
OSB sheeting
Plywood
Fibre gypsum boards
Clay plaster

Developer: VELUX
Architect: EFFEKT
Engineer: Artelia
Contractor: Enemærke & Petersen

Year (built): Not built
Floor area: 1029 m²
Reference area: 1029 m²
Use: Residential
Occupants: 28 / row
Year (calculated): 2022
Heating: Heat pump
Solar cells: Yes



VISUALISATION: EFFEKT

DESCRIPTION

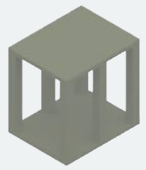
Living Places terraced housing is a CO_2-optimised version of the already registered project Living Places as a detached single-family dwelling. There are no specific plans as yet to construct the terraced version, and it is not, therefore, fully projected.

The three-storey building is built on continuous light aggregate foundations. The grade deck is reinforced concrete made with a CO_2 reduced cement product insulated with stone-wool slabs.

The house is constructed with facade cassettes and supporting structures in glulam. Exterior walls are insulated with cellulose and mineral wool. Facades are timber-clad. Decks in the building are rib-deck constructions in mass timber with an integral footfall insulation membrane and plywood, covered with fibre gypsum boards and wooden flooring, respectively. The interior walls are made in CLT, party walls are timber-frame constructions with mineral-wool insulation and gypsum-board cladding.

The roof is a cassette structure with cellulose insulation and slate covering with roof lights. In areas covered by photovoltaic modules, the underlying roofing material is bituminous felt.

The terraced housing totals 1029 m² with room for 28 occupants – a space allocation of approx. 37 m²/person, which is average for the case collection.



Hybrid

3 storeys

2,89 kg CO_2eq./m²/year

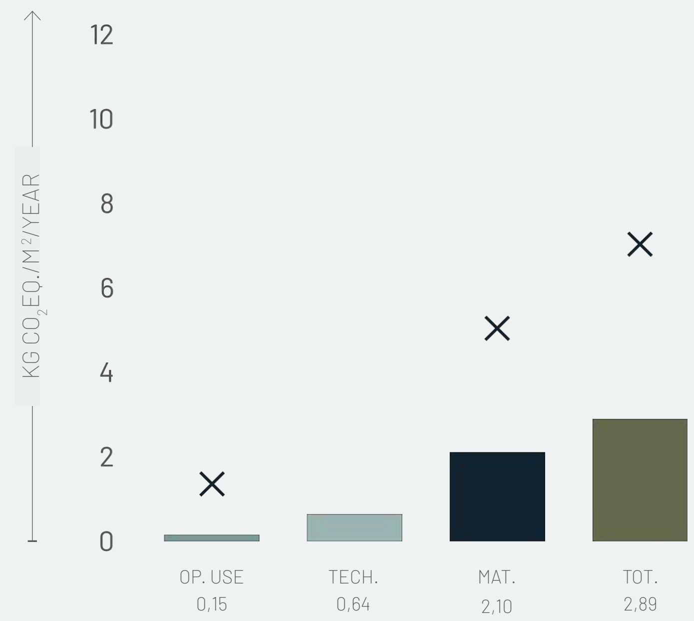


Figure R01.1: Emissions of kg CO_2eq./m²/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO_2eq./m²/year in terraced housing in the case collection.

141.157 kg CO_2eq.

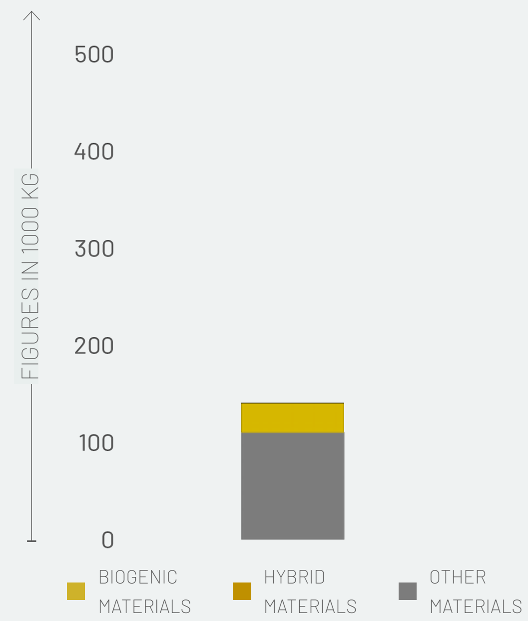


Figure R01.2: Total emission of kg CO_2eq.
The stacked bar chart shows the overall emission of kg CO_2eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

106 kg CO_2eq./person/year

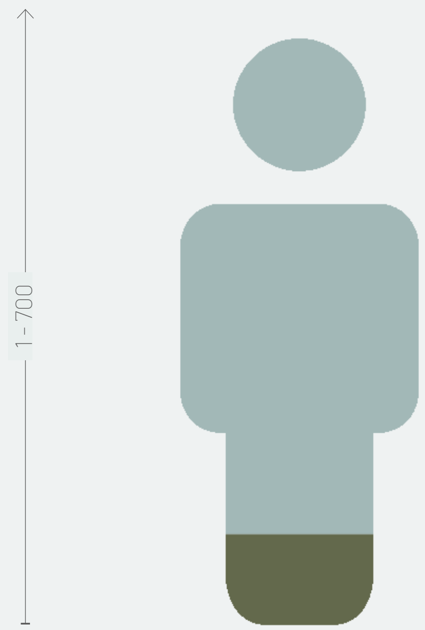


Figure R01.3: Emissions of kg CO_2eq./person/year
The span of the vertical axis is 1 to 700 kg CO_2eq./person/year

37 m²/person

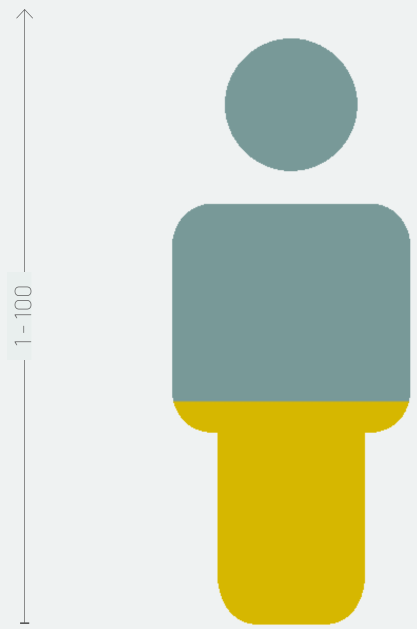


Figure R01.4: m² / person
The span of the vertical axis is 1 to 100 m²/person

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m²/year.

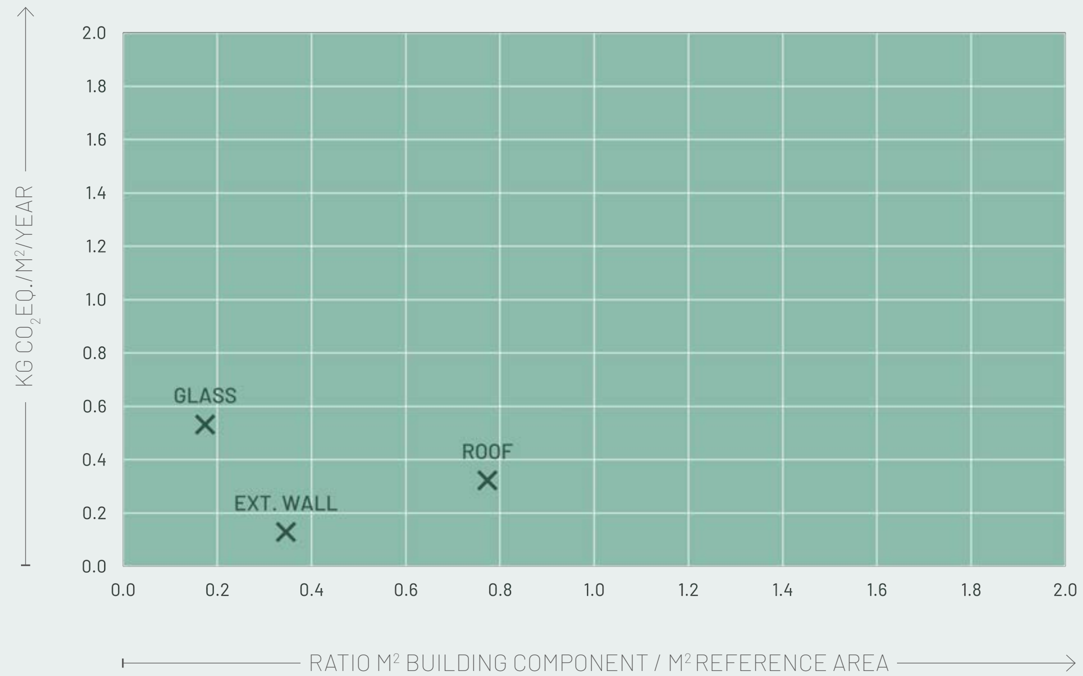
Figure R01.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m²/year. The horizontal axis shows the 24 best practice cases.

ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in CO_2eq./m²/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is well within the fastest reduction rate: the 83% likelihood scenario.

Figure R01.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq./m²/year, and the 'safe operating space'.

RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS



ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

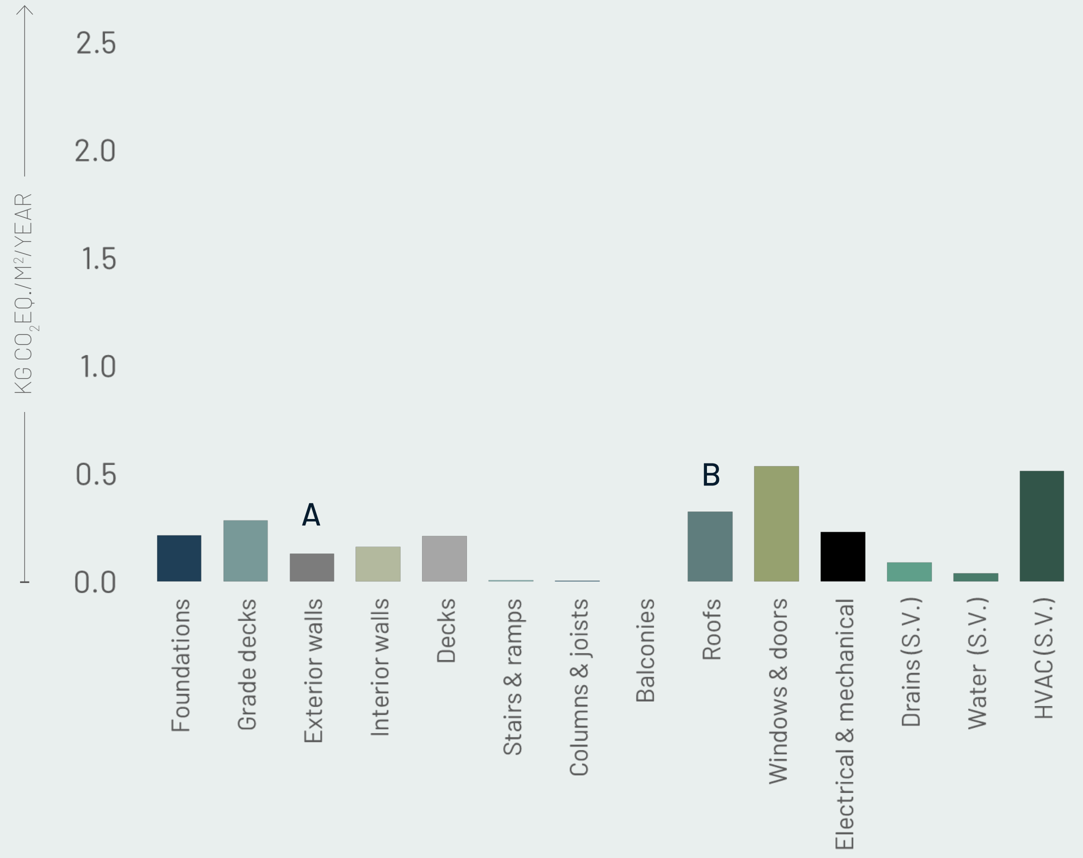


Figure R01.7: CO_2 accounting for building components
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades, electrical and mechanical systems, and technical installations (standard values).

R01: Living Places II PIXIE CASE

SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

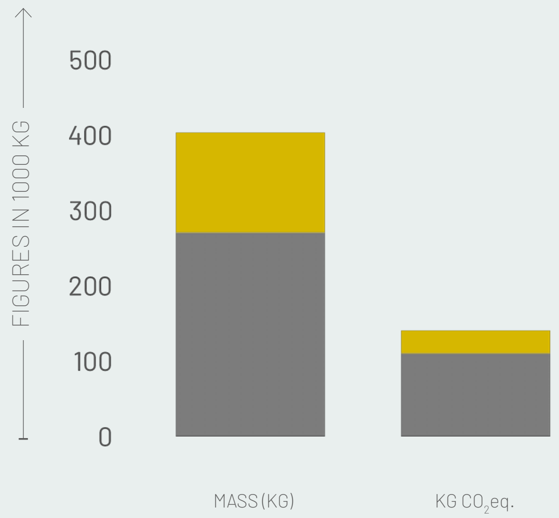
Figure R01.8:
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

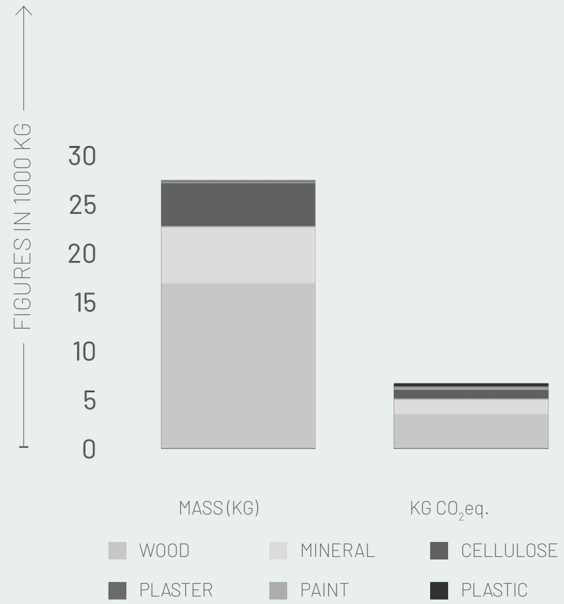
The bar on the left shows the building mass in kg grouped into material categories.

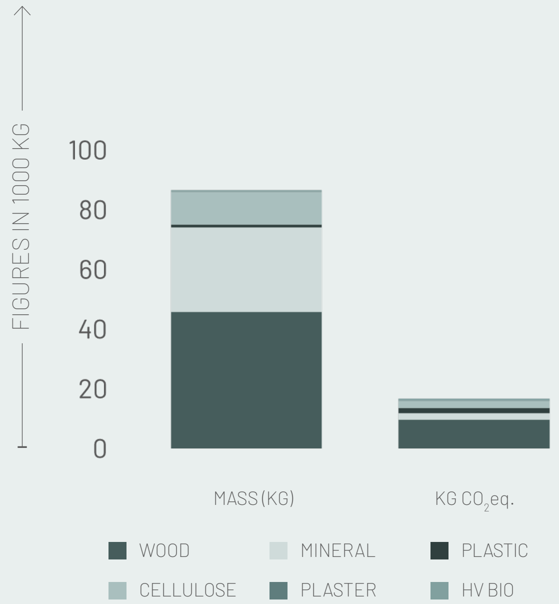
The bar on the right shows the building's total CO_2eq grouped similarly.

BIOGENIC MATERIALS | HYBRID MATERIALS | OTHER MATERIALS



MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG CO_2EQ.





A. EXTERIOR WALL

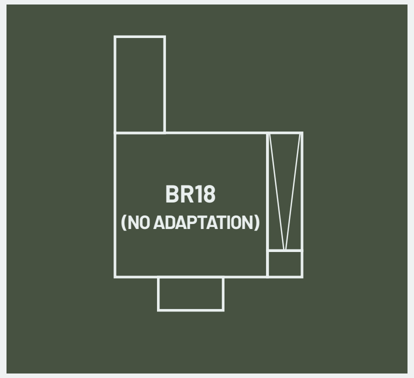
Wooden cladding
Fibre gypsum
OSB sheeting
Timber frame
Cellulose insulation
Vapour barrier
Wooden strips
Glass wool insulation
Fibre gypsum
Filler and paint

B. INTERIOR WALL

Sloping roof, slate covering
Flat roof, bituminous felt
Plywood
Timber frame with cellulose insulation
OSB sheeting
Vapour barrier
Wooden strips
Glass wool insulation
Fibre gypsum
Filler and paint

R02: Skademosen

Developer: Boligselskabet Sjælland
Architect: Vilhelm Lauritzen Arkitekter
Engineer: Holmsgaard A/S
Landscape: Thing Brandt Landskab
Contractor: Adserballe Knudsen A/S
Year (built): 2021
Floor area: 4146 m^2
Reference area: 4146 m^2
Use: Residential
Occupants: 148
Year (calculated): 2022
Heating: Electric
Solar cells: Yes



DESCRIPTION

Skademosen is a housing scheme comprising 13 blocks of timber terraced housing. The Product stage primarily took place at a factory, which is likely to help reduce the consumption of building materials and resources on the building site. Using low-emission and non-allergenic construction materials is a special focal point.

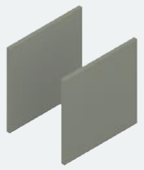
The two-storey blocks are built on combined pile and continuous foundations of lightweight aggregate blocks and reinforced concrete insulated with PIR foam. The grade deck is concrete and EPS.

The houses are constructed with prefabricated solid timber modules in cross-laminated timber (CLT) with a glass wool insulation system. Insulated posts were installed directly on the supporting structure, after which specially moulded insulation was fitted between the posts.

The houses have a limited number of partition walls to ensure flexibility, and the size of the units vary between 30 and 115 m^2 to appeal to a broad range of occupants.

The facades have timber facing and the roofing is bituminous felt.

The terraced housing totals 4146 m^2 with room for 148 occupants and a space allocation of approx. 28 m^2/person, which on the low side in the case collection.



CLT

2 storeys

R02: Skademosen

5,91 kg CO_2eq./m^2/year

Figure R02.1: Emissions of kg CO_2eq./m^2/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO_2eq./m^2/year in terraced housing in the case collection.

942.098 kg CO_2eq.

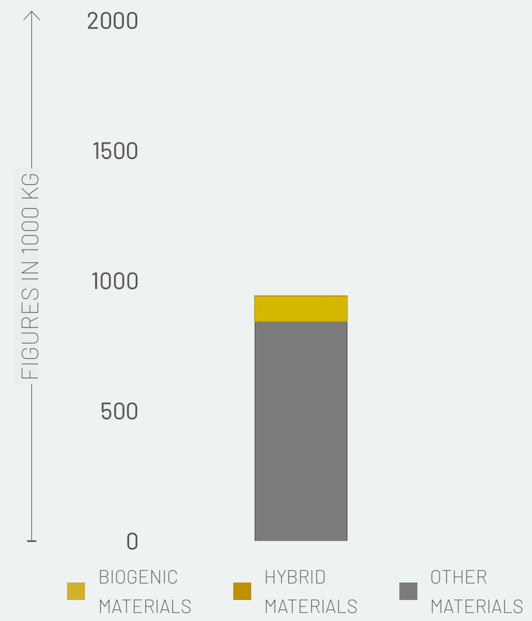


Figure R02.2: Total emission of kg CO_2eq.
The stacked bar chart shows the overall emission of kg CO_2eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

165 kg CO_2eq./person/year

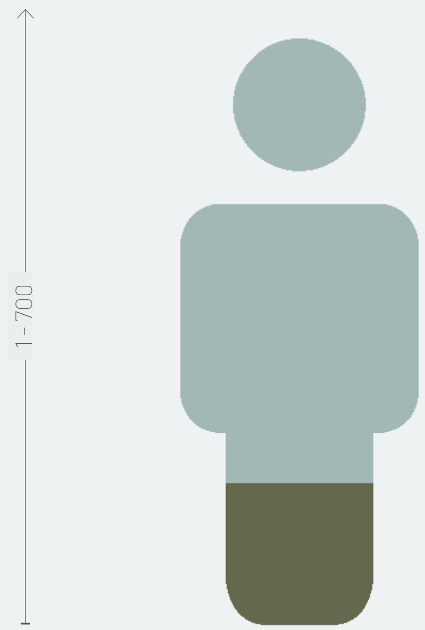


Figure R02.3: Emissions of kg CO_2eq./person/year
The span of the vertical axis is 1 to 700 kg CO_2eq./person/year

28 m^2/person

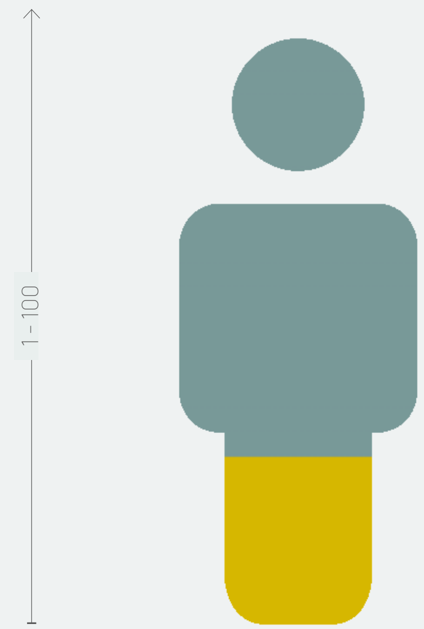


Figure R02.4: m^2/person
The span of the vertical axis is 1 to 100 m^2/person

R02: Skademosen

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m²/year.

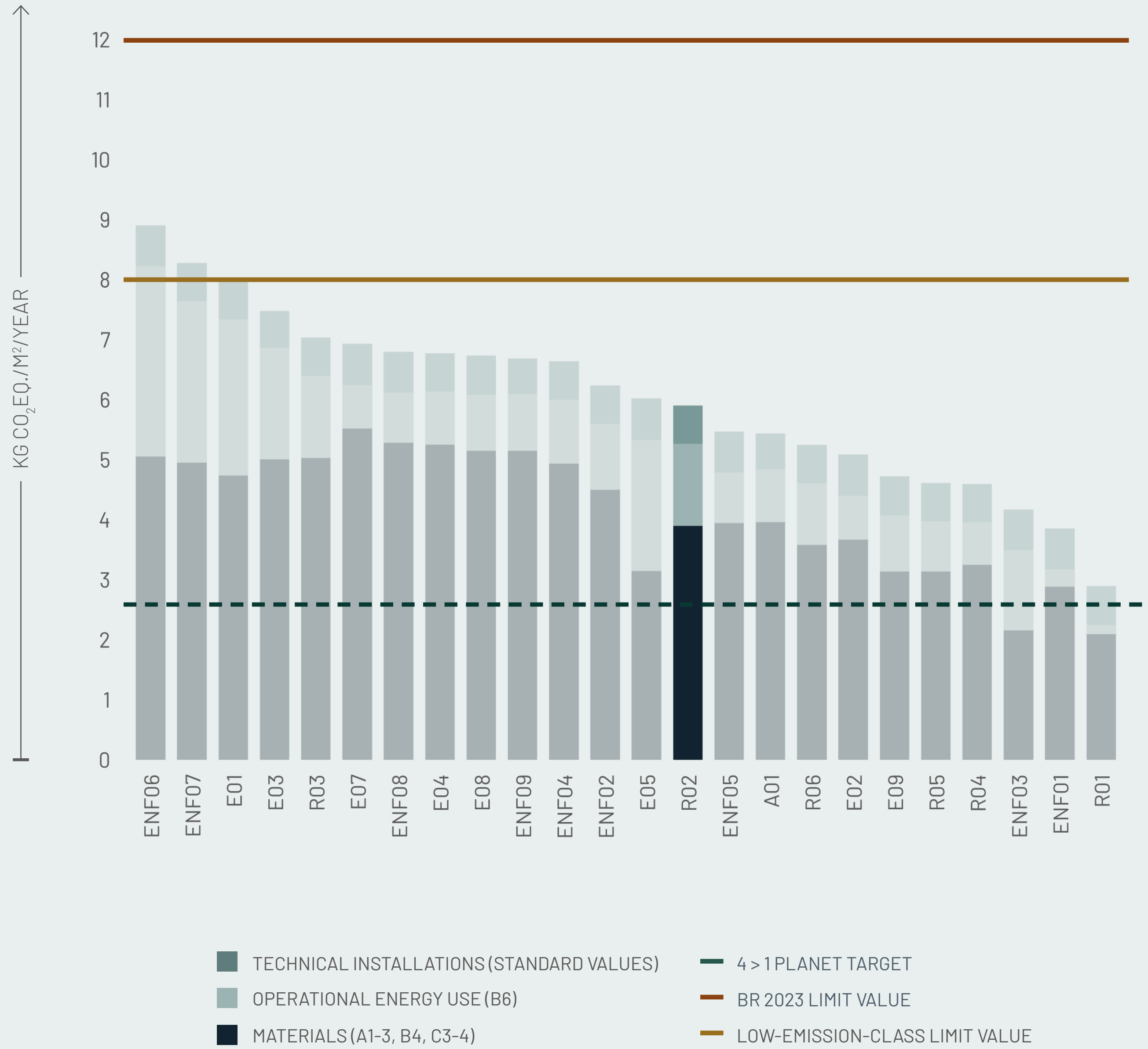


Figure R02.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m²/year. The horizontal axis shows the 24 best practice cases.

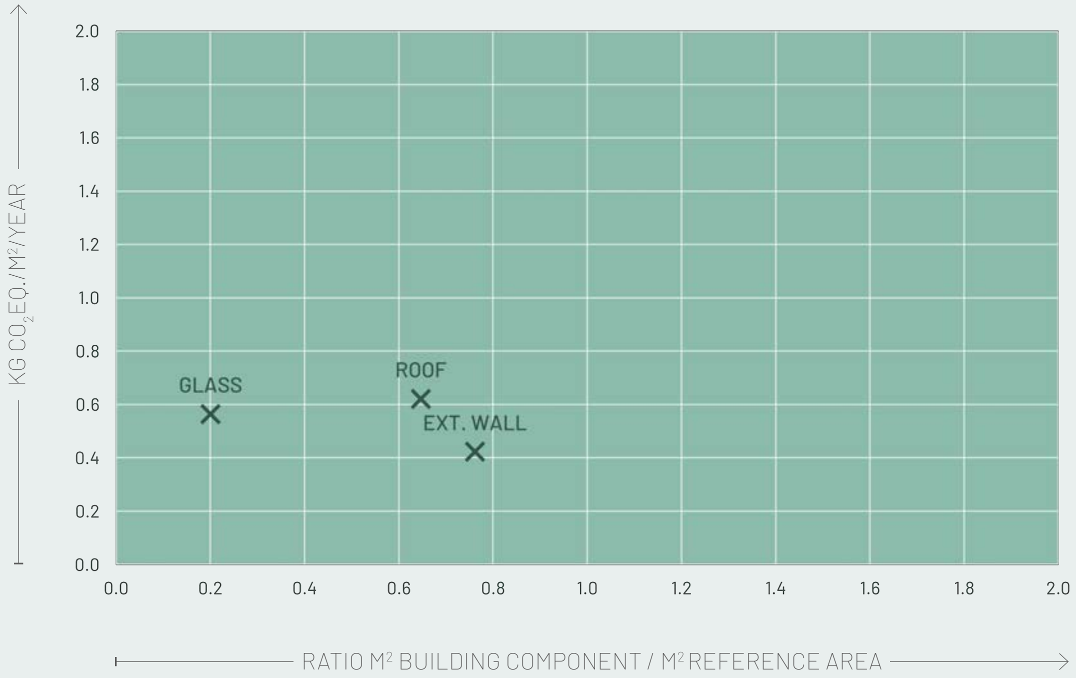
R02: Skademosen

ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in CO_2eq./m²/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is well within the fastest reduction rate: the 83% likelihood scenario.

Figure R02.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq./m²/year, and the 'safe operating space'.

RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS



ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

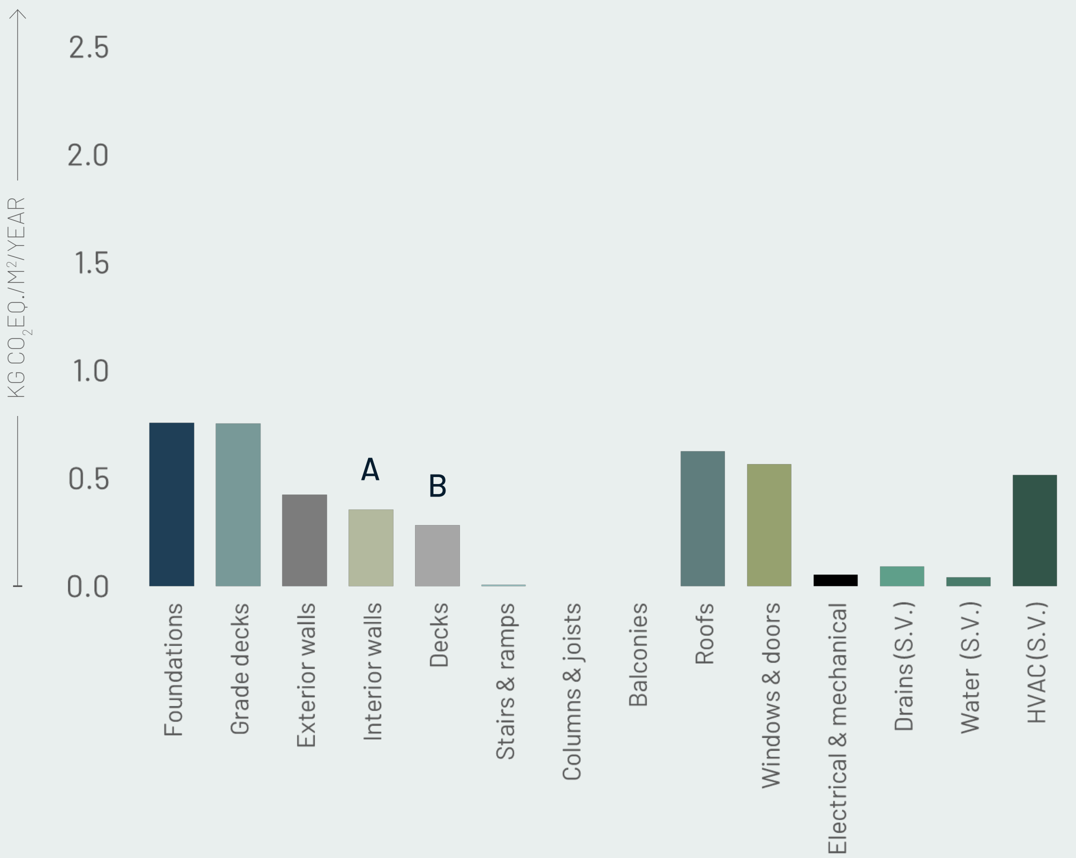


Figure R02.7: CO_2 accounting for building components
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades, electrical and mechanical systems, and technical installations (standard values).

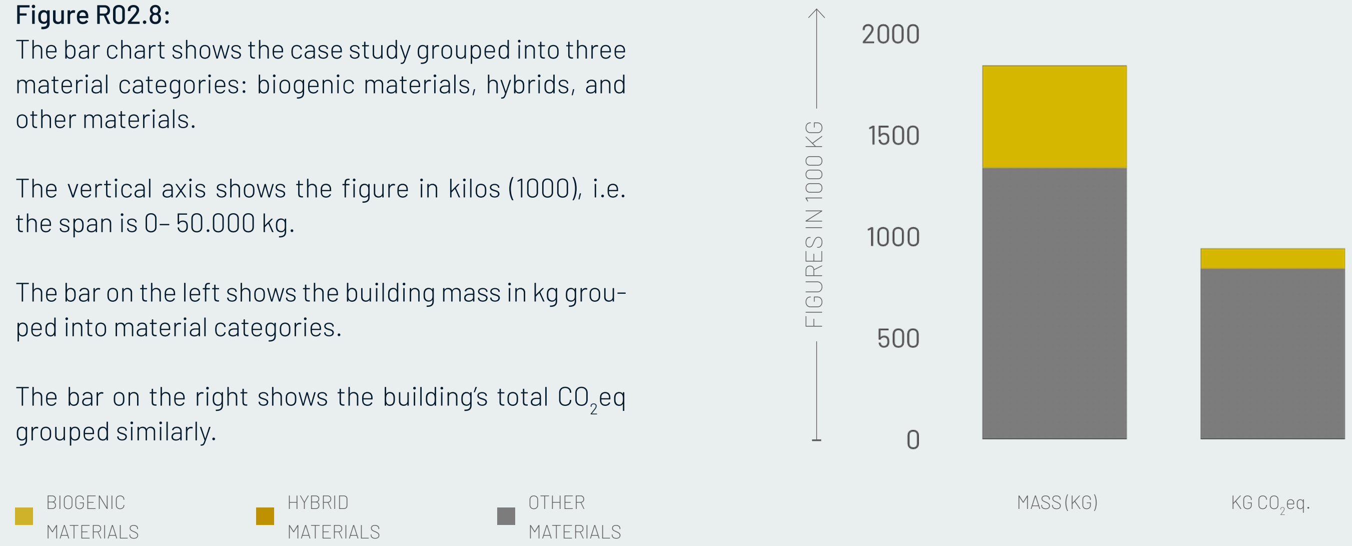
SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

Figure R02.8:
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

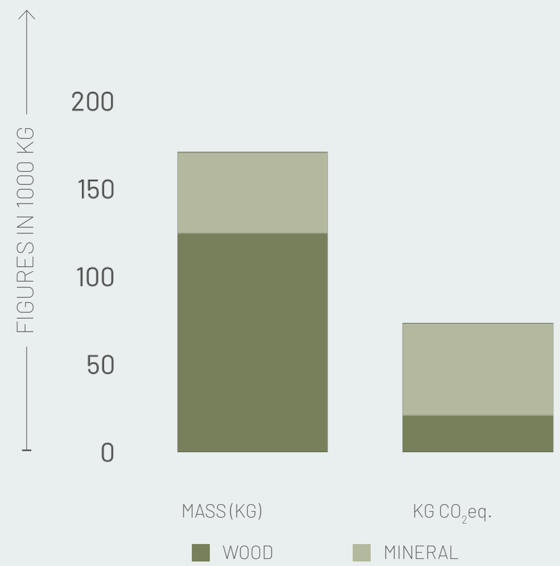
The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

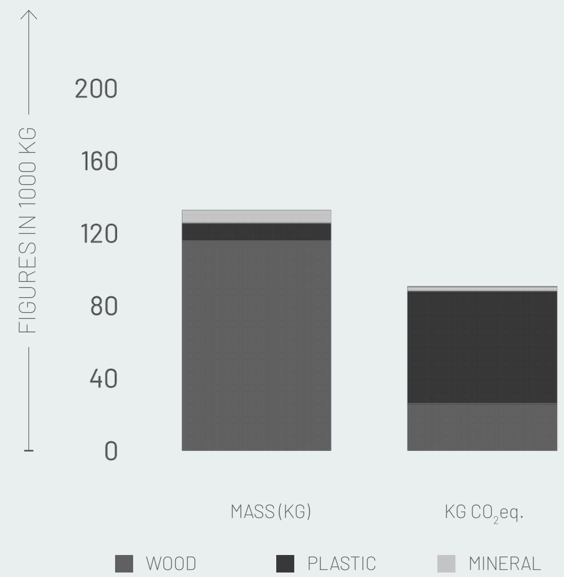
The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total CO_2eq grouped similarly.



MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG CO_2EQ.





A. INTERIOR WALL

CLT cassette
Mineral wool insulation
Gypsum plasterboard

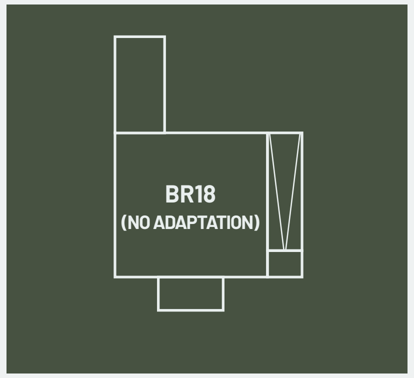
B. DECK

Parquet flooring, wood
PVC flooring
CLT deck

R03: Tømmergården

Developer: Roskilde Nord / KAB
Architect: ONV / JaJa Architects
Engineer: Bascon
Contractor: Scandi Byg

Year (built): 2021
Floor area: 531 m²
Reference area: 531 m²
Use: Residential
Occupants: 148
Year (calculated): 2022
Heating: Natural gas
Solar cells: Yes



DESCRIPTION

Tømmergården is a housing scheme comprising seven blocks of multi-family housing, each comprising five housing units. The product stage primarily took place at a factory, which is likely to help reduce the consumption of building materials and resources on the building site. Daylight factors and individualised accommodation as a resource-reduction strategy were special focal points.

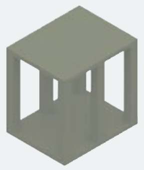
The one- or two-storey buildings are built on concrete point foundations of steel girders. Grids are mounted in the facade line to vent the cavity space beneath the building, and there is level access to the building. The grade deck is made of glulam modules with mineral wool and pressure-impregnated plywood with an underlay of base-course aggregate.

The housing is constructed in timber cassette modules, the exterior walls are insulated with mineral wool, and the facades are timber-clad.

Storey partitions and partitions between housing units are timber constructions with mineral wool insulation and a sound-dampening profile and felt.

The roof is a glulam construction with vented cavity space, and mineral wool insulation. This is covered with bituminous felt doubling as an underlay for a sedum roof (green roof).

One of the seven buildings in the housing project was subject to a life-cycle assessment. This area comprises 531 m² with room for 19 occupants, which gives a space allocation of approx. 28 m²/person, which is on the low side in the case collection.



Hybrid

1 - 2 storeys

R03: Tømmergården

7,04 kg CO_2eq./m²/year

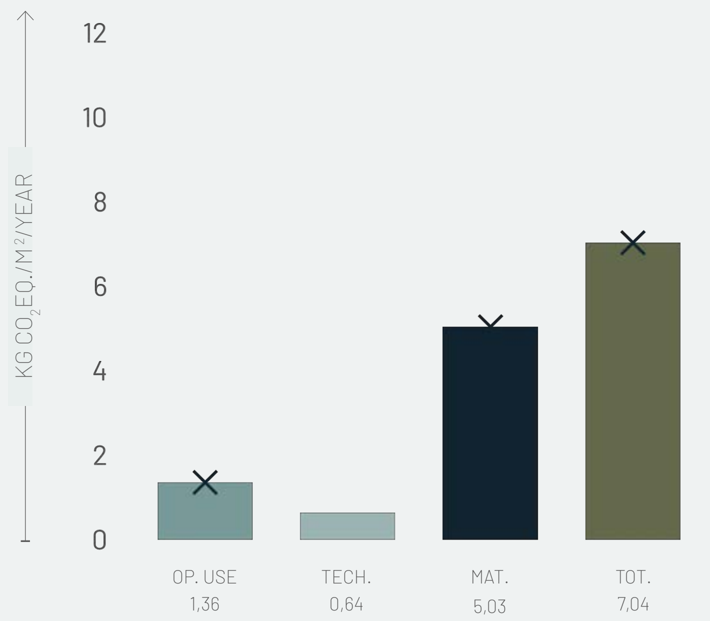


Figure R03.1: Emissions of kg CO_2eq./m²/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO_2eq./m²/year in terraced housing in the case collection.

150.725 kg CO_2eq.

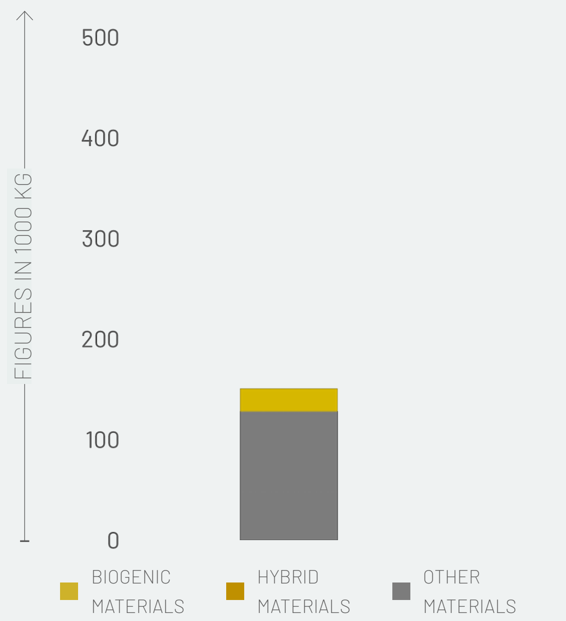


Figure R03.2: Total emission of kg CO_2eq.
The stacked bar chart shows the overall emission of kg CO_2eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

189 kg CO_2eq./person/year

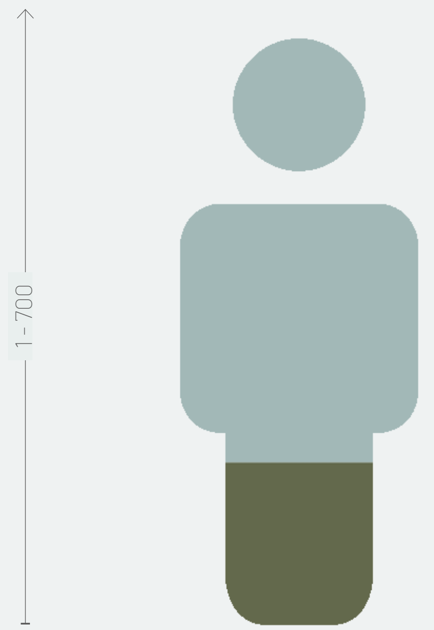


Figure R03.3: Emissions of kg CO_2eq./person/year
The span of the vertical axis is 1 to 700 kg CO_2eq./person/year

28 m²/person

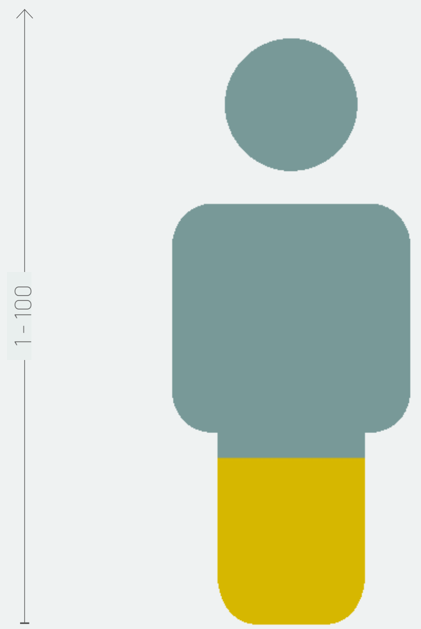


Figure R03.4: m²/person
The span of the vertical axis is 1 to 100 m²/person

R03: Tømmergården

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m²/year.

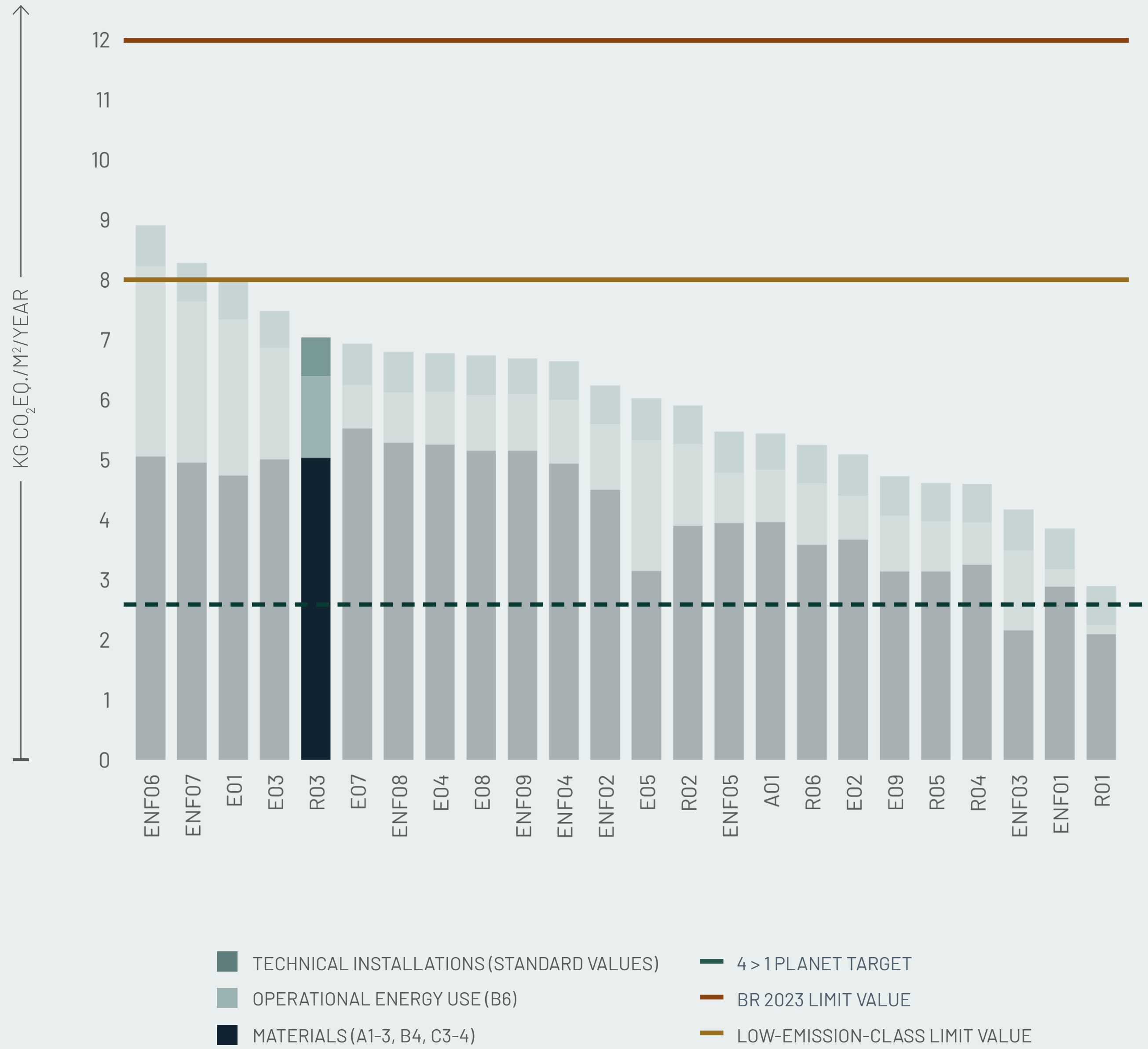


Figure R03.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m²/year. The horizontal axis shows the 24 best practice cases.

R03: Tømmergården

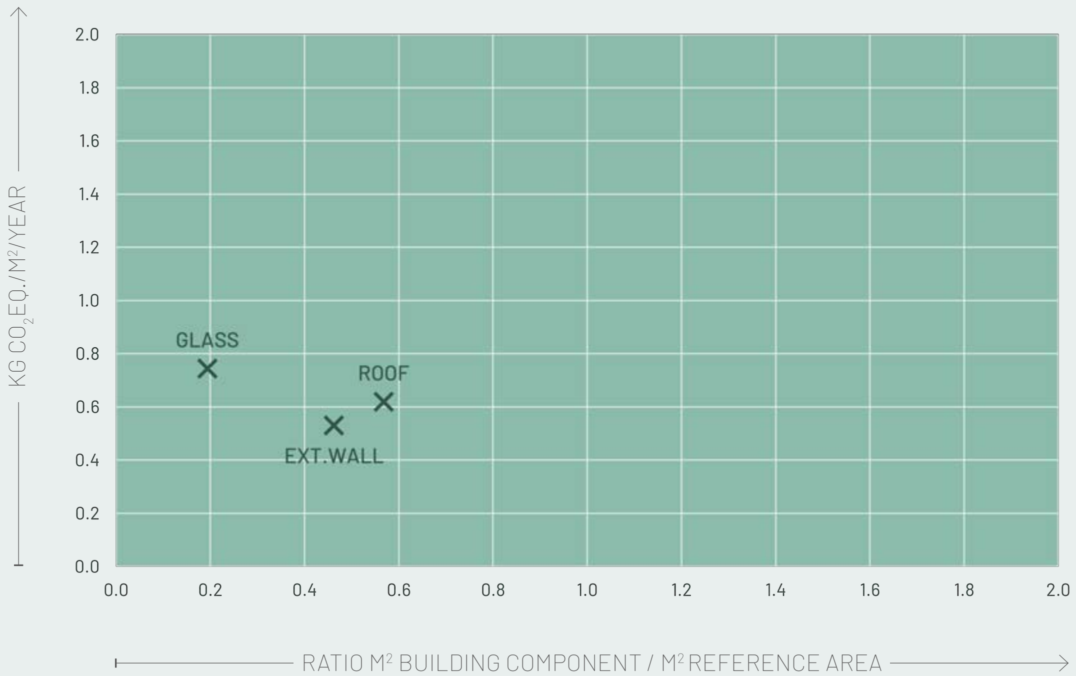
ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in CO_2eq./m²/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is well within the fastest reduction rate: the 83% likelihood scenario.

Figure R03.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq./m²/year, and the 'safe operating space'.

R03: Tømmergården

RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS



ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

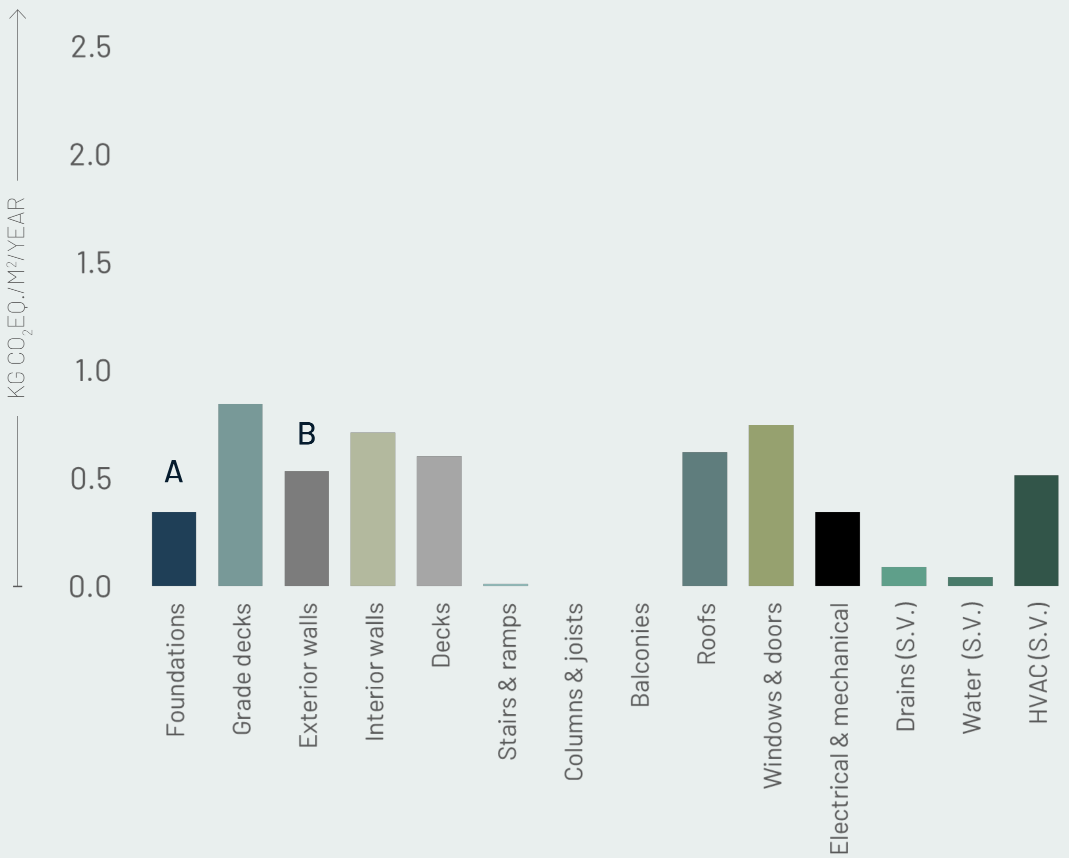


Figure R03.7: CO_2 accounting for building components
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades, electrical and mechanical systems, and technical installations (standard values).

R03: Tømmergården

SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

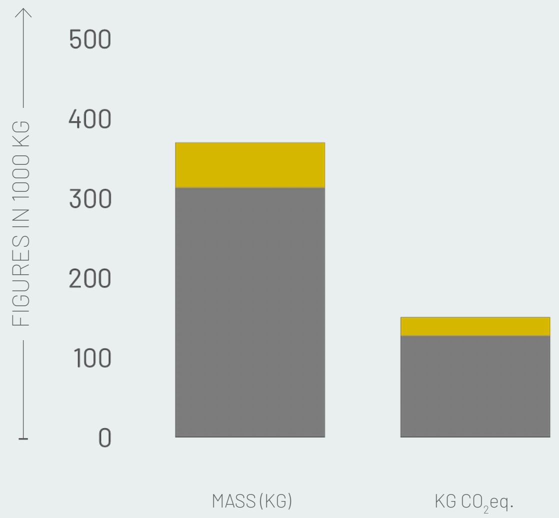
Figure R03.8:
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

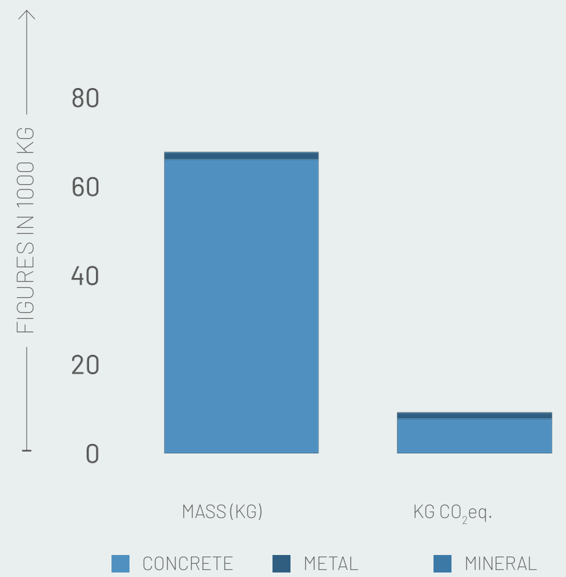
The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total CO_2eq grouped similarly.

BIOGENIC MATERIALS
HYBRID MATERIALS
OTHER MATERIALS

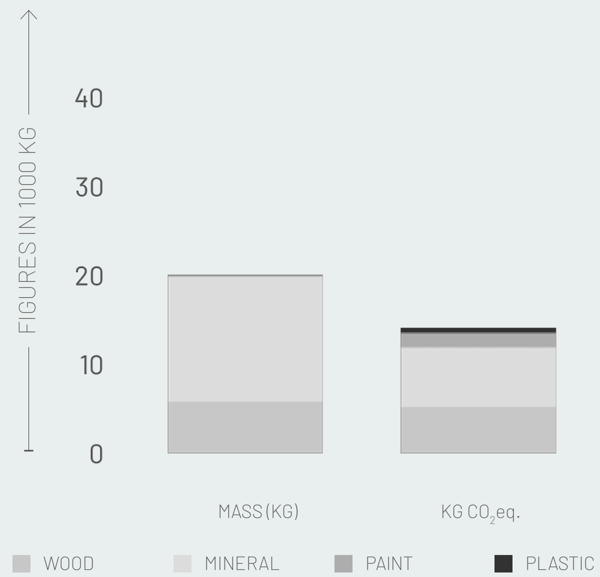


MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG CO_2EQ.



A. FOUNDATION

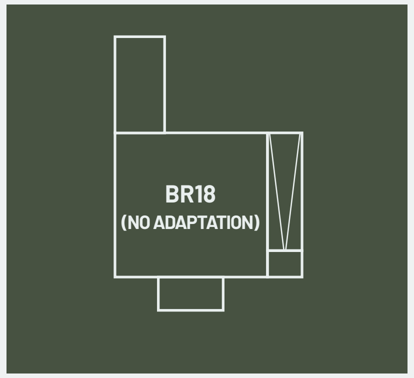
Concrete point foundations
Steel girders



B. EXTERIOR WALL

Wooden cladding
Wooden strips
Vapour barrier
Fibre cement sheeting
Timber frame
Mineral wool insulation batts
Fibre gypsum
Plaster and paint

Developer:	Boligselskabet AKB c/o KAB
Architect:	Vandkunsten
Engineer:	Dansk Energimanagement + Esbensen
Contractor:	GVL Entreprise + BM Tag
Year (built):	2014
Floor area:	8378 m²
Reference area:	8378 m²
Use:	Residential
Occupants:	19 / unit
Year (calculated):	2022
Heating:	Heat pump
Solar cells:	No



DESCRIPTION

Danmarksgrunden is a housing scheme in five rows with a total of 72 dwellings. The Product stage primarily took place at a factory, which is likely to help reduce the consumption of building materials and resources on the building site. A special focal point was to keep down rentals by optimising energy use and reducing the need for maintenance.

The three-storey buildings are built on continuous and pile foundations in concrete insulated with EPS and foamed glass. The grade deck is a cassette construction insulated with mineral wool and EPS and covered with cement particle board.

The housing is a prefabricated wedge-shaped modular cassette construction forming an arch. The facade cladding is slate and cedar wood, requiring no or very little maintenance.

Storey partitions and partitions between housing units are cassette constructions with mineral wool insulation and gypsum boards, the gypsum being fire-impregnated in the storey partitions. Surfaces are lime-plastered and painted.

The roof is a cassette construction with mineral wool insulation. Further, bituminous felt roof covering and overhangs prolong the lifetime of facade materials. The underside of the roof overhang is covered with wood and given a coat of wood paint.

Danmarksgrunden totals 8378 m² with room for 207 occupants, which gives a space allocation of approx. 41 m²/person. This is on the high side in the case collection.

Cassette

3 storeys

R04: Danmarksgrunden

4,60 kg CO_2eq./m²/year

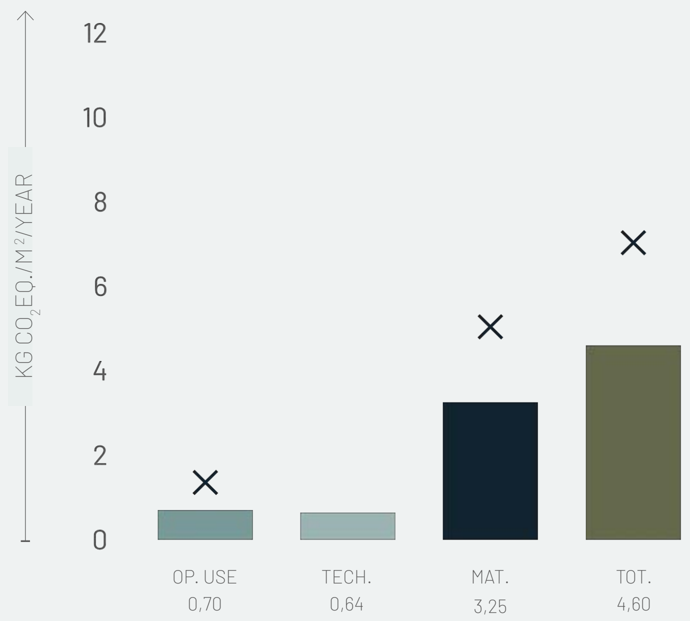


Figure R04.1: Emissions of kg CO_2eq./m²/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO_2eq./m²/year in terraced housing in the case collection.

1.632.490 kg CO_2eq.

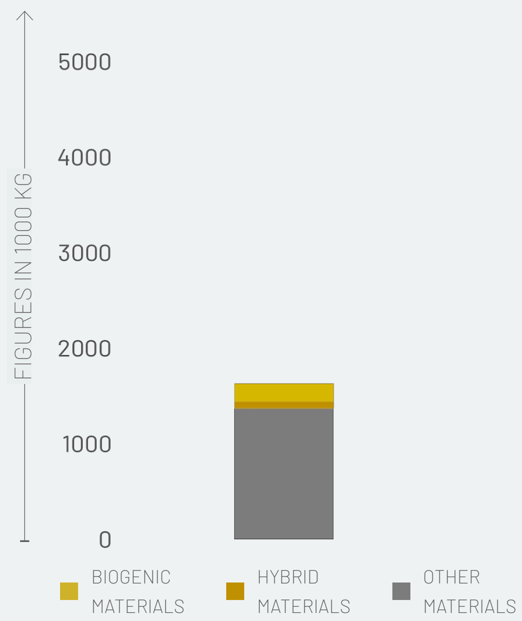


Figure R04.2: Total emission of kg CO_2eq.
The stacked bar chart shows the overall emission of kg CO_2eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

186 kg CO_2eq./person/year

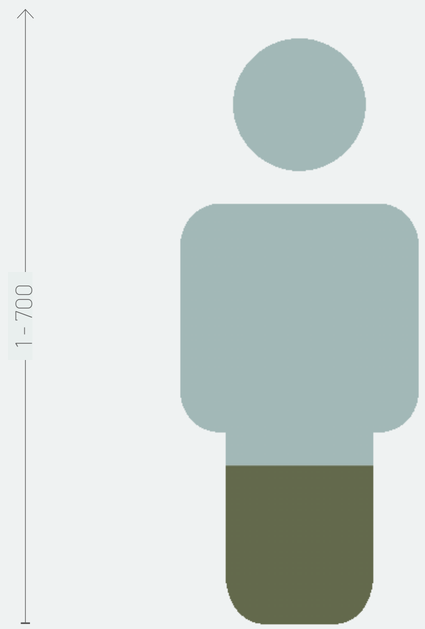


Figure R04.3: Emissions of kg CO_2eq./person/year
The span of the vertical axis is 1 to 700 kg CO_2eq./person/year

41 m²/person

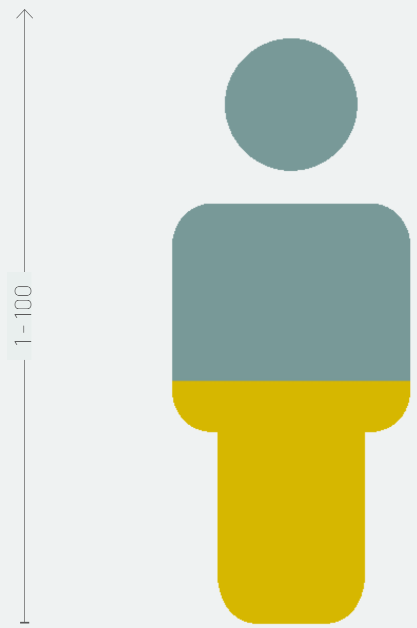


Figure R04.4: m²/person
The span of the vertical axis is 1 to 100 m²/person

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m²/year.

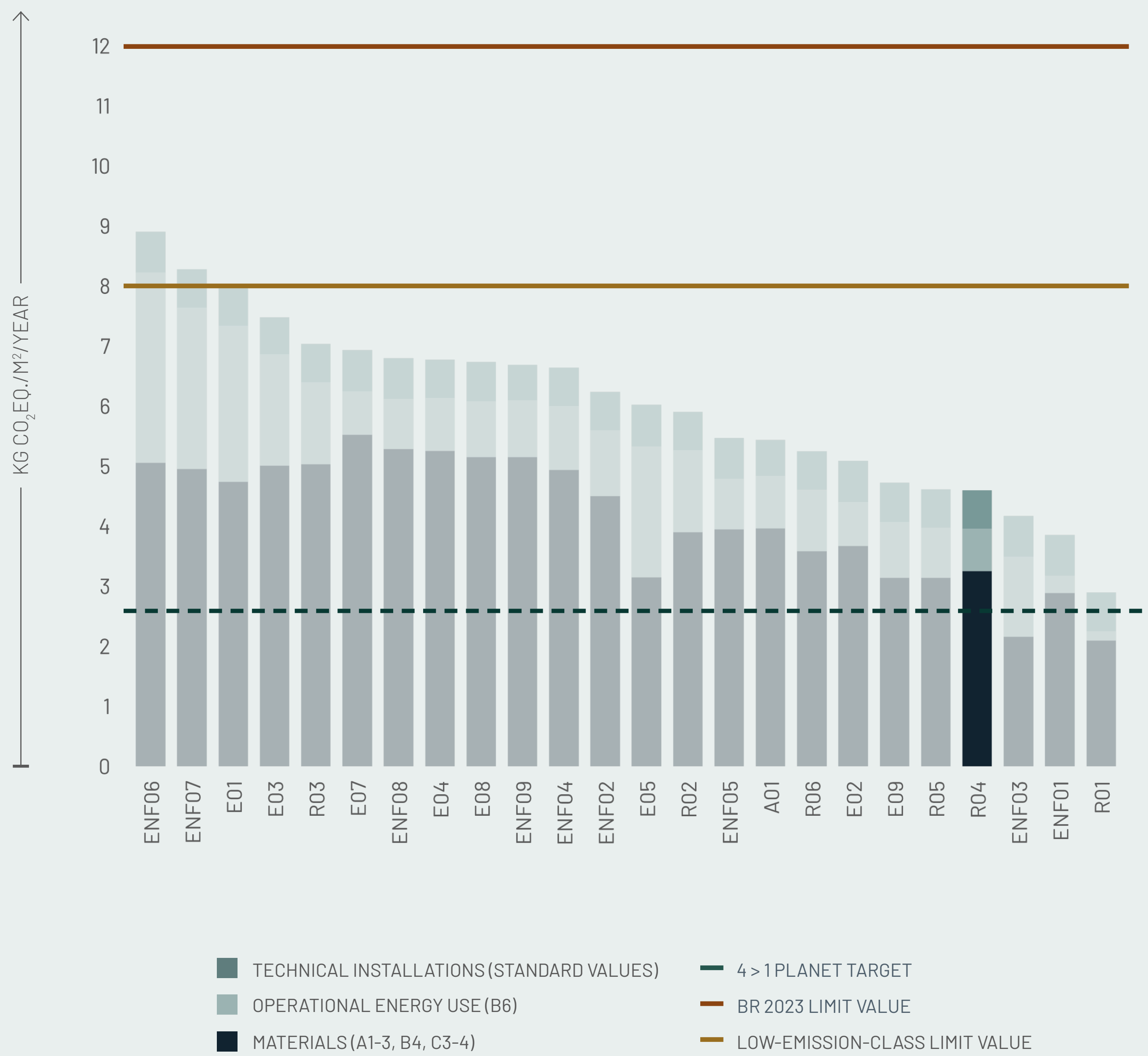


Figure R04.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m²/year. The horizontal axis shows the 24 best practice cases.

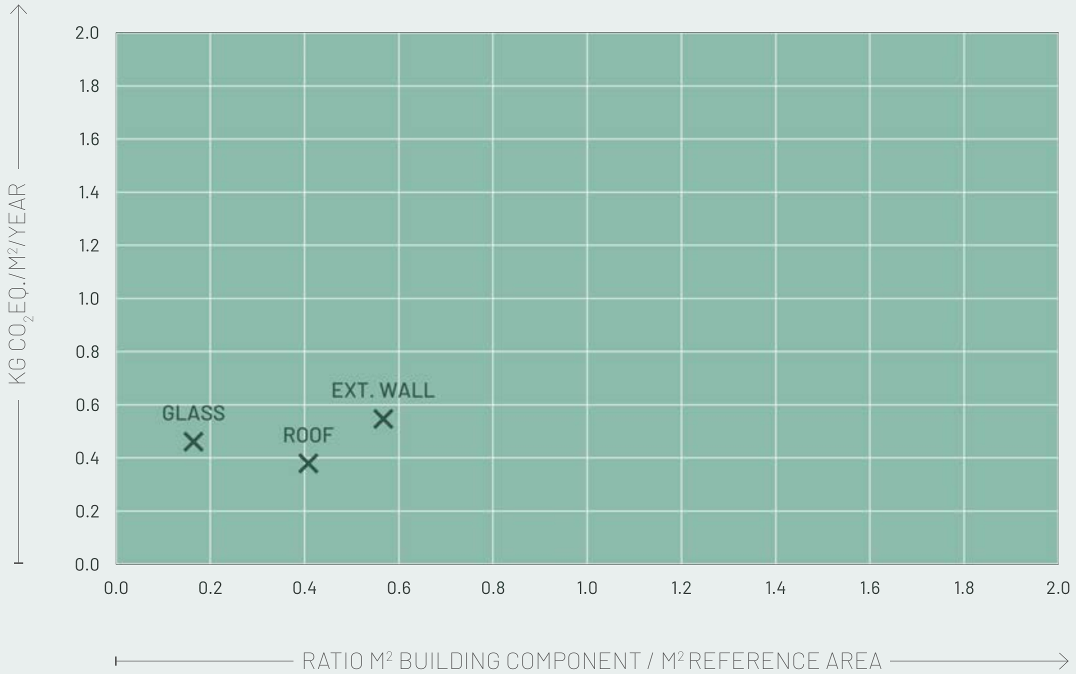
R04: Danmarksgrunden

ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in CO_2eq./m²/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is well within the fastest reduction rate: the 83% likelihood scenario.

Figure R04.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq/m²/year, and the 'safe operating space'.

RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS



ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

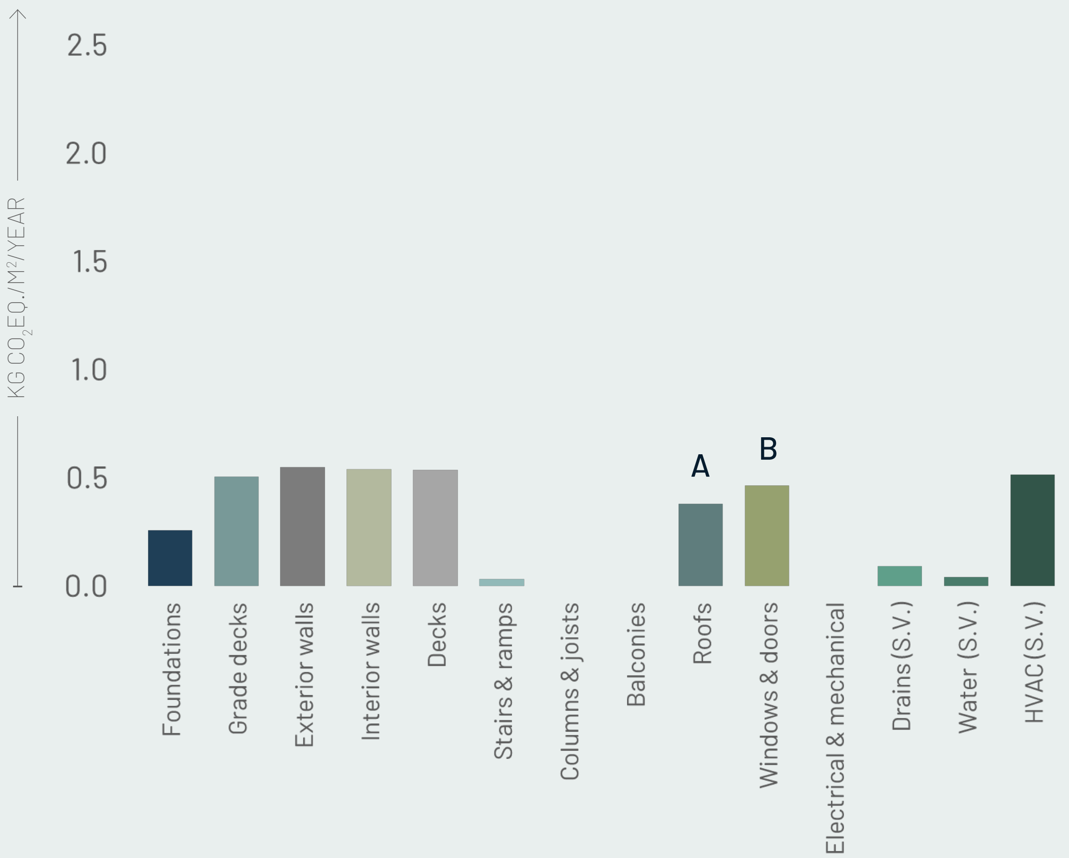


Figure R04.7: CO_2 accounting for building components
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades, electrical and mechanical systems, and technical installations (standard values).

SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

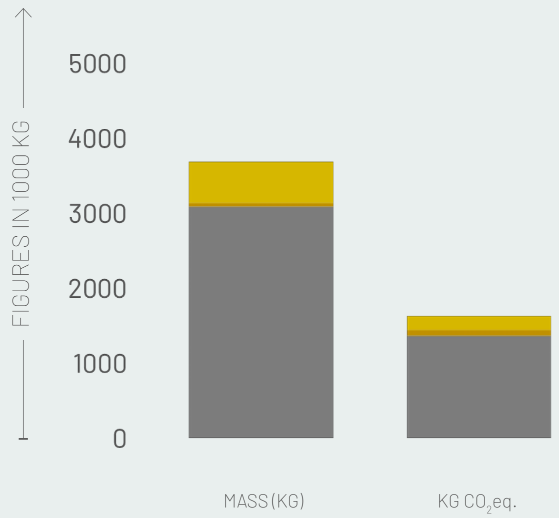
Figure R04.8:
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

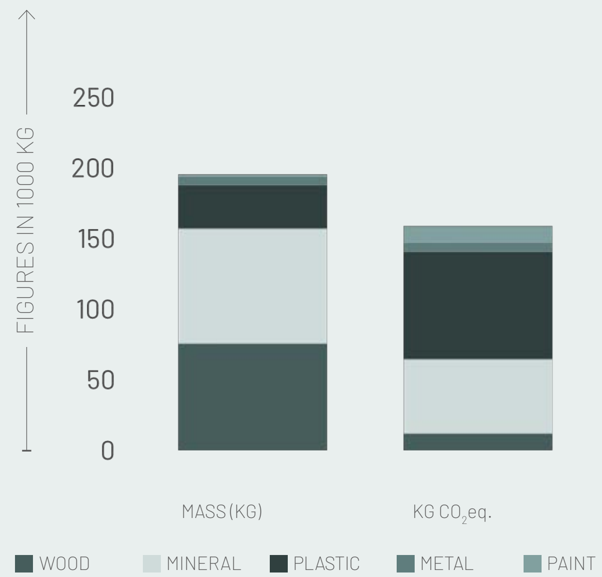
The bar on the left shows the building mass in kg grouped into material categories.

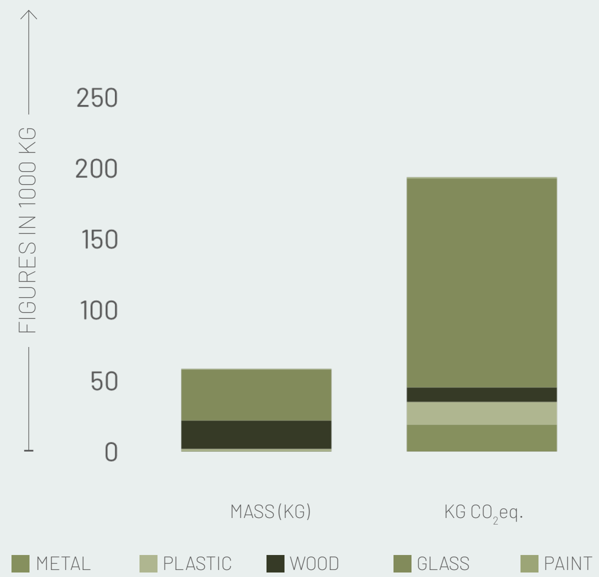
The bar on the right shows the building's total CO_2eq grouped similarly.

BIOGENIC MATERIALS
HYBRID MATERIALS
OTHER MATERIALS



MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG CO_2EQ.





A. ROOF

Bituminous felt roofing
Bituminous felt underlay
Plywood
Wooden strips
Timber frame
Mineral wool insulation
Vapour barrier
Wooden strips
Gypsum plasterboard
Filler and paint

B. WINDOWS AND DOORS

CONSTRUCTION:
Window, triple-layer
(glulam + aluminium + plastic)

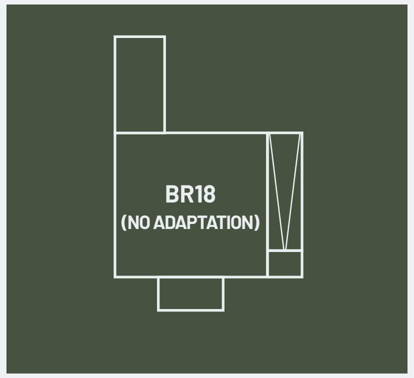
Glass door, exterior, triple-layer
(glulam + aluminium + plastic)

RATIO:
0,16 m² window/m² reference area

R05: Skråningen I

Developer: Eco Village + Casa
Architect: Vandkunsten
Engineer: Scandi Byg
Contractor: Scandi Byg

Year (built): 2019
Floor area: 4788 m^2
Reference area: 4788 m^2
Use: Residential
Occupants: 216
Year (calculated): 2022
Heating: Heat pump
Solar cells: Yes



DESCRIPTION

Skråningen is a cohousing scheme based on the vision of construction that respects the environment. It is a focal point, therefore, that construction principles and choice of materials along with design and combination of housing units fulfil this vision. The first phase, Skråningen I, was constructed in 2019. The second phase, Skråningen II, is also part of the case collection.

The two-storey buildings are built on continuous foundations of lightweight aggregate blocks over concrete footings cast in situ. Under the grade deck, a layer of EPS insulation, and the grade deck consists of a supporting timber frame with cellulose insulation covered with cement particle board.

The housing is constructed in cassette modules. Exterior walls are insulated with mineral wool and cellulose, and the facades are timber-clad. Storey partitions and partitions between housing units are constructed with supporting timber framing and insulated with cellulose. They are constructed with cavities and cement-bonded particle board. Gypsum sheets are used for walls and ceilings, and the surfaces are smoothed over with filler and painted. Impregnated gypsum boards are mounted to the vertical partitions between housing units.

The roof structure consists of a supporting timber frame with a vented cavity space and cellulose insulation. Bituminous felt roofing.

Skråningen I totals 4788 m^2 with room for 216 occupants, which gives a space allocation of approx. 22 m^2/person. This is on the low side in the case collection.

Cassette

2 storeys

R05: Skråningen I

4,62 kg CO_2eq./m^2/year

Figure R05.1: Emissions of kg CO_2eq./m^2/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO_2eq./m^2/year in terraced housing in the case collection.

906.298 kg CO_2eq.

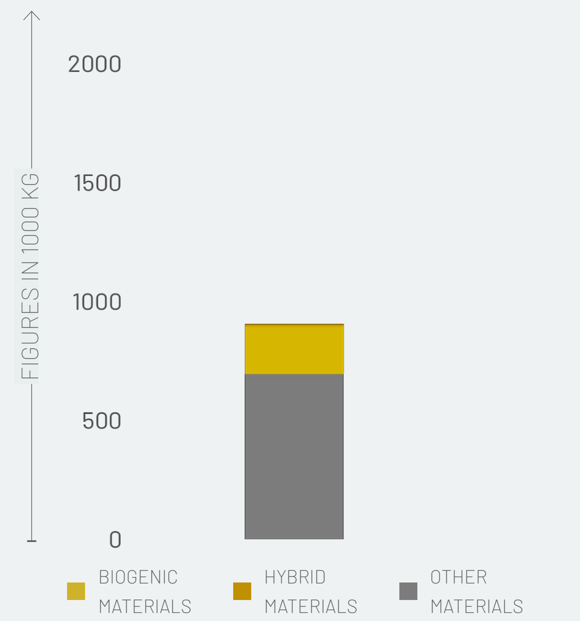


Figure R05.2: Total emission of kg CO_2eq.
The stacked bar chart shows the overall emission of kg CO_2eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

102 kg CO_2eq./person/year

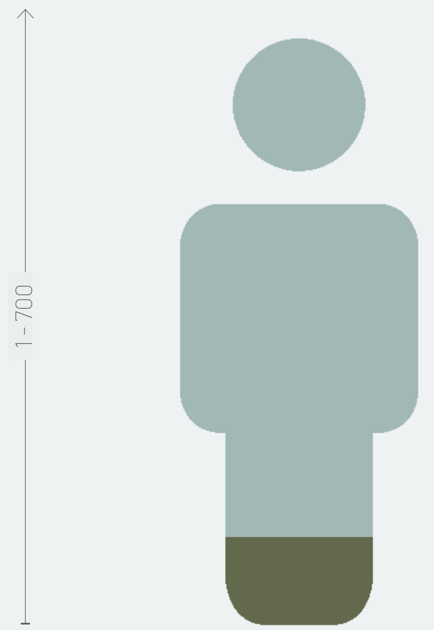


Figure R05.3: Emissions of kg CO_2eq./person/year
The span of the vertical axis is 1 to 700 kg CO_2eq./person/year

22 m^2/person

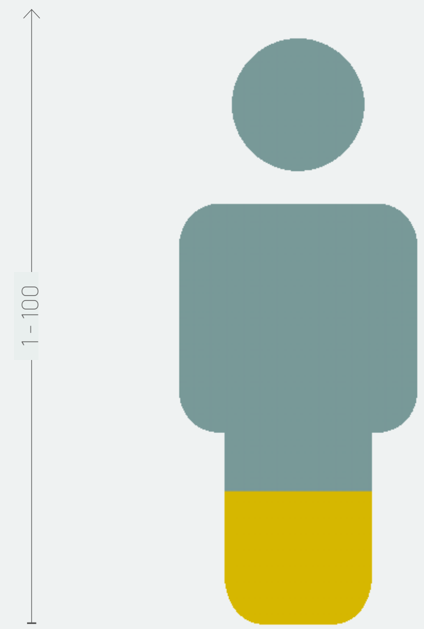
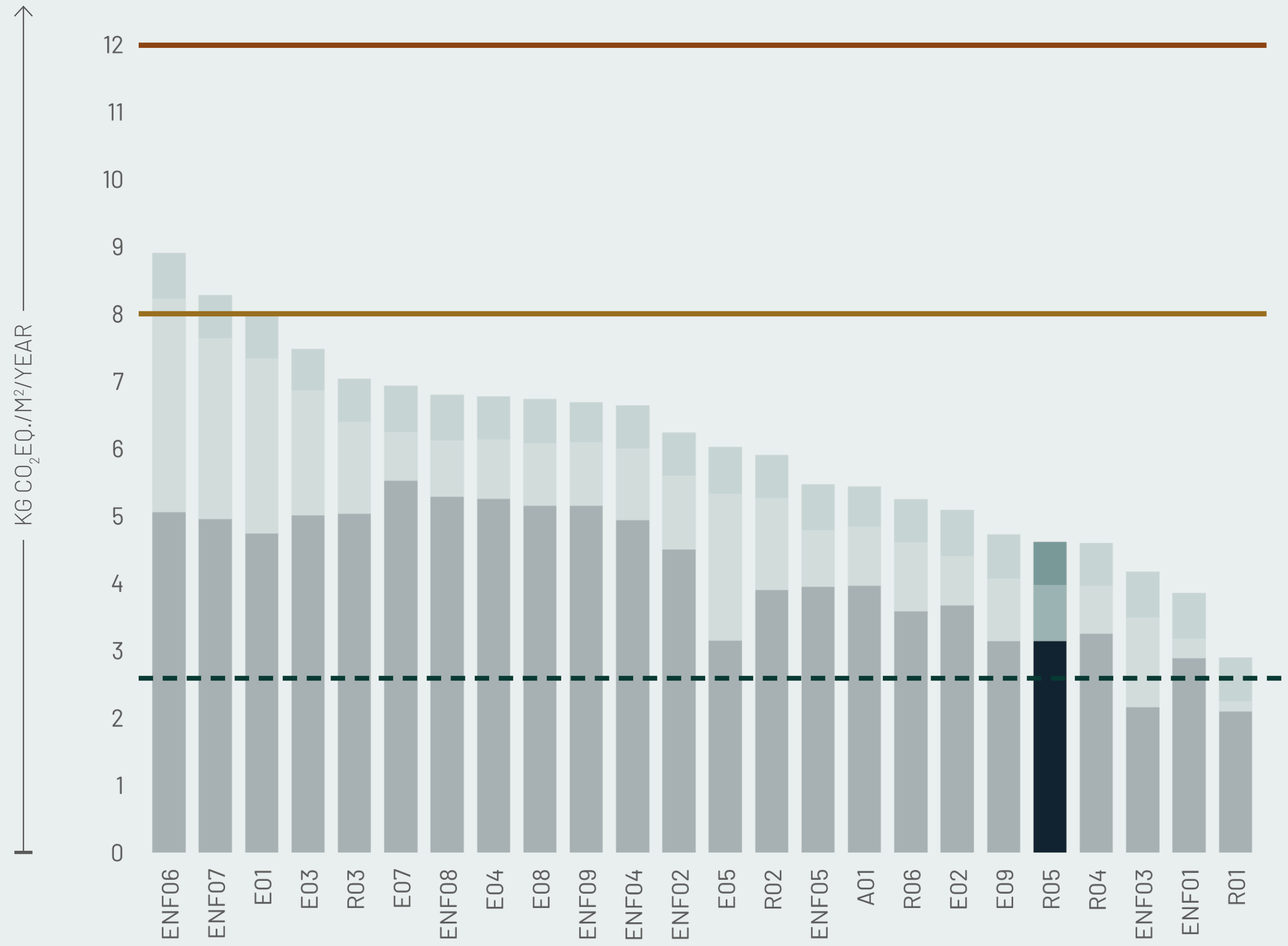


Figure R05.4: m^2/person
The span of the vertical axis is 1 to 100 m^2/person

R05: Skråningen I

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m²/year.



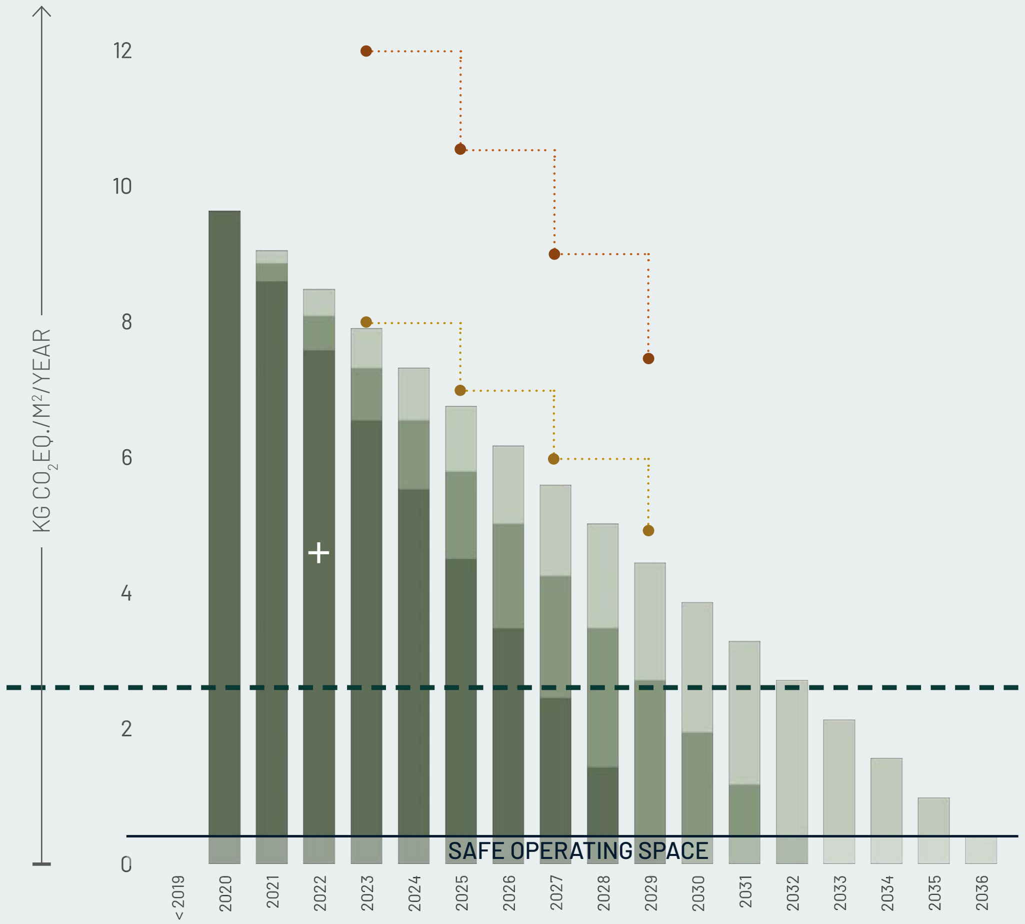
TECHNICAL INSTALLATIONS (STANDARD VALUES)
OPERATIONAL ENERGY USE (B6)
MATERIALS (A1-3, B4, C3-4)
4 > 1 PLANET TARGET
BR 2023 LIMIT VALUE
LOW-EMISSION-CLASS LIMIT VALUE

Figure R05.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m²/year. The horizontal axis shows the 24 best practice cases.

R05: Skråningen I

ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

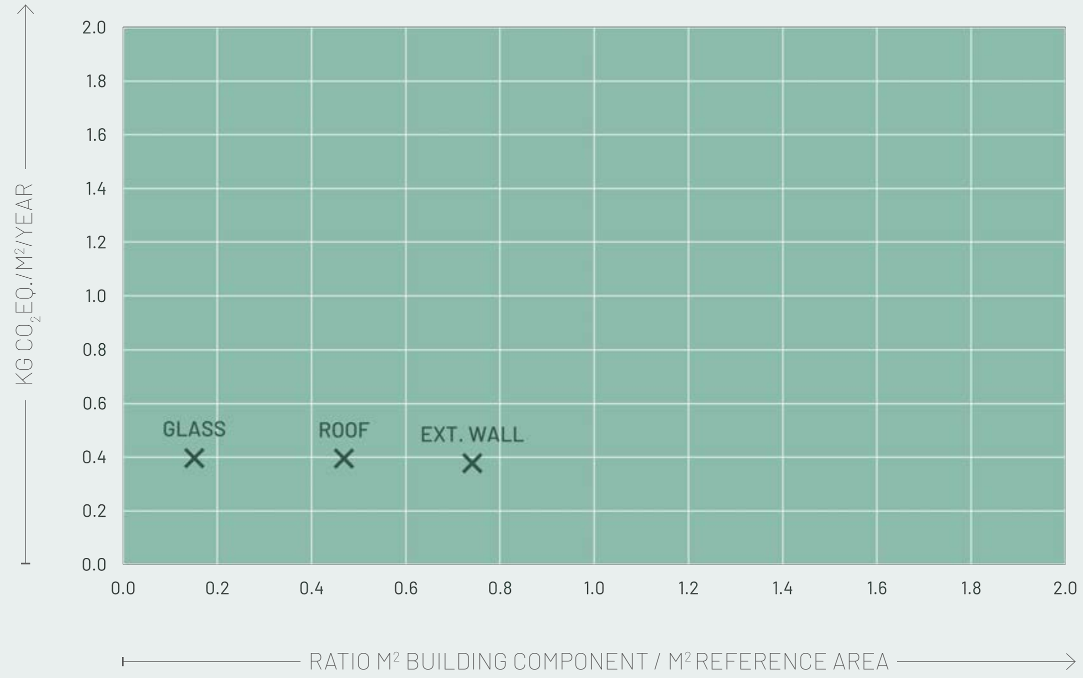
Environmental impact is shown in CO_2eq./m²/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is well within the fastest reduction rate: the 83% likelihood scenario.



83 % LIKELIHOOD SCENARIO
67 % LIKELIHOOD SCENARIO
50 % LIKELIHOOD SCENARIO
4 > 1 PLANET TARGET
BR 2023 LIMIT VALUE
LOW-EMISSION-CLASS LIMIT VALUE

Figure R05.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq./m²/year, and the 'safe operating space'.

RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS



ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

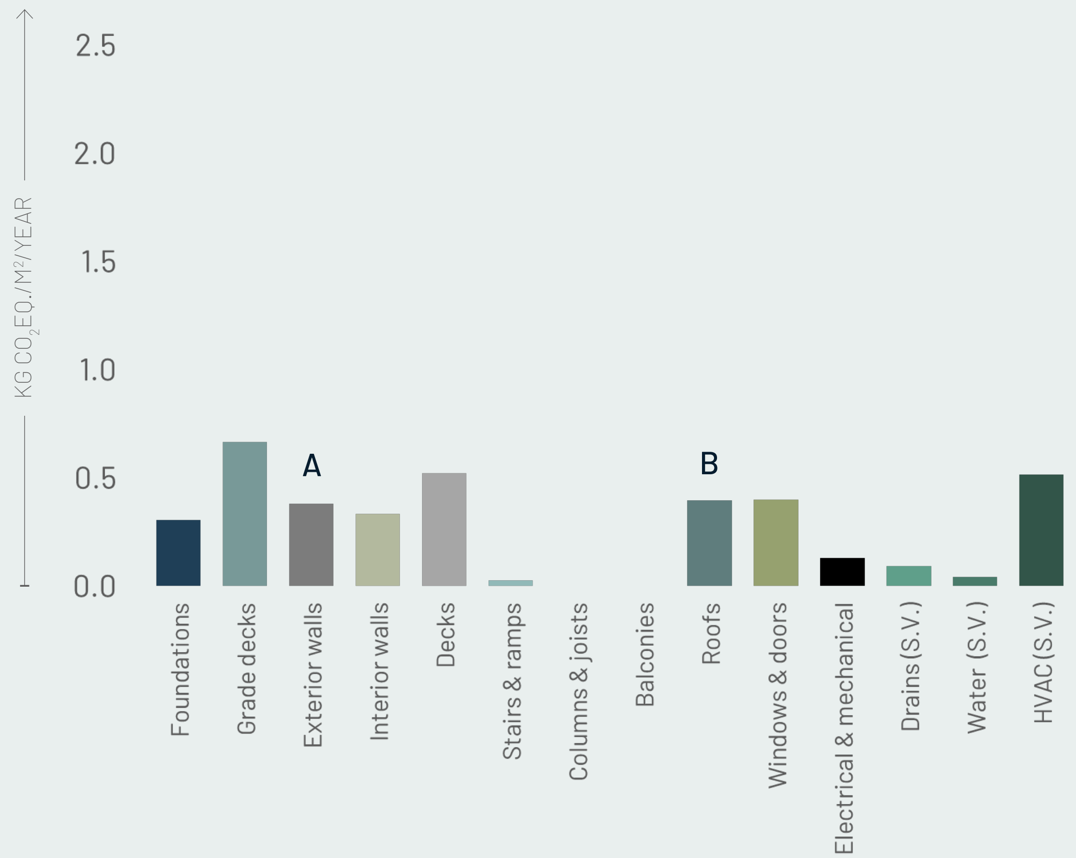


Figure R05.7: CO_2 accounting for building components
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades, electrical and mechanical systems, and technical installations (standard values).

R05: Skråningen I

SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

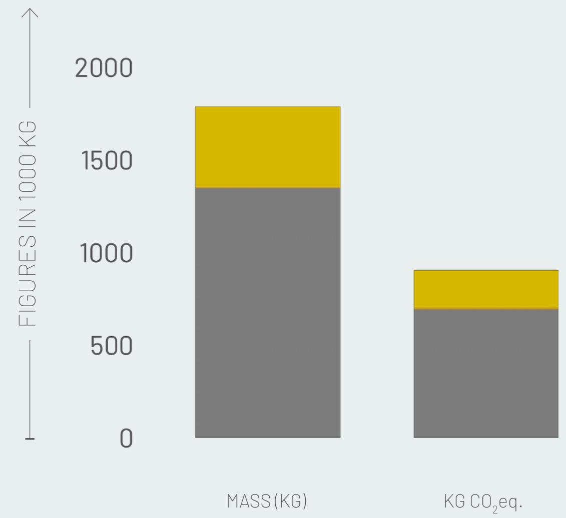
Figure R05.8:
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

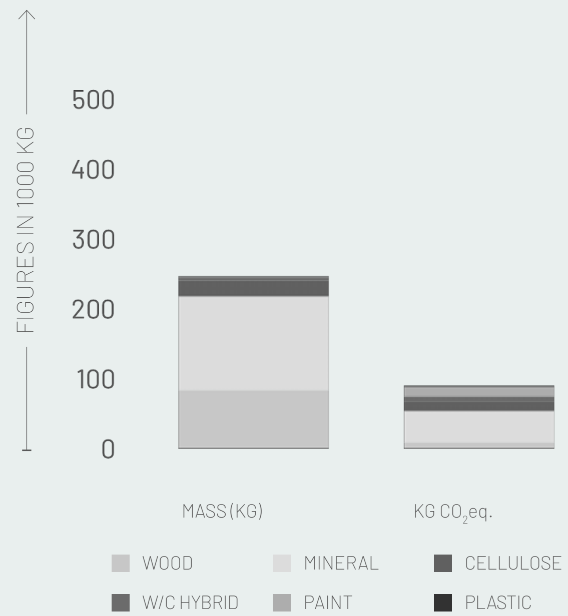
The bar on the left shows the building mass in kg grouped into material categories.

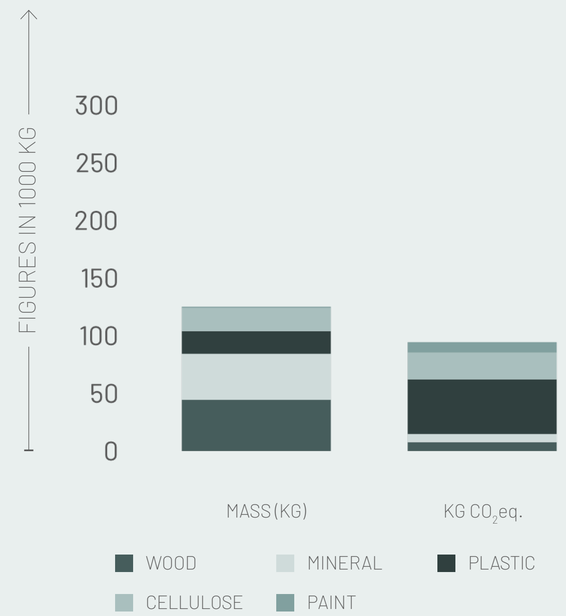
The bar on the right shows the building's total CO_2eq grouped similarly.

BIOGENIC MATERIALS
HYBRID MATERIALS
OTHER MATERIALS



MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG CO_2EQ.





A. EXTERIOR WALL

Wooden cladding
Wooden strips
Cement-bonded particle board
Fibre cement
Timber frame
Cellulose insulation
Vapour barrier
Wooden strips
Mineral wool insulation
Gypsum plasterboard

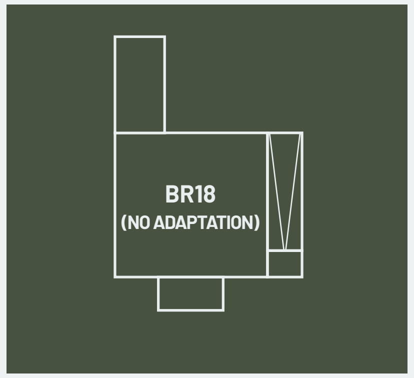
B. ROOF

Bituminous felt roofing
Bituminous felt underlay
Plywood
Wooden strips
Wind barrier
Timber frame
Cellulose insulation
Vapour barrier
Plywood
Gypsum plasterboard

R06: Skråningen II

Developer: Eco Village + Casa
Architect: Vandkunsten
Engineer: Scandi Byg
Contractor: Scandi Byg

Year (built): 2021
Floor area: 4788 m^2
Reference area: 4788 m^2
Use: Residential
Occupants: 216
Year (calculated): 2022
Heating: Heat pump
Solar cells: Yes



DESCRIPTION

Skråningen is a cohousing scheme based on the vision of construction that respects the environment. It is a focal point, therefore, that construction principles and choice of materials along with design and combination of housing units fulfil this vision. The second phase is Skråningen II which was constructed in 2021 .

Since the construction principles are very similar to those in phase I (see Skråningen I), this description will focus on the special initiatives perhaps not best illustrated by showing kg CO_2 /m^2/year emission results. Many of the details used in the project will, for example, impact on results for the project's emission of kg CO_2eq/person/year.

In this cohousing scheme, 12% of the built area is communal, which keeps the living area/person low in both Skråningen I and II. The housing comprises one basic module and various extra modules, addressing different and varying needs of space in the house, while many of the space-intensive areas are placed outside the private housing units. For example, a large communal house and several smaller facilities placed close to the housing units. The smaller communal facilities could house a music room, teenage rooms, guest rooms, or workshops and tool rooms in conjunction with the large outdoor spaces.

The shallow depth of the housing units of 7.5 m means that there is much natural light, although the units do not have a high ratio of window and floor space compared to many other housing projects in the case collection.

Skråningen II totals 5071 m^2 with room for 222 occupants, which gives a space allocation of approx. 23 m^2/person. This is on the low side in the case collection.

Cassette

2 storeys

R06: Skråningen II

5,25 kg CO_2eq./m^2/year

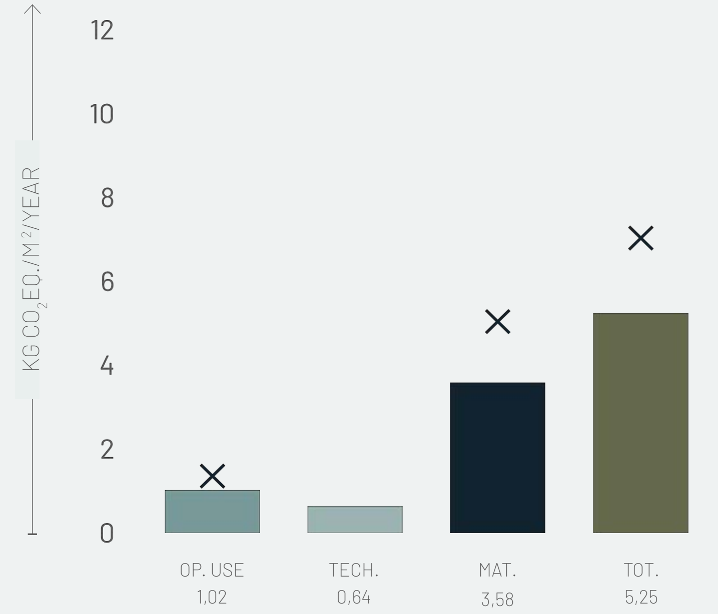


Figure R06.1: Emissions of kg CO_2eq./m^2/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO_2eq./m^2/year in terraced housing in the case collection.

1.071.358 kg CO_2eq.

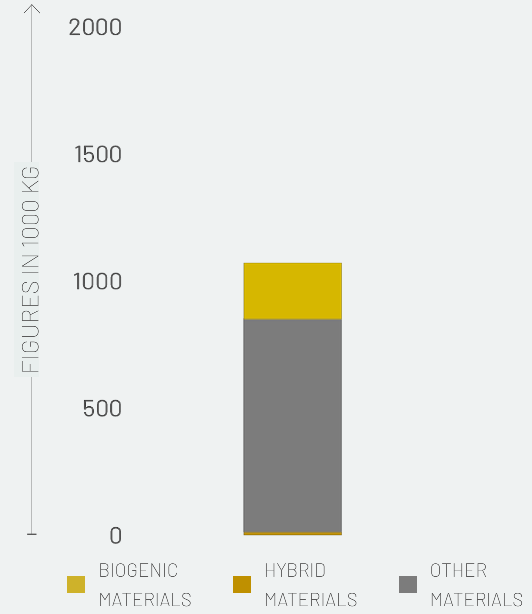


Figure R06.2: Total emission of kg CO_2eq.
The stacked bar chart shows the overall emission of kg CO_2eq. in the case study grouped into the three material categories: other, hybrids, and biogenic.

120 kg CO_2eq./person/year

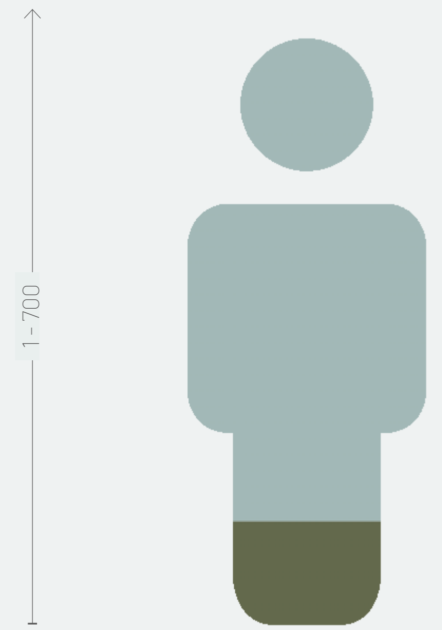


Figure R06.3: Emissions of kg CO_2eq./person/year
The span of the vertical axis is 1 to 700 kg CO_2eq./person/year

23 m^2/person

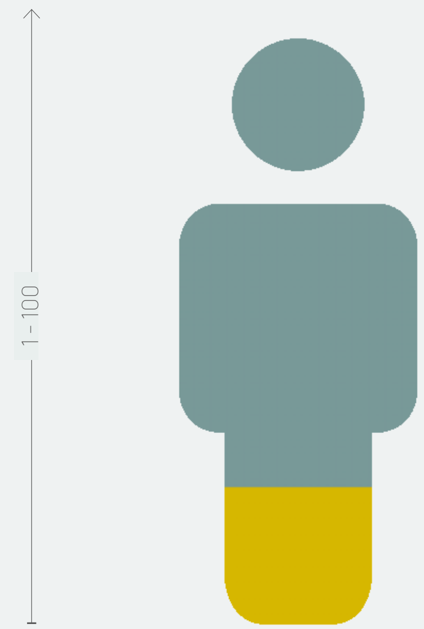


Figure R06.4: m^2/person
The span of the vertical axis is 1 to 100 m^2/person

R06: Skråningen II

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m²/year.

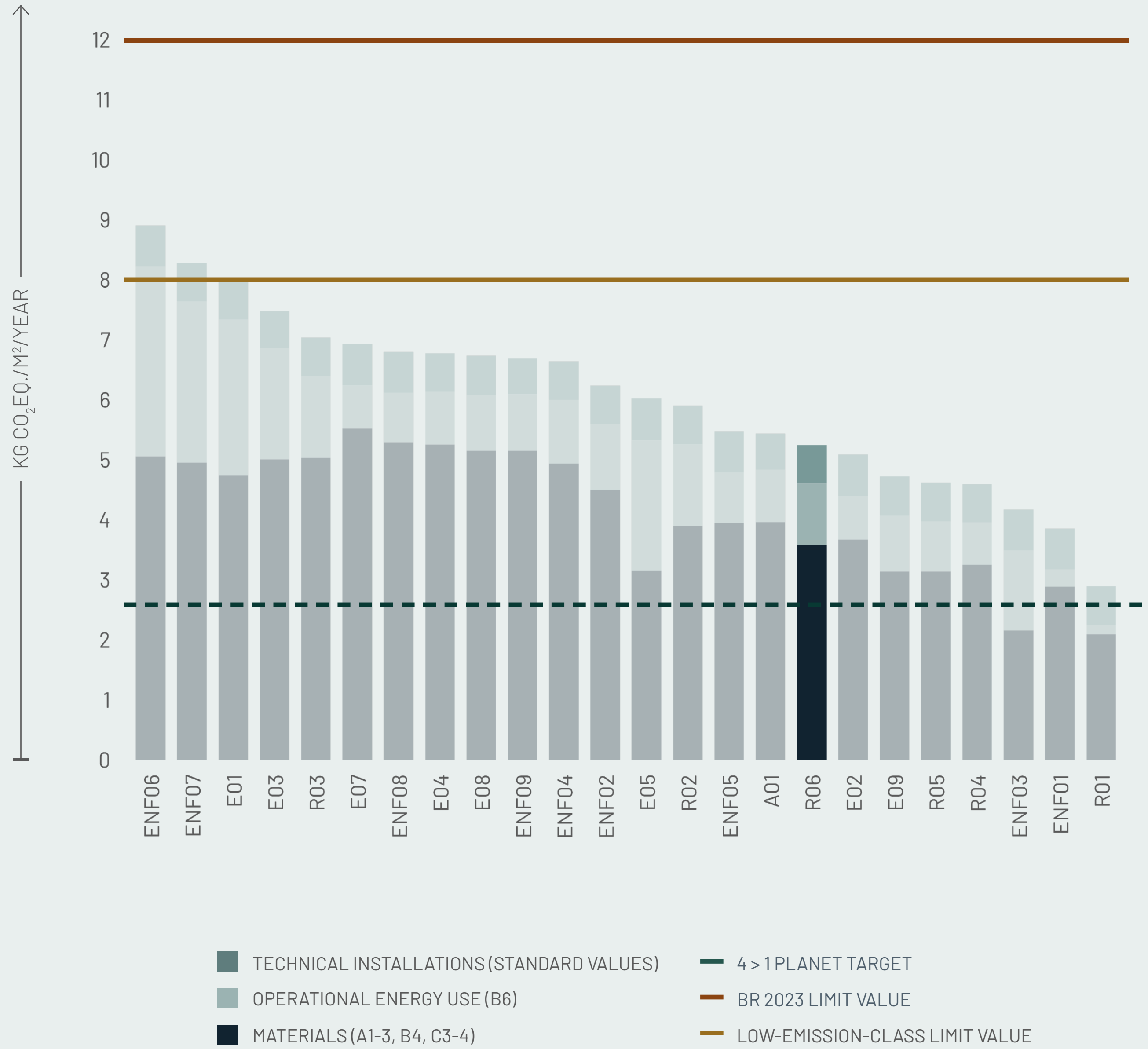


Figure R06.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m²/year. The horizontal axis shows the 24 best practice cases.

R06: Skråningen II

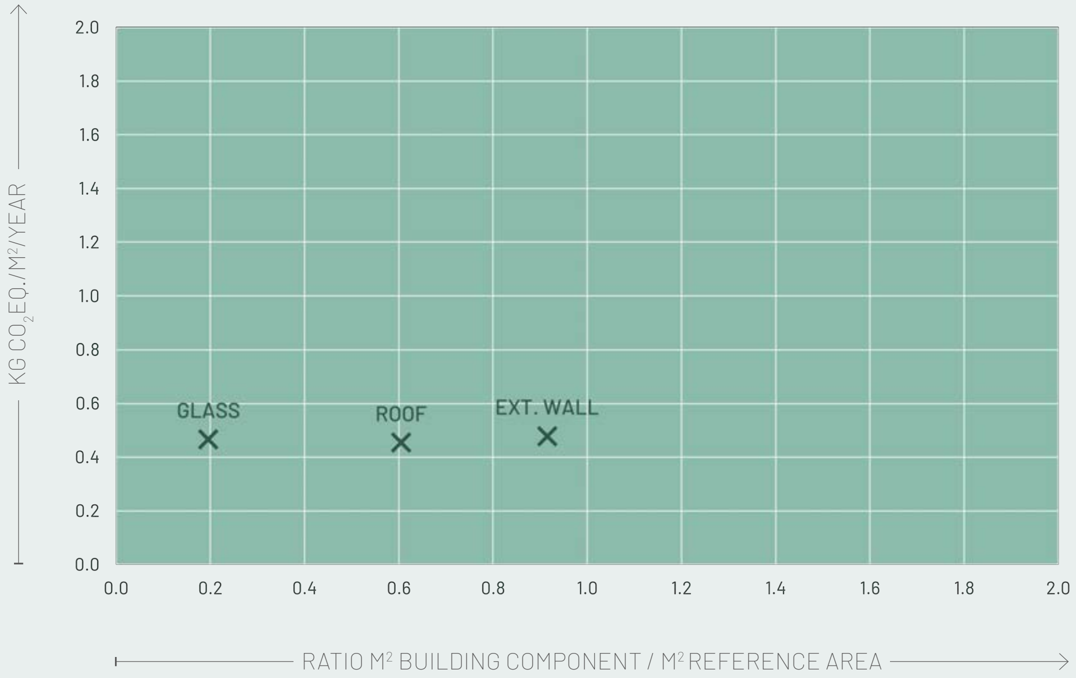
ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in CO_2eq./m²/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is well within the fastest reduction rate: the 83% likelihood scenario.

Figure R06.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq./m²/year, and the 'safe operating space'.

R06: Skråningen II

RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS



ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

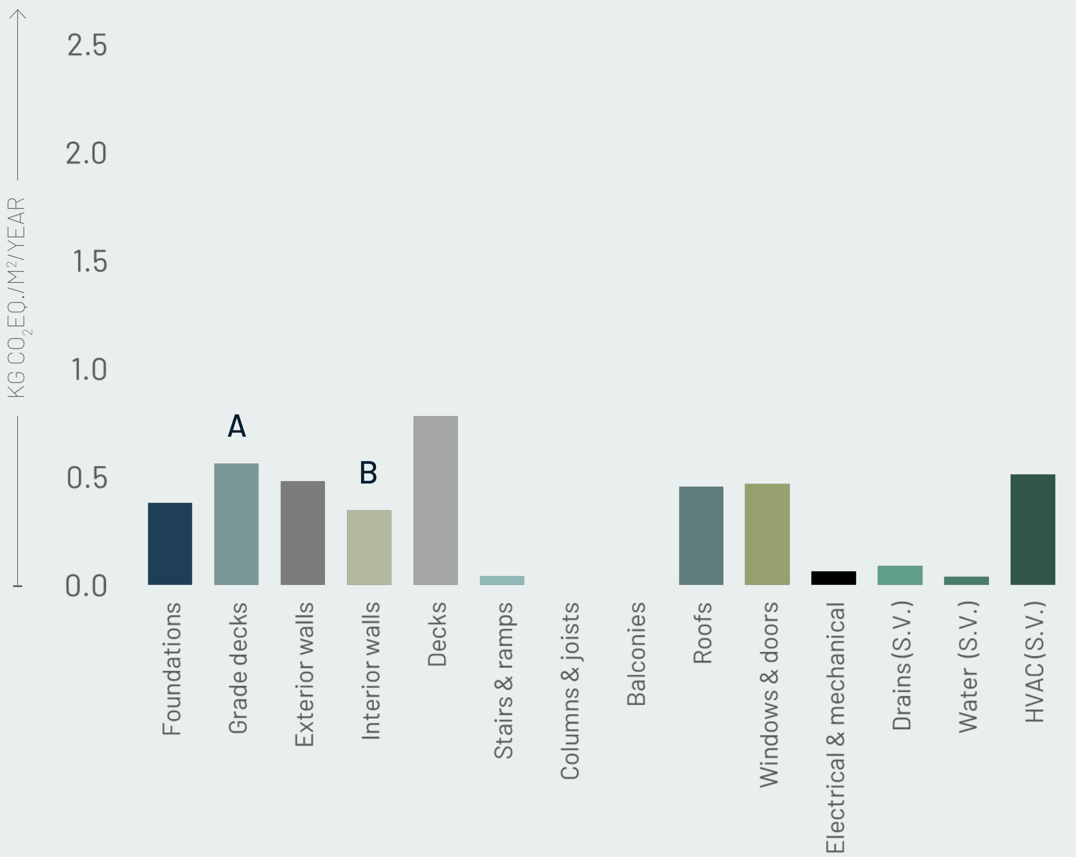


Figure R06.7: CO_2 accounting for building components
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades, electrical and mechanical systems, and technical installations (standard values).

R06: Skråningen II

SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

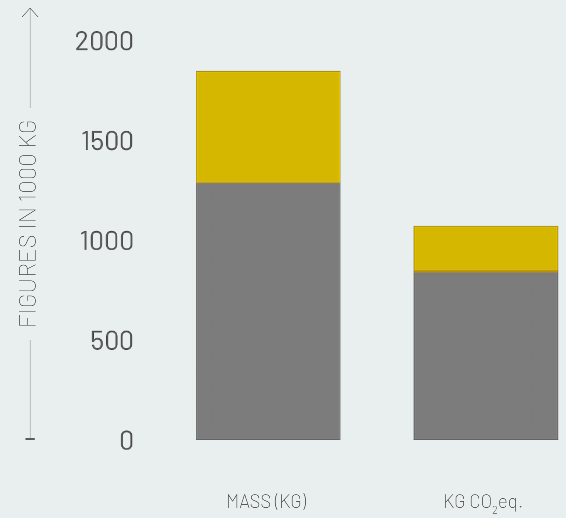
Figure R06.8:
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

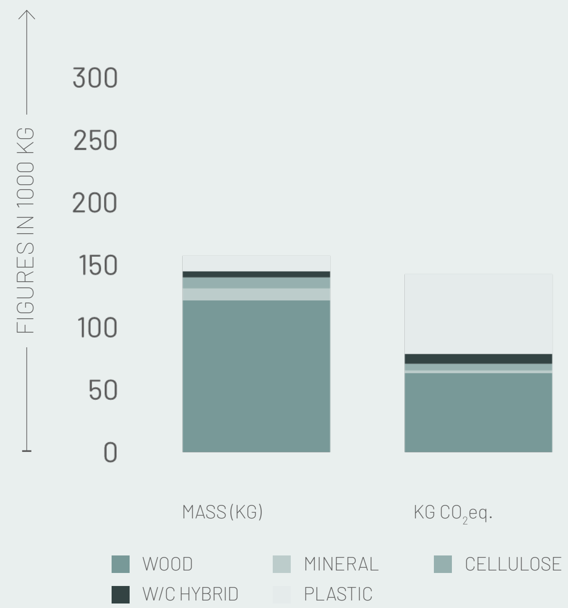
The bar on the left shows the building mass in kg grouped into material categories.

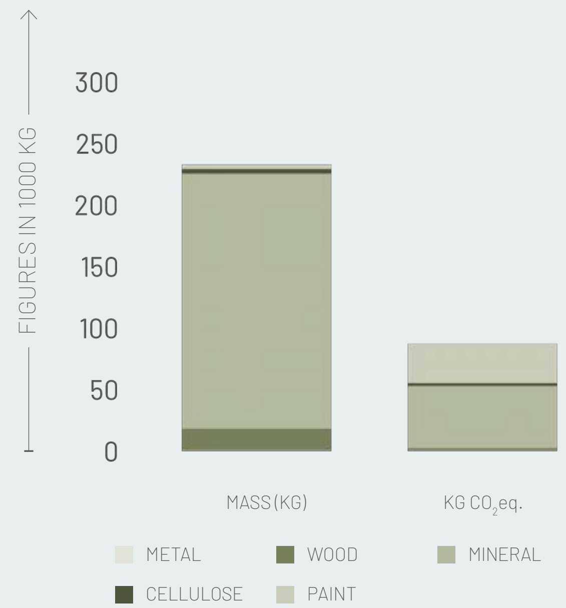
The bar on the right shows the building's total CO_2eq grouped similarly.

BIOGENIC MATERIALS
HYBRID MATERIALS
OTHER MATERIALS



MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG CO_2EQ.





A. GRADE DECK

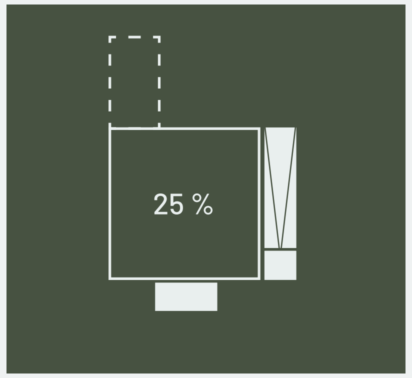
Particle board (reuse)
Cement-bonded particle board
Vapour barrier
Timber frame
Loose-fill cellulose insulation
EPS insulation

B. INTERIOR WALL

Mass timber
Loose-fill cellulose insulation
and/or
Mineral wool
Gypsum plasterboard
Paint

E01: MiniCO2 High-rise TIMBER

Developer:	Realdania By & Byg
Architect:	JAJA Architects + ONV Arkitekter
Engineer:	Artelia
Contractor:	Egil Rasmussen + Bluhmer Lehmann
Year (built):	2023
Floor area:	565 m²
Reference area:	579 m²
Use:	Residential
Occupants:	18
Year (calculated):	2022
Heating:	District heating
Solar cells:	Yes



DESCRIPTION

MiniCO₂ High-rise TIMBER is a pilot project under the auspices of Realdania By og Byg, which funds several projects, each using a different primary material. The purpose of MiniCO₂ is to use timber as the primary construction material to facilitate comparison with similar buildings constructed in concrete and brick. for example. The pilot projects are subject to requirements to enable comparisons to be made in relation to CO_2 footprints and strength. This pilot project will function as housing and comprises one housing unit per storey. The project is under construction, which may result in changes that will affect results in the report.

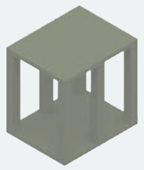
The five-storey building is built on pile footings and a reinforced concrete foundation plate. Concrete grade deck with EPS insulation.

Supporting structures in CLT, glulam, and steel. Mineral wool and wood-fibre insulation. The lightweight exterior walls are timber-frame constructions with wood-fibre insulation. The facade cladding is cedar wood and the interior surfaces are covered with fibre gypsum boards. The lightweight interior walls are timber-frame constructions with fibre gypsum boards and mineral wool insulation.

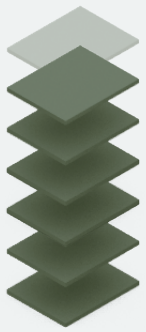
Ribbed storey decks with CLT and glulam with cellulose insulation. A special focal point has been to meet acoustic requirements in storey partitions, which can be a challenge when not using concrete.

The roof is a timber-beam and rafter structure with mineral wool insulation, OSB and fibre gypsum sheeting with a steel-sheet roof covering. Triple-glazing windows with wooden window and head frames. Roof-light frames are in wood and aluminium.

The multi-storey housing totals 565 m² with room for 18 occupants, which gives a space allocation of approx. 31 m²/person. This is average for the case collection.



Hybrid



5 storeys

E01: MiniCO2 Etagehus TRÆ

8,01 kg CO_2eq./m²/year

Figure E01.1: Emissions of kg CO_2eq./m²/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO_2eq./m²/year in multi-storey housing in the case collection.

156.713 kg CO_2eq.

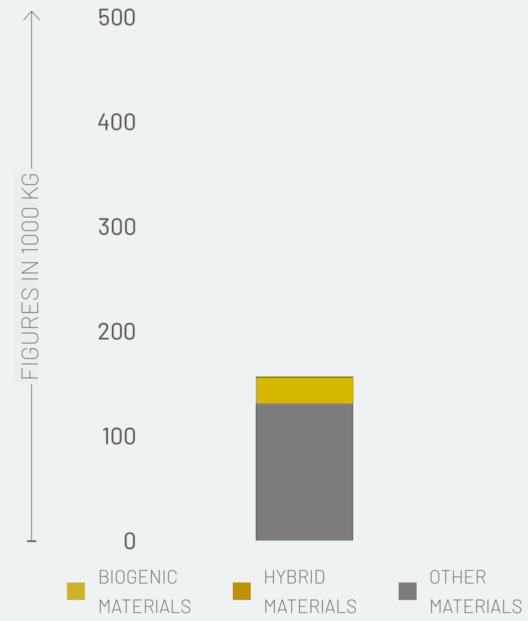


Figure E01.2: Total emission of kg CO_2eq.
The stacked bar chart shows the overall emission of kg CO_2eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

258 kg CO_2eq./person/year

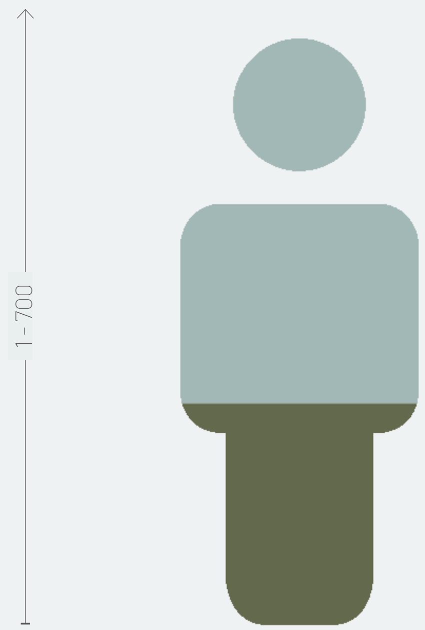


Figure R01.3: Emissions of kg CO_2eq./person/year
The span of the vertical axis is 1 to 700 kg CO_2eq./person/year

31 m²/person

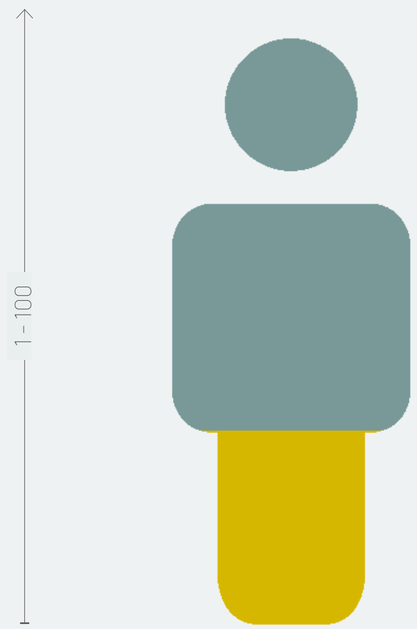


Figure R01.4: m²/person
The span of the vertical axis is 1 to 100 m²/person

E01: MiniCO2 Etagehus TRÆ

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m²/year.

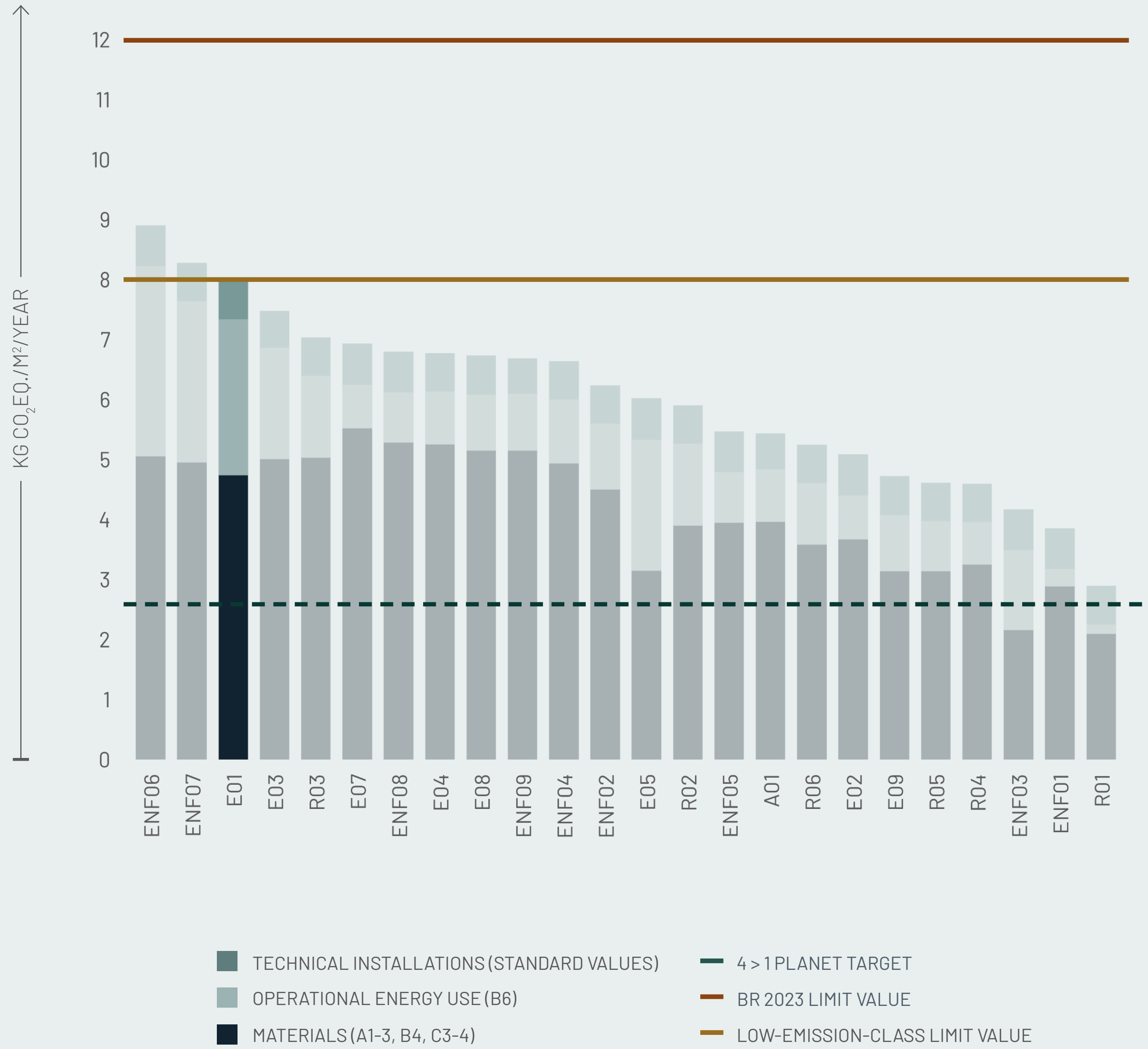


Figure E01.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m²/year. The horizontal axis shows the 24 best practice cases.

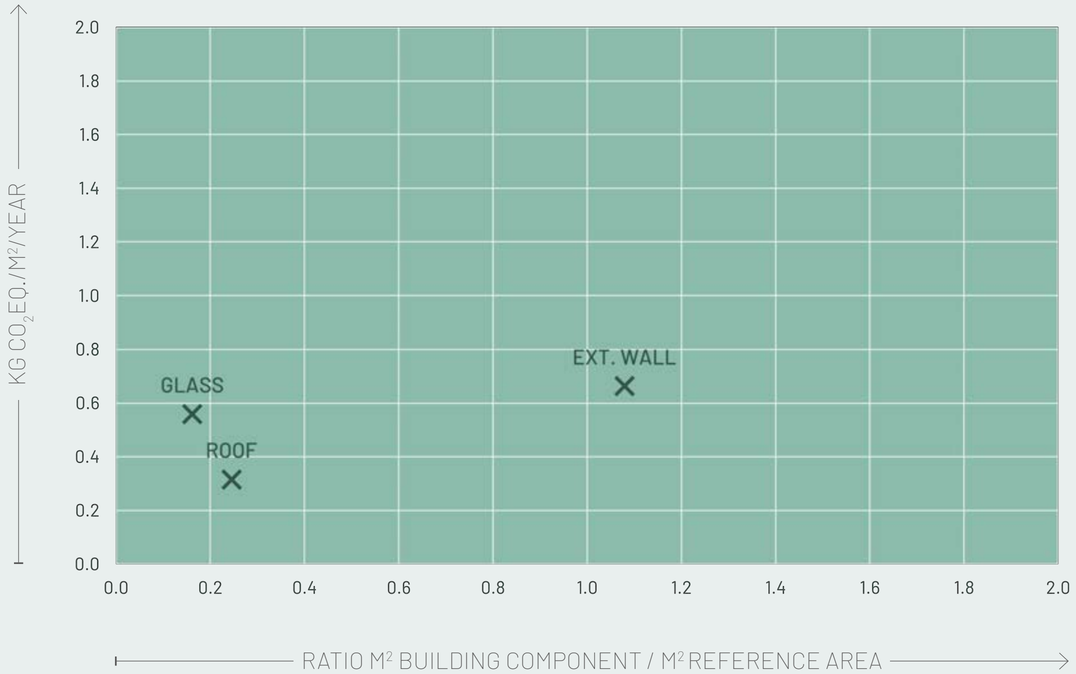
E01: MiniCO2 Etagehus TRÆ

ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in CO_2eq./m²/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is within the second fastest reduction rate: the 67% likelihood scenario.

Figure E01.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq./m²/year, and the 'safe operating space'.

RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS



ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

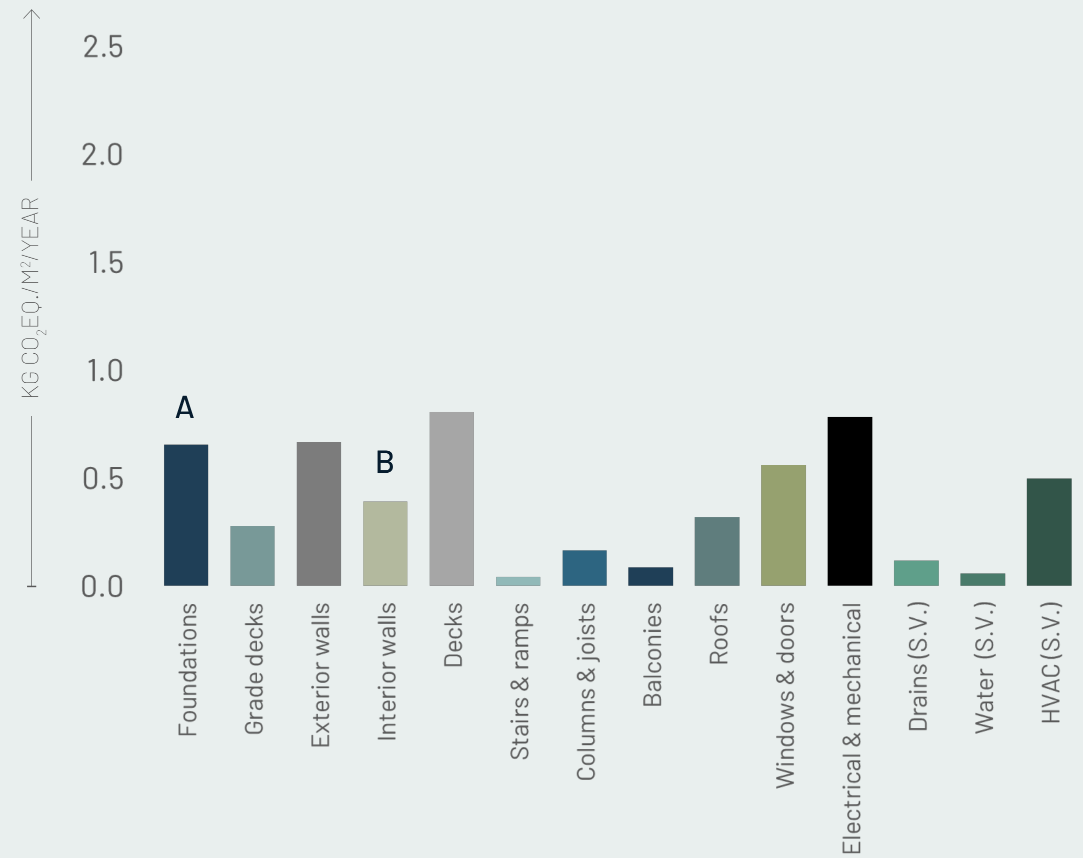


Figure E01.7: CO_2 accounting for building components
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades, electrical and mechanical systems, and technical installations (standard values).

E01: MiniCO2 Etagehus TRÆ

SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

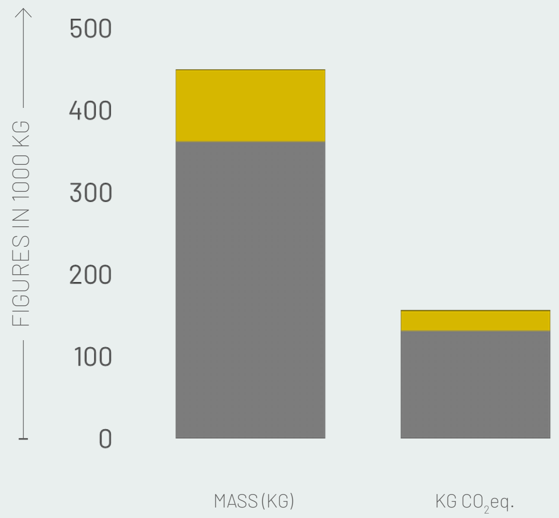
Figure E01.8:
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

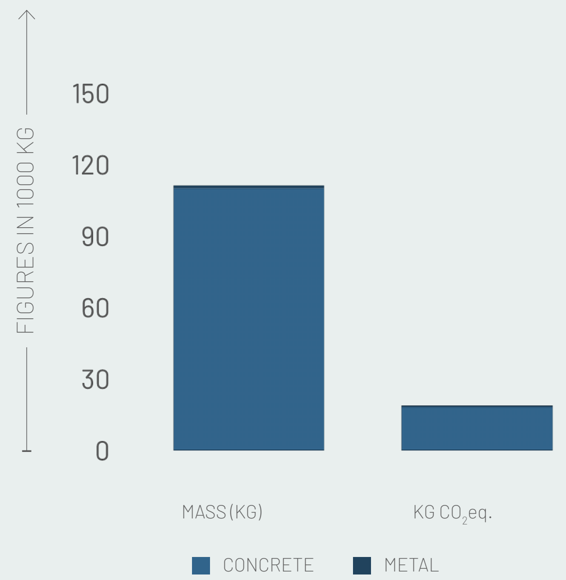
The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total CO_2eq grouped similarly.

BIOGENIC MATERIALS — HYBRID MATERIALS — OTHER MATERIALS



MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG CO_2EQ.



A. FOUNDATION

Reinforced concrete pile footings
Continuous concrete foundations

B. INTERIOR WALLS

Interior wall types:

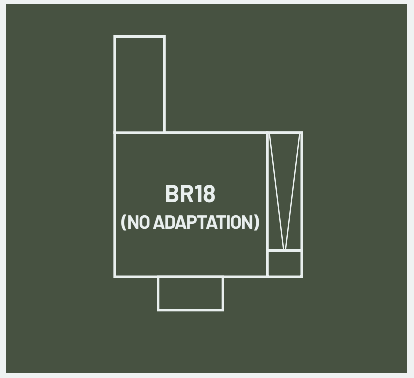
CLT interior wall
Timber frame with glass wool insulation

Surface:

Fibre gypsum boards Paint

E02: Tankefuld II

Developer:	FAB - Fyns Almennyttige Boligselskab
Architect:	C & W Arkitekter
Engineer:	Rambøll
Contractor:	G.K. Kaysen
Year (built):	2020
Floor area:	2853 m²
Reference area:	2853 m²
Use:	Residential
Occupants:	189
Year (calculated):	2022
Heating:	Heat pump
Solar cells:	No



DESCRIPTION

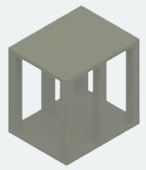
Tankefuld II is the second phase of a housing scheme comprising 44 housing units. The unit types are flexible and vary, based on five different housing types between 41-97 m². Special emphasis has been on developing a new urban area with focus on sustainability.

The housing is built on concrete foundations with lightweight aggregate blocks and EPS. The grade deck is a concrete construction with EPS insulation.

The exterior walls are supporting timber structures with mineral wool insulation and a vented cavity space. On the outside, fibre-cement boards or timber cladding. Interior surfaces are covered with gypsum boards and painted. Housing unit partitions are insulated vertically and horizontally with mineral wool, providing fire stops and sound insulation. Interior walls and ceilings are clad with fire-rated gypsum boards.

Timber lattice-truss roof structure with overhang. The soffit is covered with fibre-cement boards and the roof is a sedum roof (green roof) with bituminous felt and plywood covering the timber structure.

The multi-storey housing totals 2853 m² with room for 128 occupants, which gives a space allocation of approx. 22 m²/person. This is on the low side in the case collection.



Hybrid

2 storeys

E02: Tankefuld II

5,09 kg CO_2eq./m²/year

Figure E02.1: Emissions of kg CO_2eq./m²/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO_2eq./m²/year in multi-storey housing in the case collection.

622.575 kg CO_2eq.

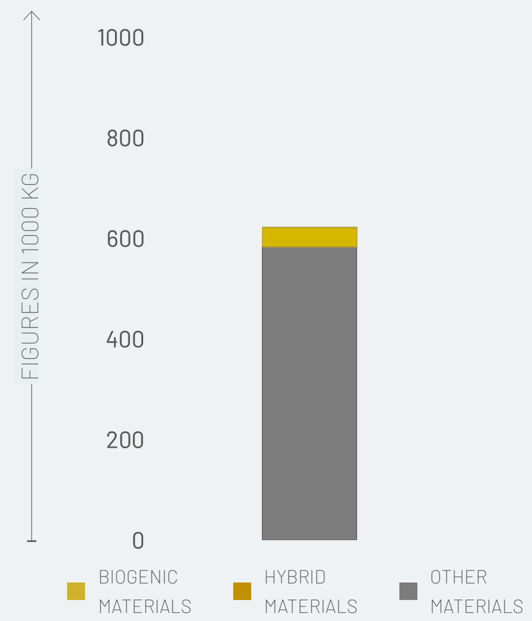


Figure E02.2: Total emission of kg CO_2eq.
The stacked bar chart shows the overall emission of kg CO_2eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

113 kg CO_2eq./person/year

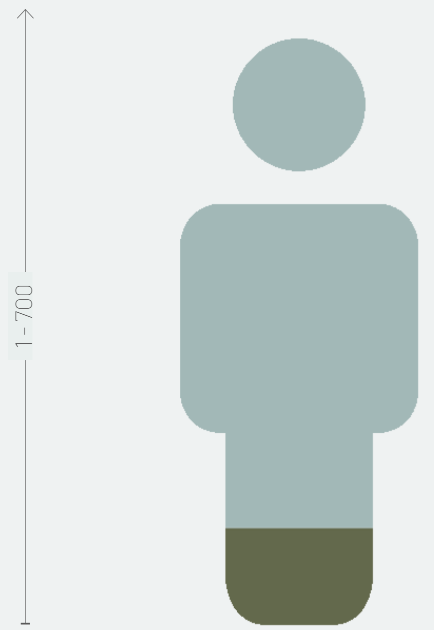


Figure E02.3: Emissions of kg CO_2eq./person/year
The span of the vertical axis is 1 to 700 kg CO_2eq./person/year

22 m² / person

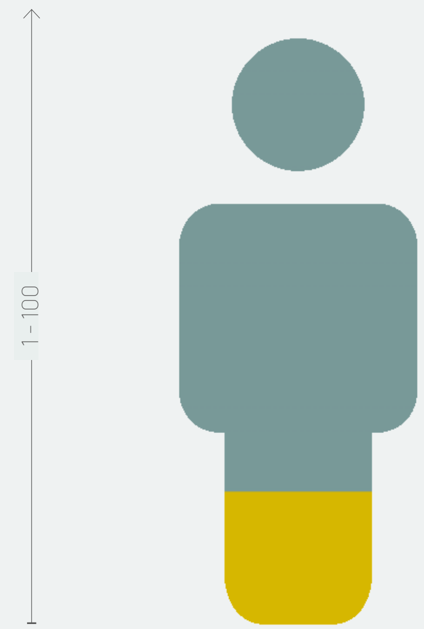


Figure E02.4: m²/person
The span of the vertical axis is 1 to 100 m²/person

E02: Tankefuld II

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m^2/year.

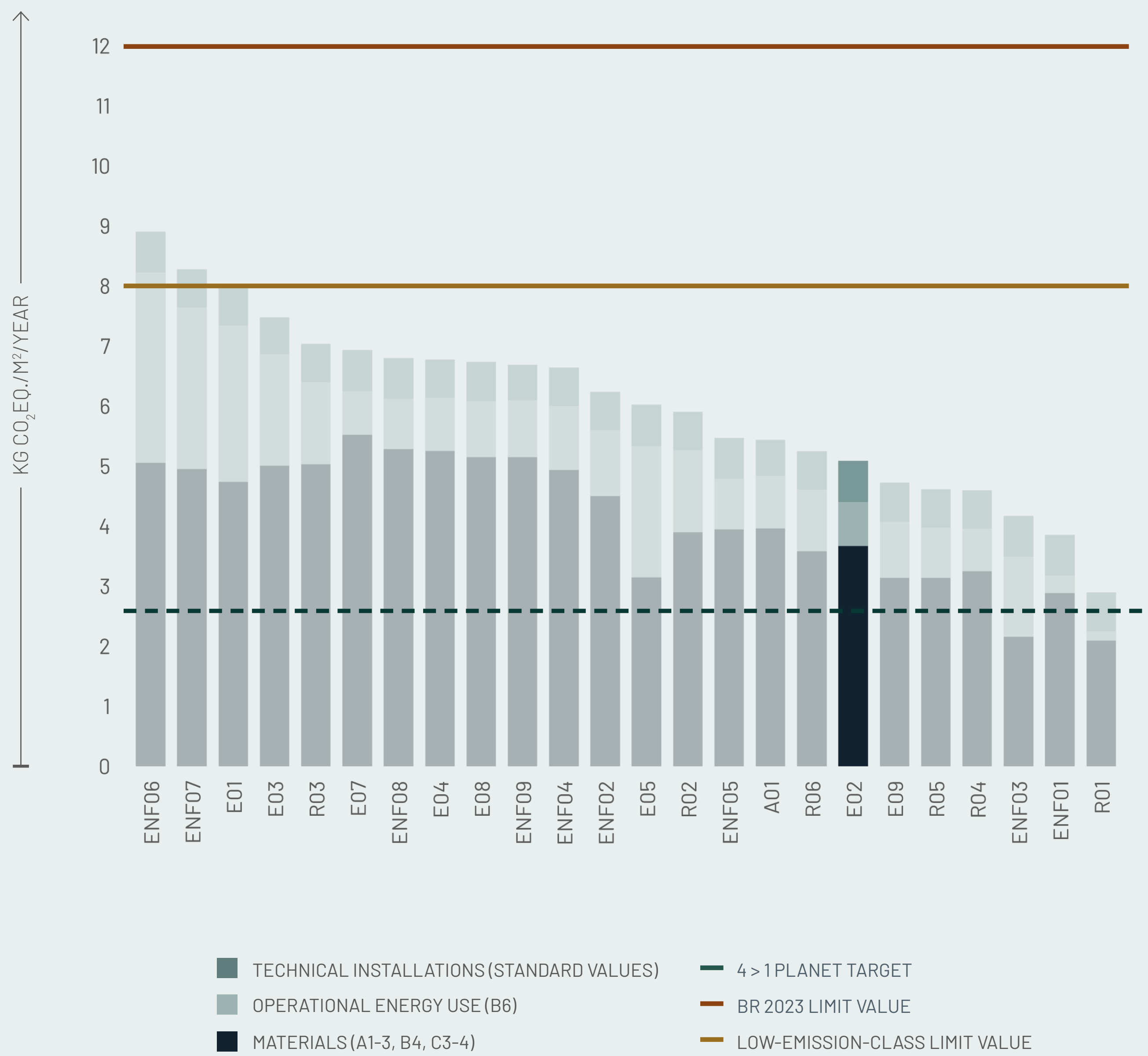


Figure E02.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m^2/year. The horizontal axis shows the 24 best practice cases.

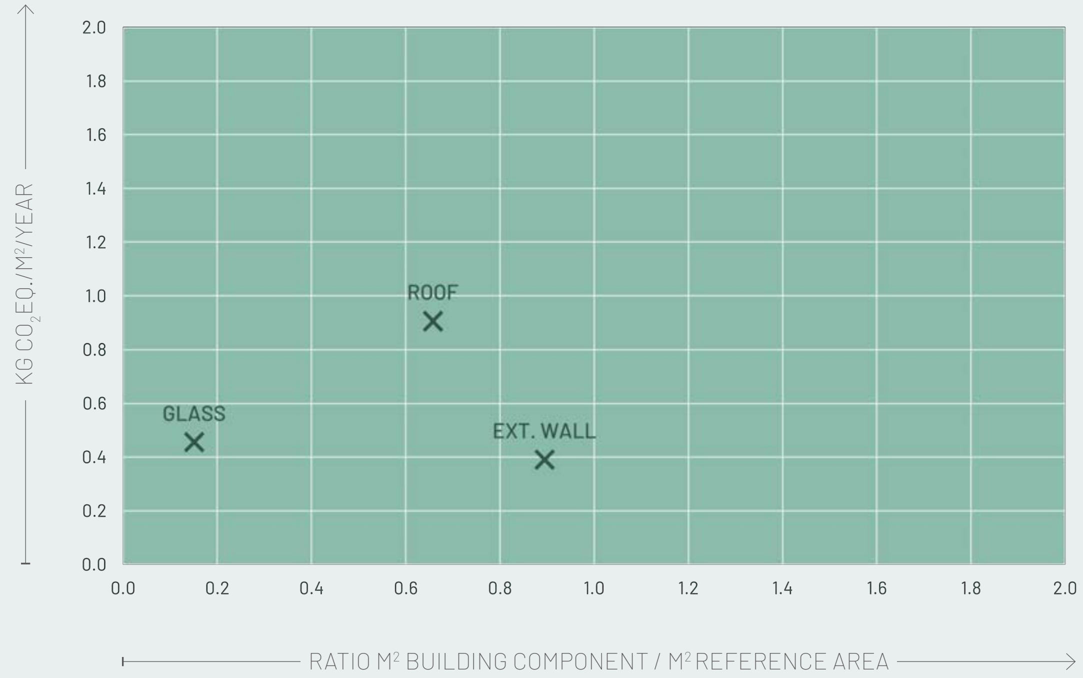
E02: Tankefuld II

ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in CO_2eq./m^2/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is well within the fastest reduction rate: the 83% likelihood scenario.

Figure E02.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq./m^2/year, and the 'safe operating space'.

RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS



ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

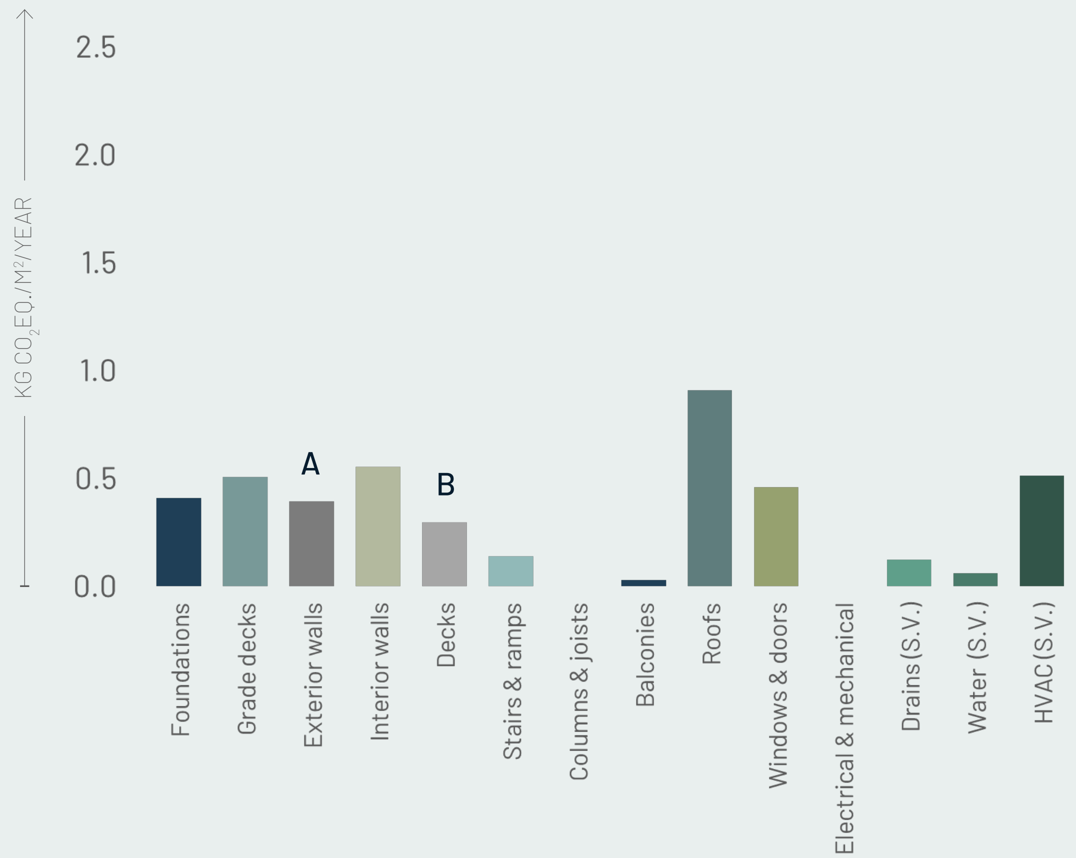


Figure E02.7: CO_2 accounting for building components
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades, electrical and mechanical systems, and technical installations (standard values).

SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

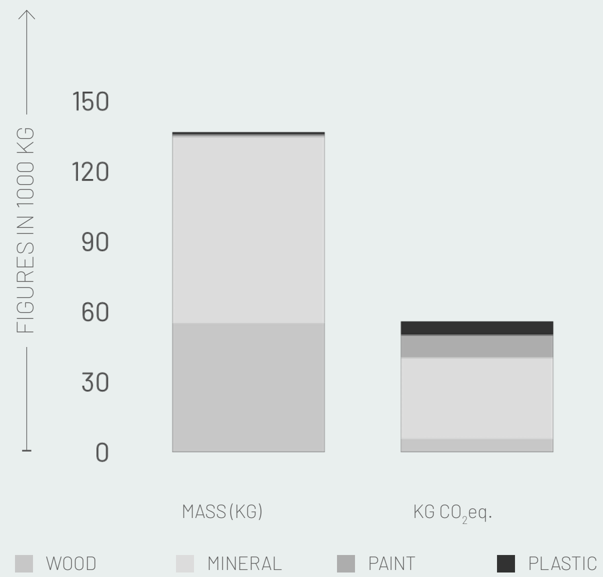
Figure E02.8:
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

The bar on the left shows the building mass in kg grouped into material categories.

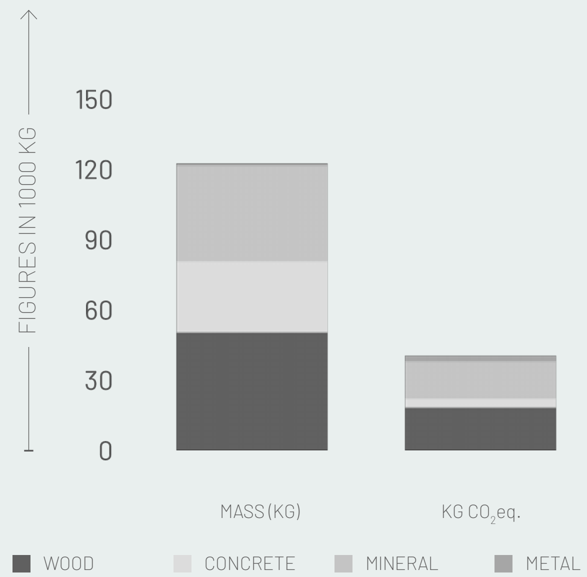
The bar on the right shows the building's total CO_2eq grouped similarly.

MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG CO_2EQ.



A. EXTERIOR WALL

Fibre-cement boards
Wooden strips
Fibre-cement boards
Timber frame
Glass wool insulation
Vapour barrier
Timber frame
Glass wool insulation
Gypsum plasterboard x 2

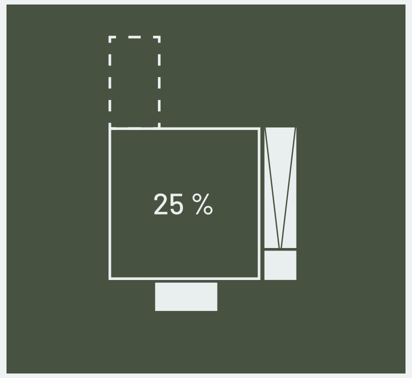


B. DECK

Wooden parquet flooring
Particle board (reuse)
Gypsum plasterboard
Wooden strips
Glass wool insulation
Plywood

E03: Store Solvænget

Developer: Boligforeningen 3B c/o KAB
Architect: ONV arkitekter
JAJA Architechts
Engineer: Scandi Byg
Contractor: Bascon
Year (built): 2020
Floor area: 5919 m²
Reference area: 6647 m²
Use: Residential
Occupants: 189
Year (calculated): 2022
Heating: District heating
Solar cells: Yes



DESCRIPTION

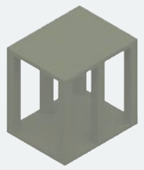
Store Solvænget is a housing scheme and the first of its kind in Denmark to carry the Swan Ecolabel. Swan Ecolabel requirements include the use of certified timber and attempst at avoiding substances that are harmful to health and the environment have been focal points in this construction project. The product stage primarily took place at a factory, which is likely to help reduce the consumption of building materials and resources on the building site.

The three-and-four-storey building is constructed on concrete foundations: wall foundations supporting load-bearing exterior walls, and continuous foundations supporting load-bearing interior walls, insulated with EPS. A gravel bed is established to ensure level-free access. The grade deck is a timber construction with an underlay of fibre-cement boards insulated with mineral wool and EPS.

The house is constructed with supporting structures in timber with wood-fibre insulation. Storey partitions and partitions between housing units are timber-frame structures with cement particle board, mineral wool insulation, and fire-rated gypsum boards. Interior surfaces have gypsum board facings, whereas partition wall facings are fire-rated gypsum boards. Surfaced are smoothed over with filler and painted.

The roof is constructed with a supporting glulam structure, a vented cavity space, and it is insulated with pressure-resistant mineral wool. Interior surface facings are fire-rated gypsum boards and the roofing is bituminous felt.

The multi-storey housing totals 5919 m² with room for 189 occupants, which gives a space allocation of approx. 31 m²/person. This is average for the case collection.



Hybrid

3-4 storeys

E03: Store Solvænget

7,48 kg CO_2eq./m²/year

Figure E03.1: Emissions of kg CO_2eq./m²/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO_2eq./m²/year in multi-storey housing in the case collection.

1.868.212 kg CO_2eq.

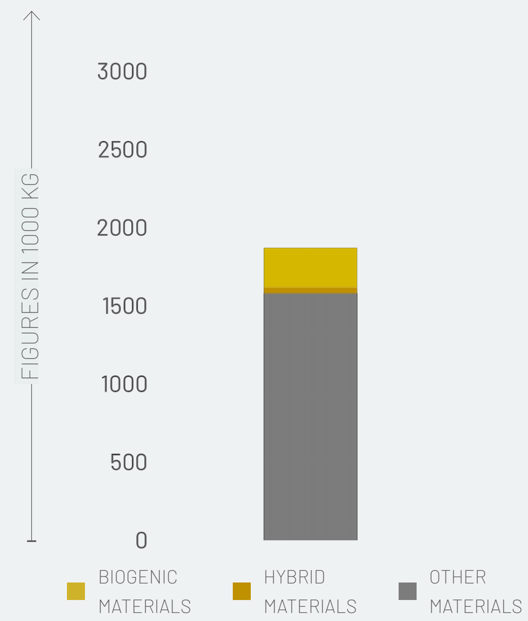


Figure E03.2: Total emission of kg CO_2eq.
The stacked bar chart shows the overall emission of kg CO_2eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

263 kg CO_2eq./person/year

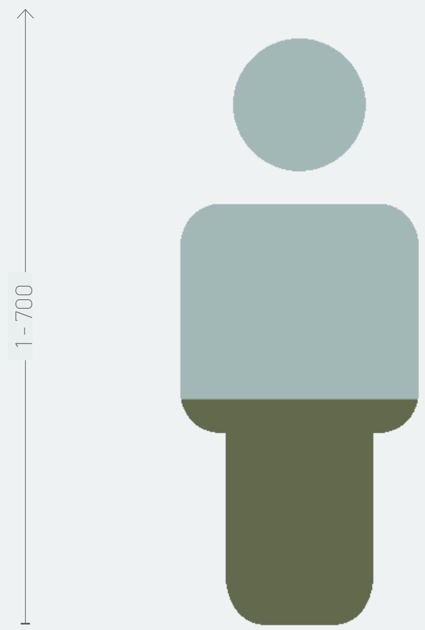


Figure E03.3: Emissions of kg CO_2eq./person/year
The span of the vertical axis is 1 to 700 kg CO_2eq./person/year

31 m²/person

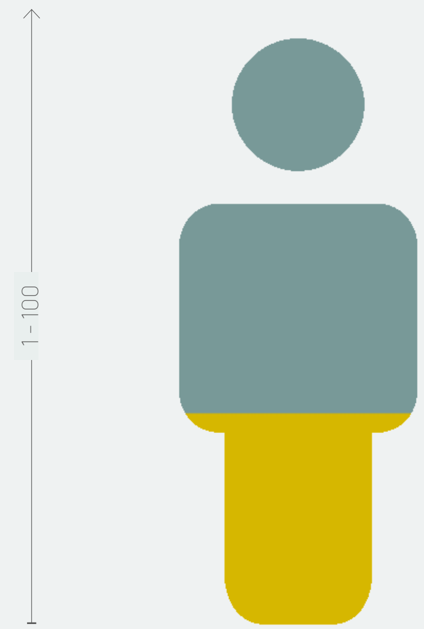


Figure E03.4: m²/person
The span of the vertical axis is 1 to 100 m²/person

E03: Store Solvænget

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m²/year.

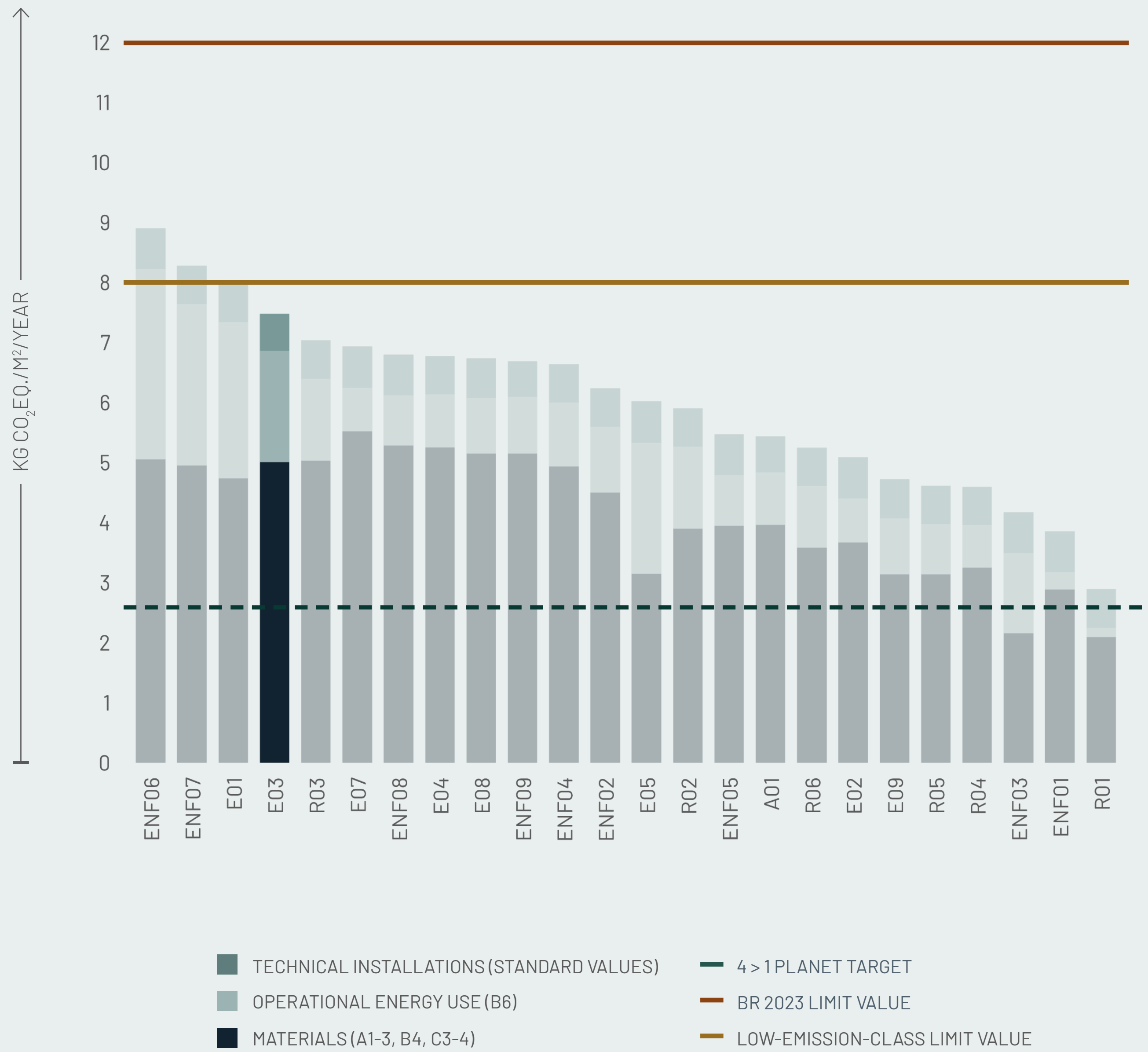


Figure E03.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m²/year. The horizontal axis shows the 24 best practice cases.

E03: Store Solvænget

ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in CO_2eq./m²/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is within the fastest reduction rate: the 83% likelihood scenario.

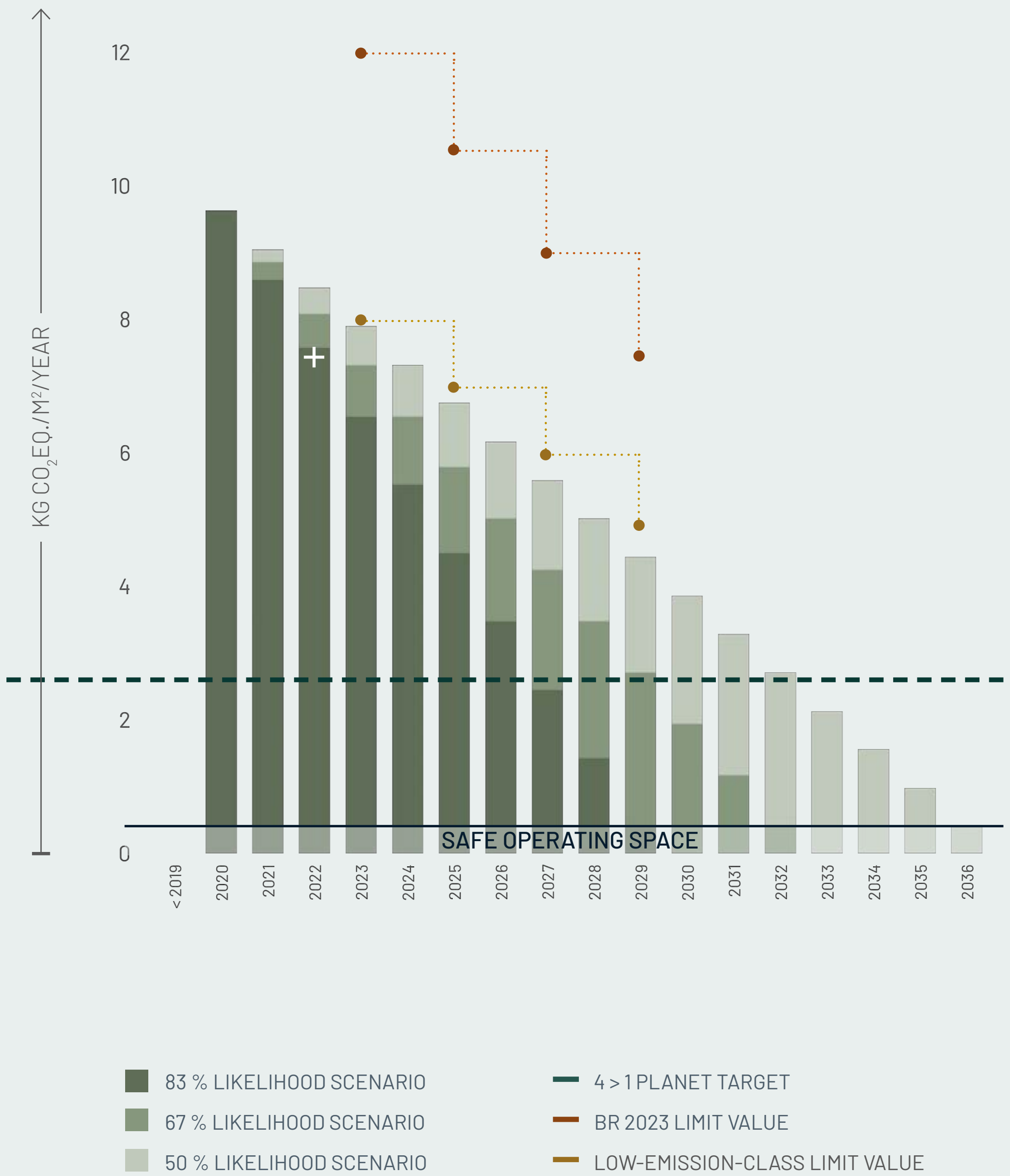
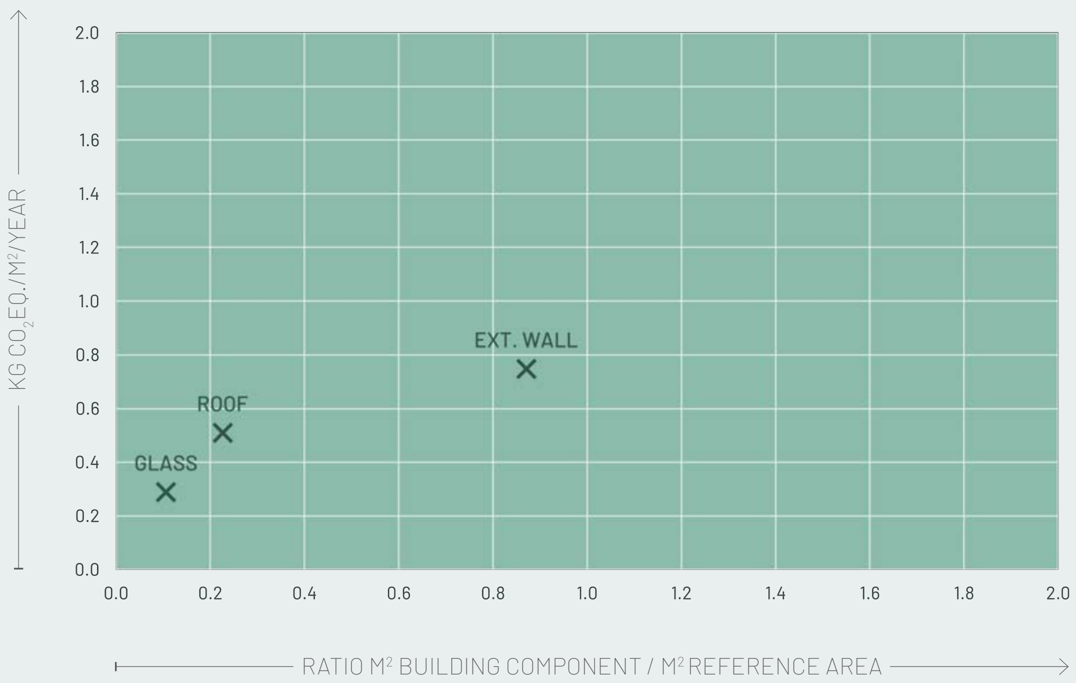


Figure E03.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq./m²/year, and the 'safe operating space'.

RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS



ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

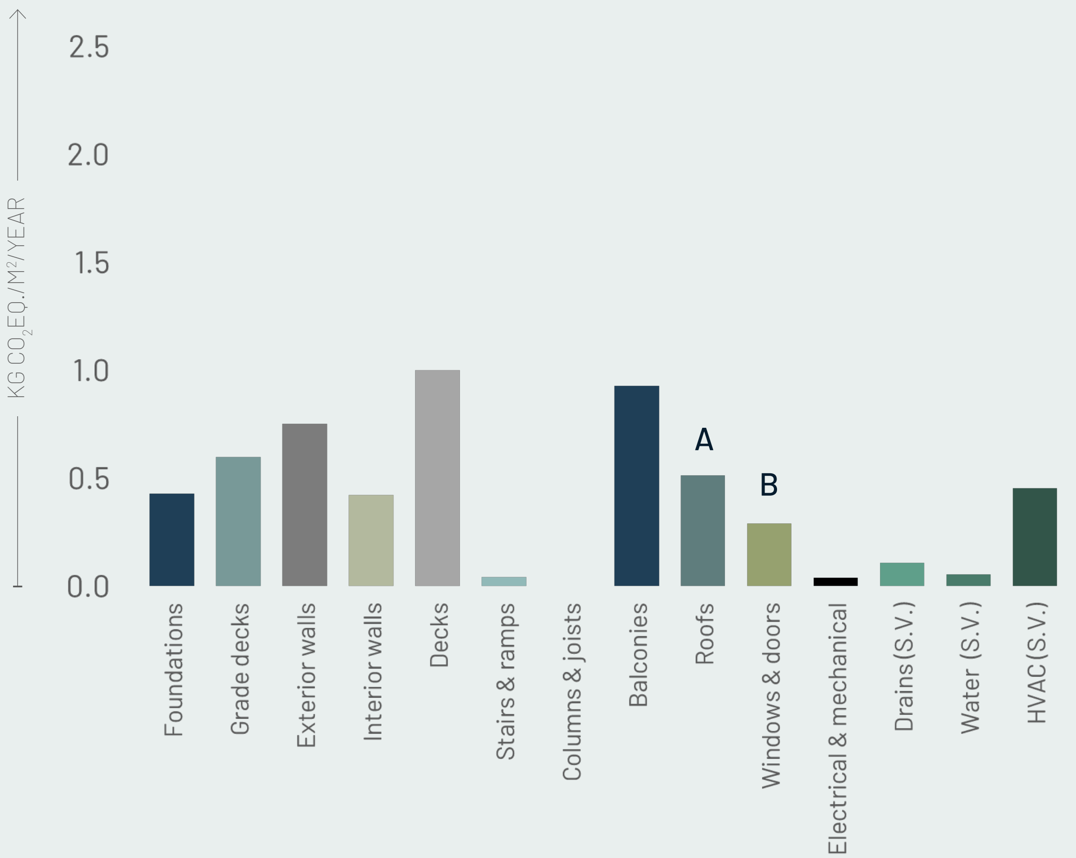


Figure E03.7: CO_2 accounting for building components
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades, electrical and mechanical systems, and technical installations (standard values).

E03: Store Solvænget

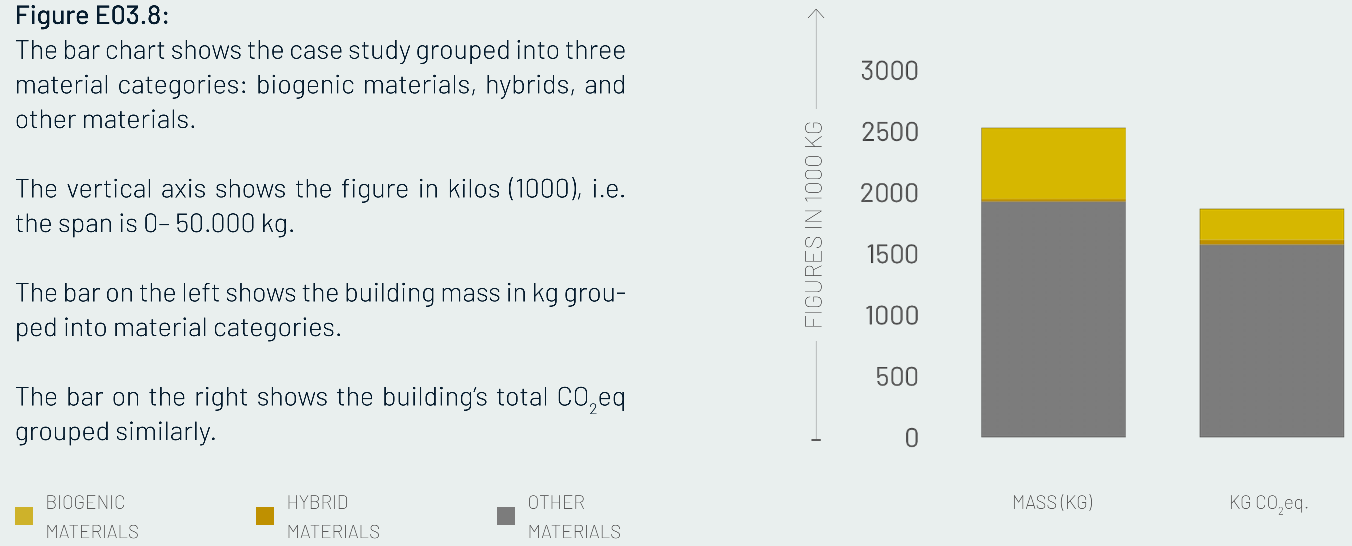
SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

Figure E03.8:
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

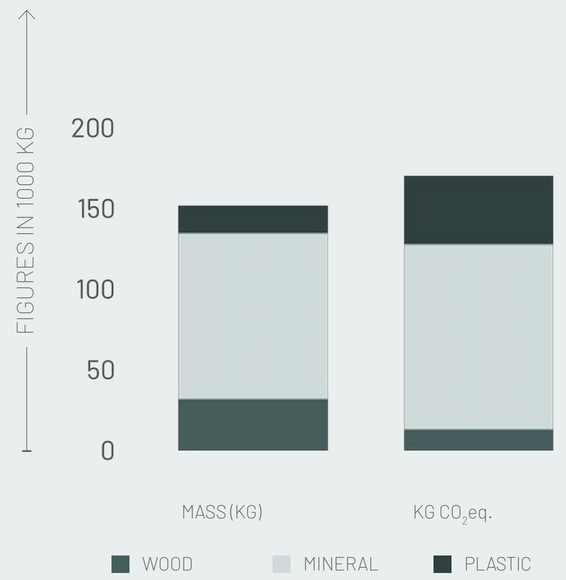
The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

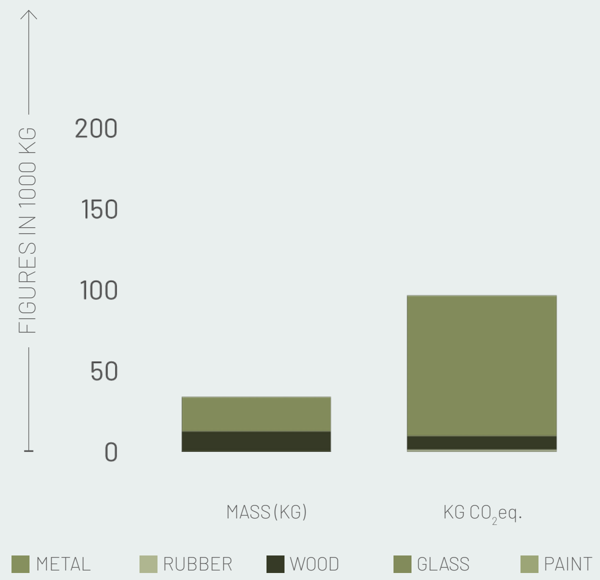
The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total CO_2eq grouped similarly.



MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG CO_2EQ.





A. ROOF

Bituminous felt roofing
Bituminous felt underlay
Plywood
Wooden strips
Wind barrier
Timber frame
Mineral wool insulation
Vapour barrier
Timber lathing
Gypsum plasterboard

B. WINDOWS AND DOORS

CONSTRUCTION:

Window in wooden frame (triple glazing)
Wooden exterior door with glass (triple glazing)

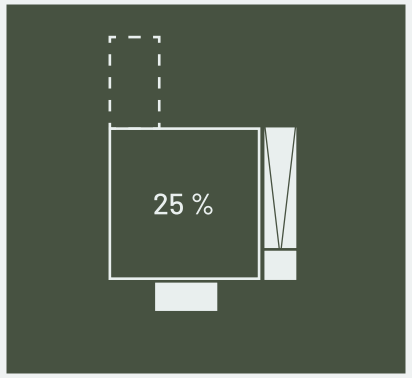
Wooden interior doors
Wooden exterior door, untreated wood

RATIO:

0,11 m²/m² reference area
(lowest ratio in the case collection)

E04: Ibihaven

Developer:	Tetris A/S
Architect:	Sangberg
Engineer:	Artelia
	Sweco
Contractor:	Rasmus Friis A/S
Year (built):	2020
Floor area:	5398 m²
Reference area:	5813 m²
Use:	Residential
Occupants:	204
Year (calculated):	2022
Heating:	Heat pump
Solar cells:	Yes



DESCRIPTION

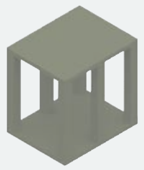
Ibihaven is a cohousing scheme for adults and senior citizens, based on a vision of independence, community, and nature. CO_2 emissions and recycling potential governed the choice of materials. A special focal area was to evolve methods which, in future, will meet the client's goal of maximum emissions for new cohousing schemes of 5 kg CO_2-eq/m²/year. Another important parameter was to use timber from responsible forest management carrying either an FSC or PEFC certificate. The Product stage primarily took place at a factory, which is likely to help reduce the consumption of building materials and resources on the building site.

The two-storey building is built on continuous concrete foundations cast on site. Cassettes are mounted with supporting structures in timber with mineral wool insulation.

The private housing units are positioned facing an atrium garden, which is planted up and functions as a large communal space for the Ibihaven residents. Facades facing the atrium gardens are untreated timber and the outward-facing facades are clad with timber and painted black. The supporting structure of the atrium garden is glulam with steel staircases and access balconies supported by a longitudinal timber structure. The atrium roof covering is clear polycarbonate, and cassette roofing is bituminous felt.

The relevant LCA analysis is made for both housing units and 25% of the atrium area in accordance with BR18 (see section on Area).

The multi-storey housing totals 5398 m² with room for 204 occupants, which gives a space allocation of approx. 26 m²/person. This is on the low side in the case collection.



Hybrid

3 storeys

E04: Ibihaven

6,77 kg CO_2eq./m²/year

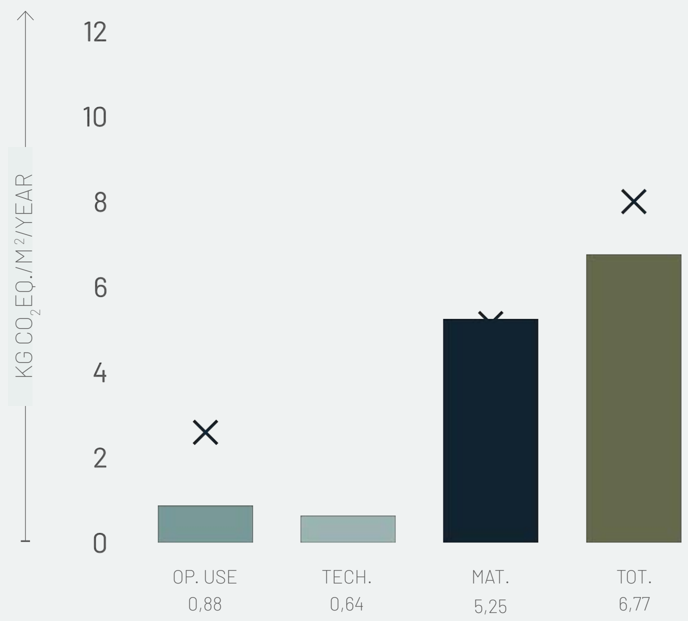


Figure E04.1: Emissions of kg CO_2eq./m²/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO_2eq./m²/year in multi-storey housing in the case collection.

1.713.283 kg CO_2eq.

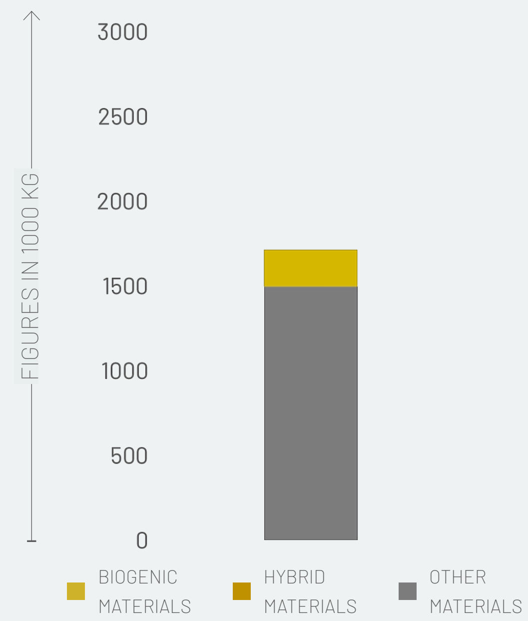


Figure E04.2: Total emission of kg CO_2eq.
The stacked bar chart shows the overall emission of kg CO_2eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

177 kg CO_2eq./person/year

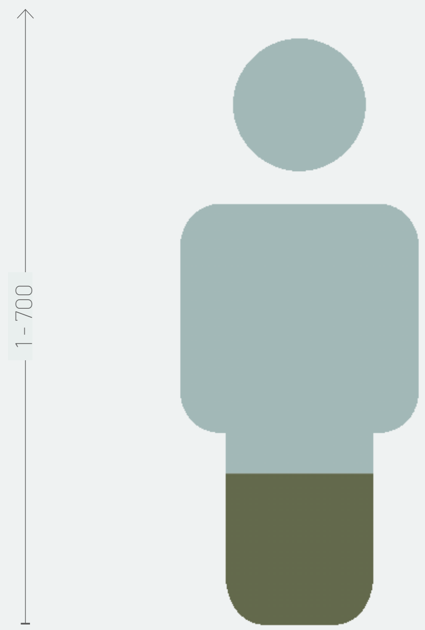


Figure E04.3: Emissions of kg CO_2eq./person/year
The span of the vertical axis is 1 to 700 kg CO_2eq./person/year

26 m²/person

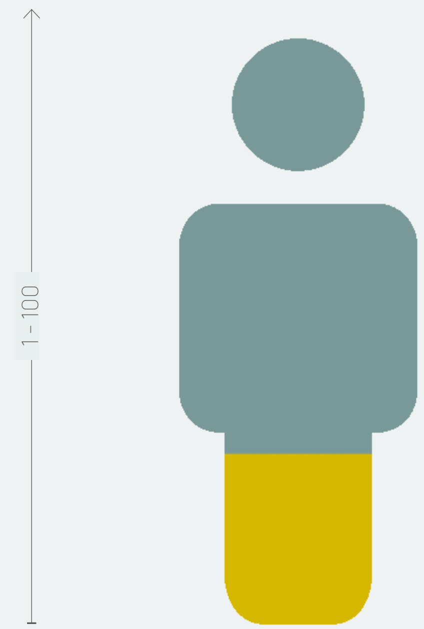


Figure E04.4: m²/person
The span of the vertical axis is 1 to 100 m²/person

E04: Ibihaven

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m²/year.

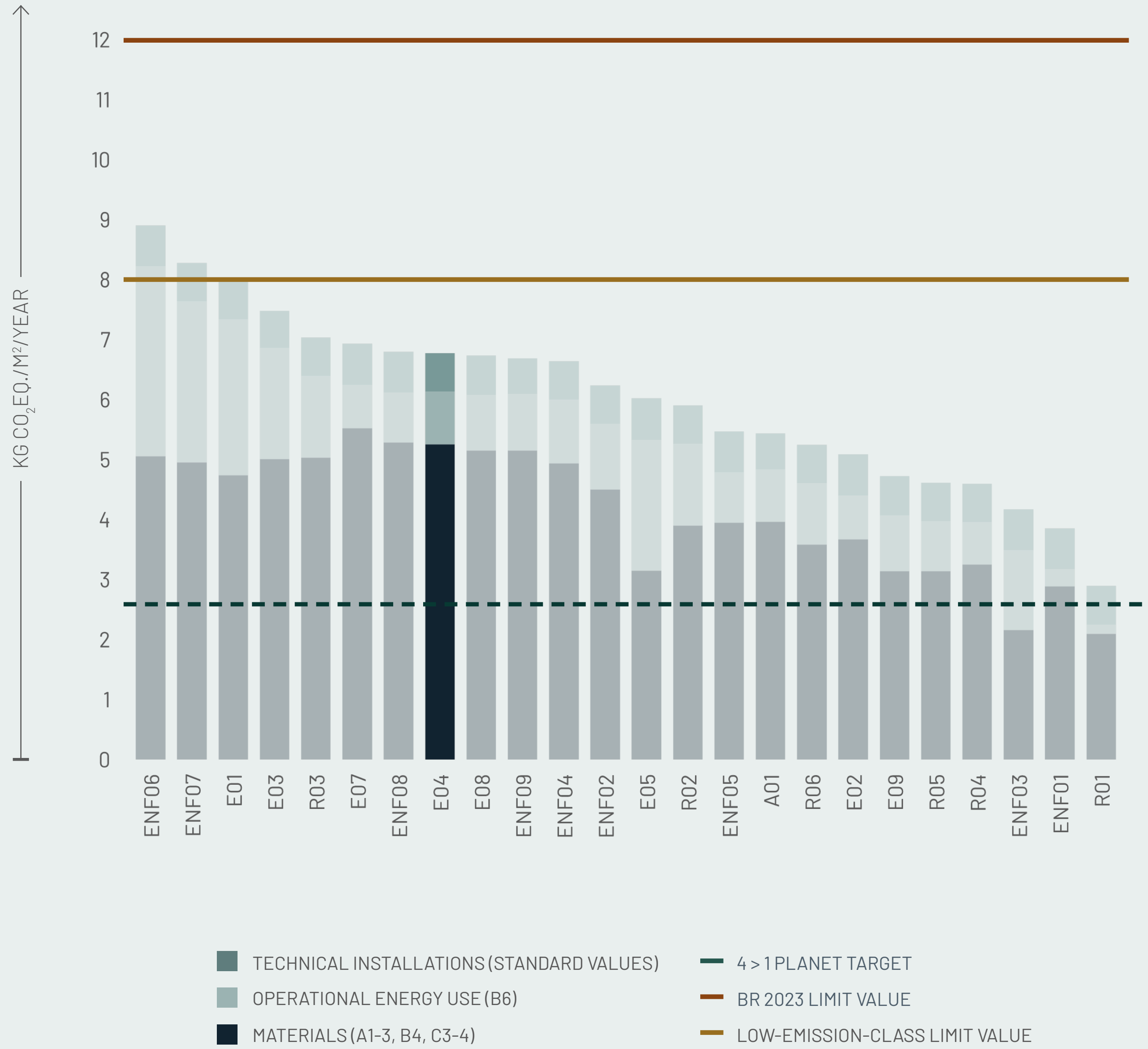


Figure E04.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m²/year. The horizontal axis shows the 24 best practice cases.

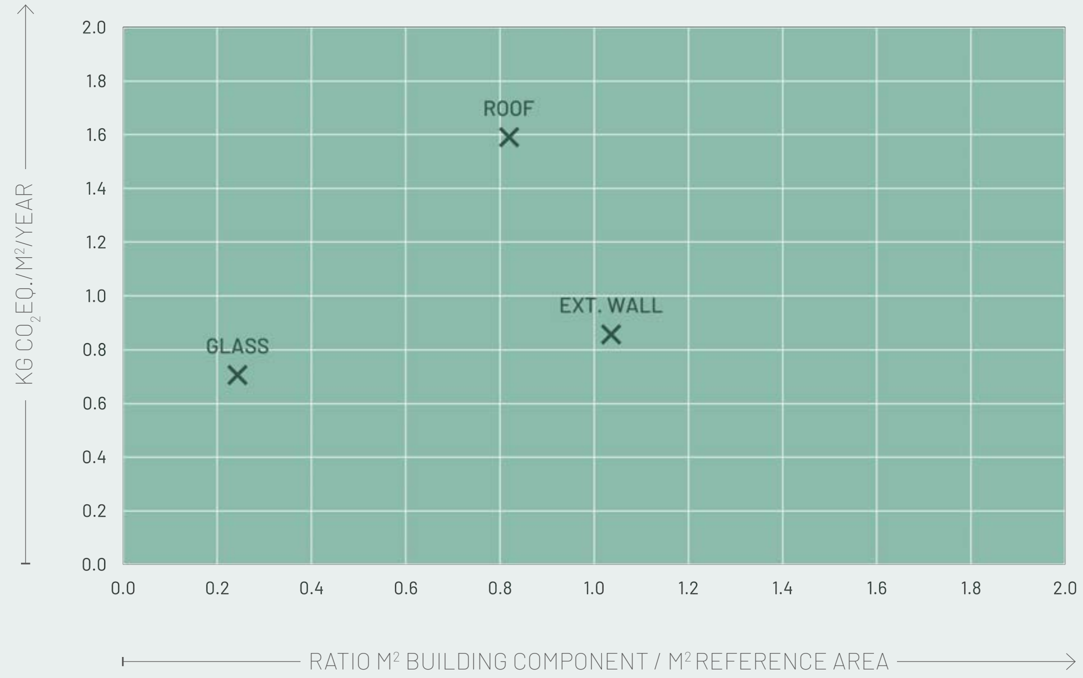
E04: Ibihaven

ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in CO_2eq./m²/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is well within the fastest reduction rate: the 83% likelihood scenario.

Figure E04.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq./m²/year, and the 'safe operating space'.

RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS



ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

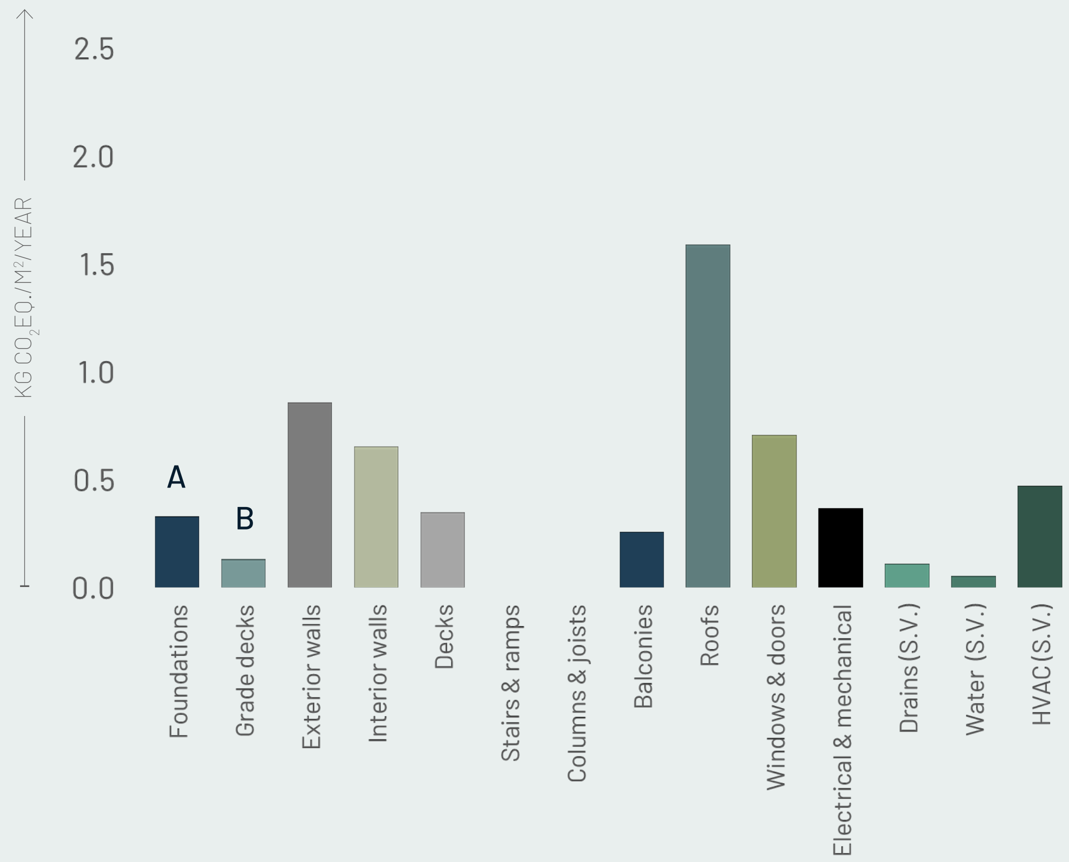


Figure E04.7: CO_2 accounting for building components
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades, electrical and mechanical systems, and technical installations (standard values).

E04: Ibihaven

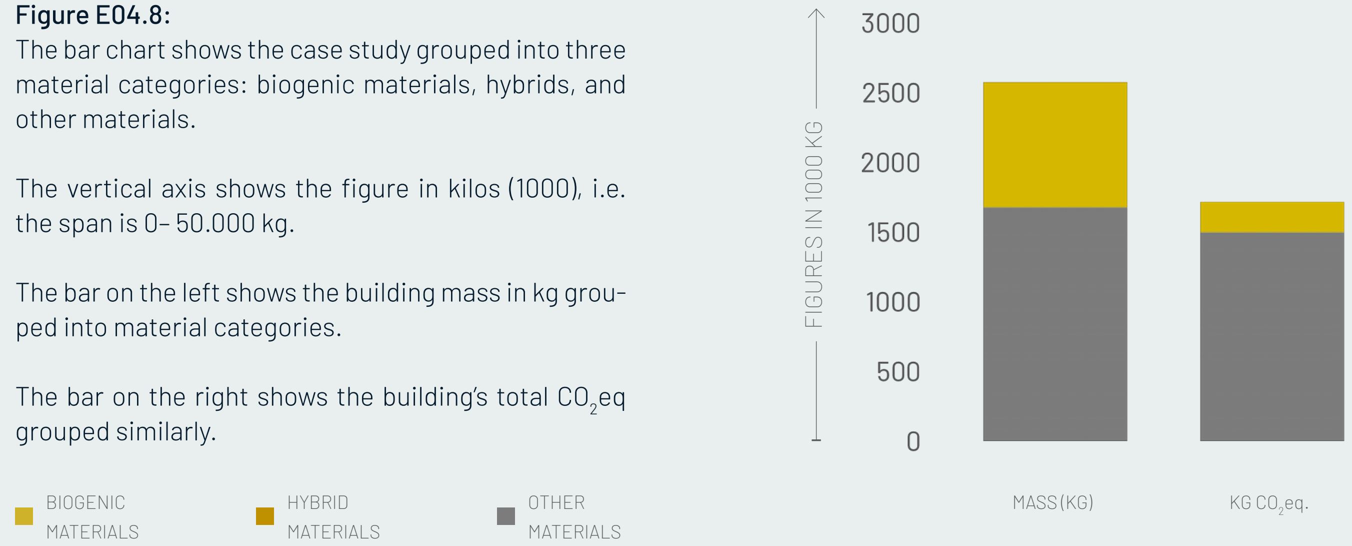
SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

Figure E04.8:
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

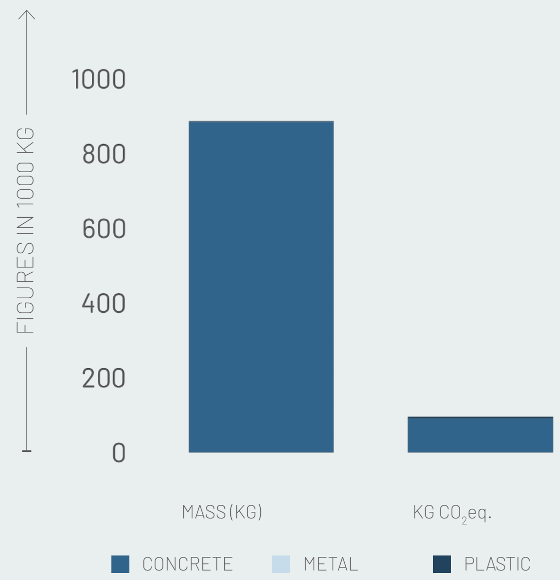
The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

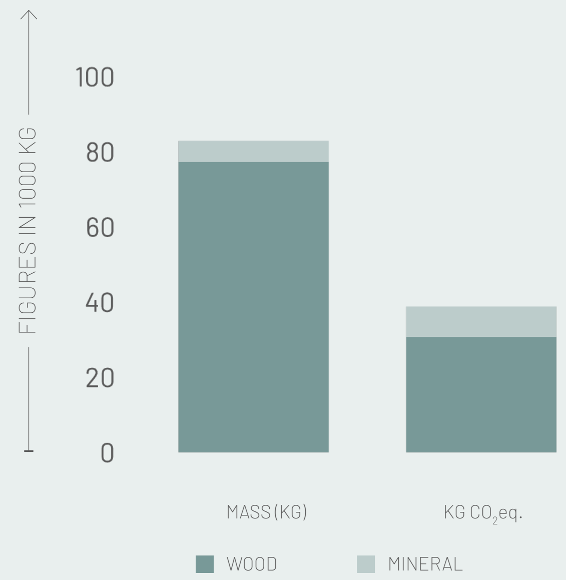
The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total CO_2eq grouped similarly.



MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG CO_2EQ.





A. FOUNDATION

Continuous footing, concrete

152 kg material/m² ref. area

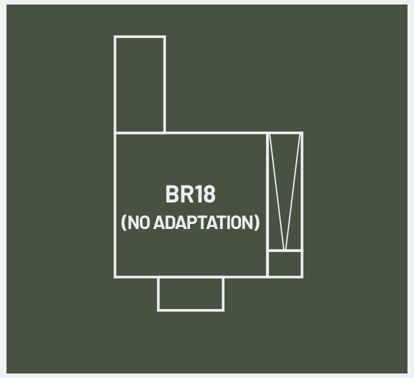
B. GRADE DECK

Wooden parquet flooring
Particle board (recycled)
Glulam
Timber frame
Mineral wool insulation
Fibre-cement boards

E05: Studio [Home] Lyngby

Developer: Pension Danmark
Architect: Vandkunsten
Engineer: Scandi Byg + COWI
Contractor: Scandi Byg

Year (built): 2021
Floor area: 17530 m^2
Reference area: 17530 m^2
Use: Student housing
Occupants: 520
Year (calculated): 2022
Heating: District heating
Solar cells: Ja



DESCRIPTION

Studio [Home] Lundtofte is a student housing concept for sustainable and affordable housing. The Product stage took place at a factory, which is likely to help reduce the consumption of building materials and resources on the building site. A special focal point was scalability and systemic design, interlinking the concept from building to furniture scale. The housing comprises a variety of units to attract students with different needs and wishes, both in terms of facilities in the private housing unit, but also in terms of living with friends. Residents need not buy new furniture when moving in, as the units are furnished with mainly wooden furniture, designed to make the compact units functional. The housing project is the first in Denmark to be awarded both the Swan Ecolabel and DGNB Gold.

The two-to-four-storey buildings are built on concrete foundations and insulated with PIR with a self-compacting concrete deck insulated with EPS. The cassettes are installed on the grade deck, separated from this by a layer of PIR insulation.

The housing is constructed with prefabricated cassettes, timber supporting structures, and insulated with mineral wool. Stone wool insulation is used vertically and horizontally in cassette partitions as fire stops and, on the inside, the cassettes have a fire-rated gypsum board facing. Linoleum flooring.

Slate facade cladding and several access points have been added on the outside in the form steel stairwells. Part of the roof functions as a roof terrace.

Studio [Home] Lundtofte totals 17530 m^2 with room for 520 occupants, which gives a space allocation of approx. 34 m^2/person. This is average for the case collection.

Cassette

2-4 storeys

E05: Studio [Home] Lyngby

6,02 kg CO_2eq./m^2/year

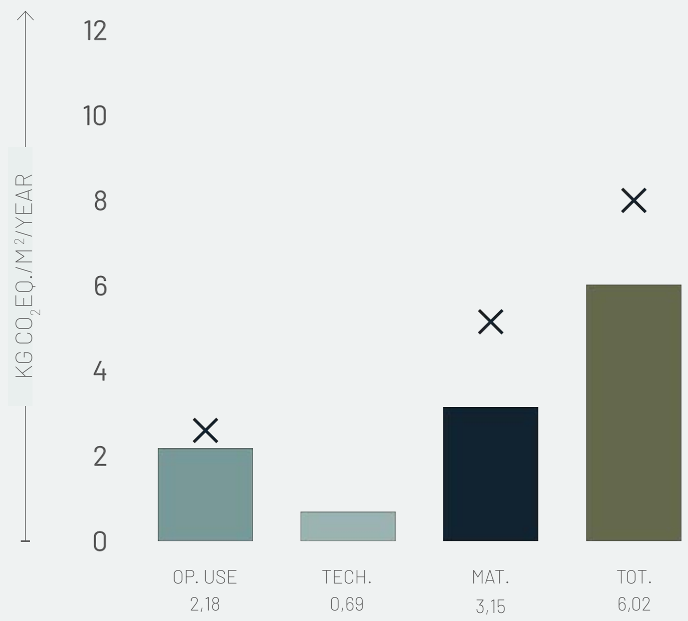


Figure E05.1: Emissions of kg CO_2eq./m^2/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO_2eq./m^2/year in multi-storey housing in the case collection.

3.368.417 kg CO_2eq.

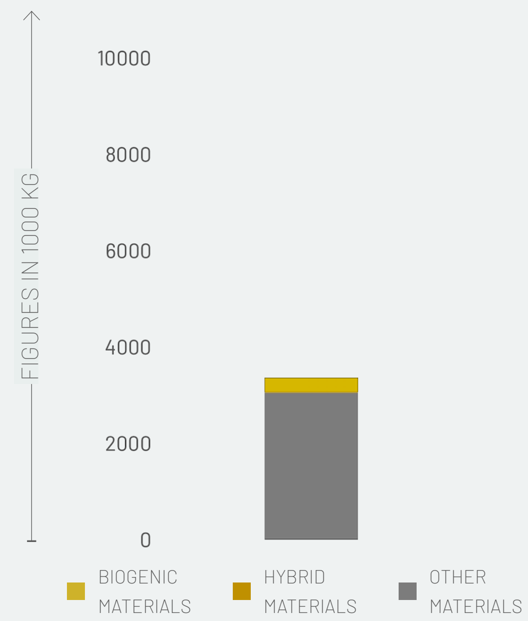


Figure E05.2: Total emission of kg CO_2eq.
The stacked bar chart shows the overall emission of kg CO_2eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

203 kg CO_2eq./person/year

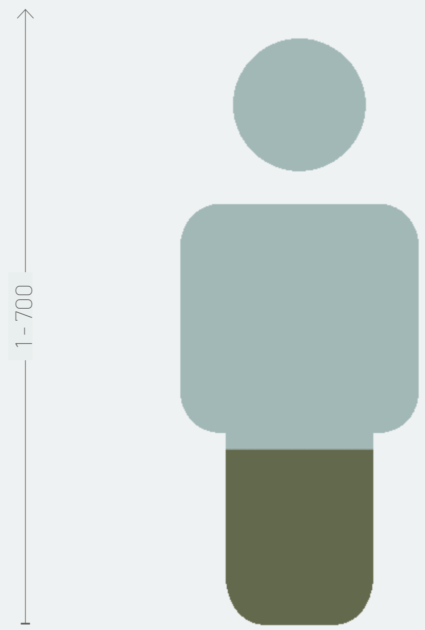


Figure E05.3: Emissions of kg CO_2eq./person/year
The span of the vertical axis is 1 to 700 kg CO_2eq./person/year

34 m^2/person

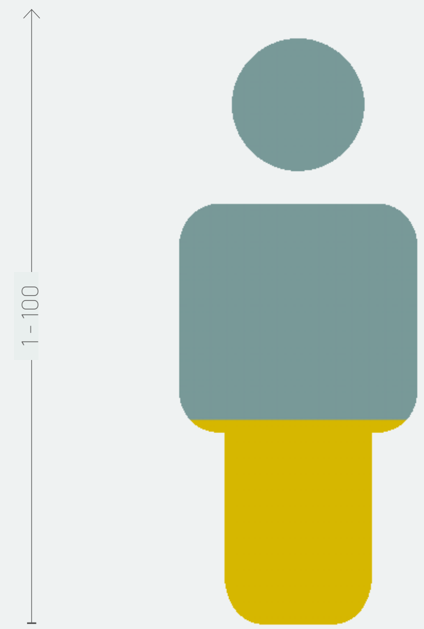


Figure E05.4: m^2/person
The span of the vertical axis is 1 to 100 m^2/person

E05: Studio [Home] Lyngby

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m^2/year.

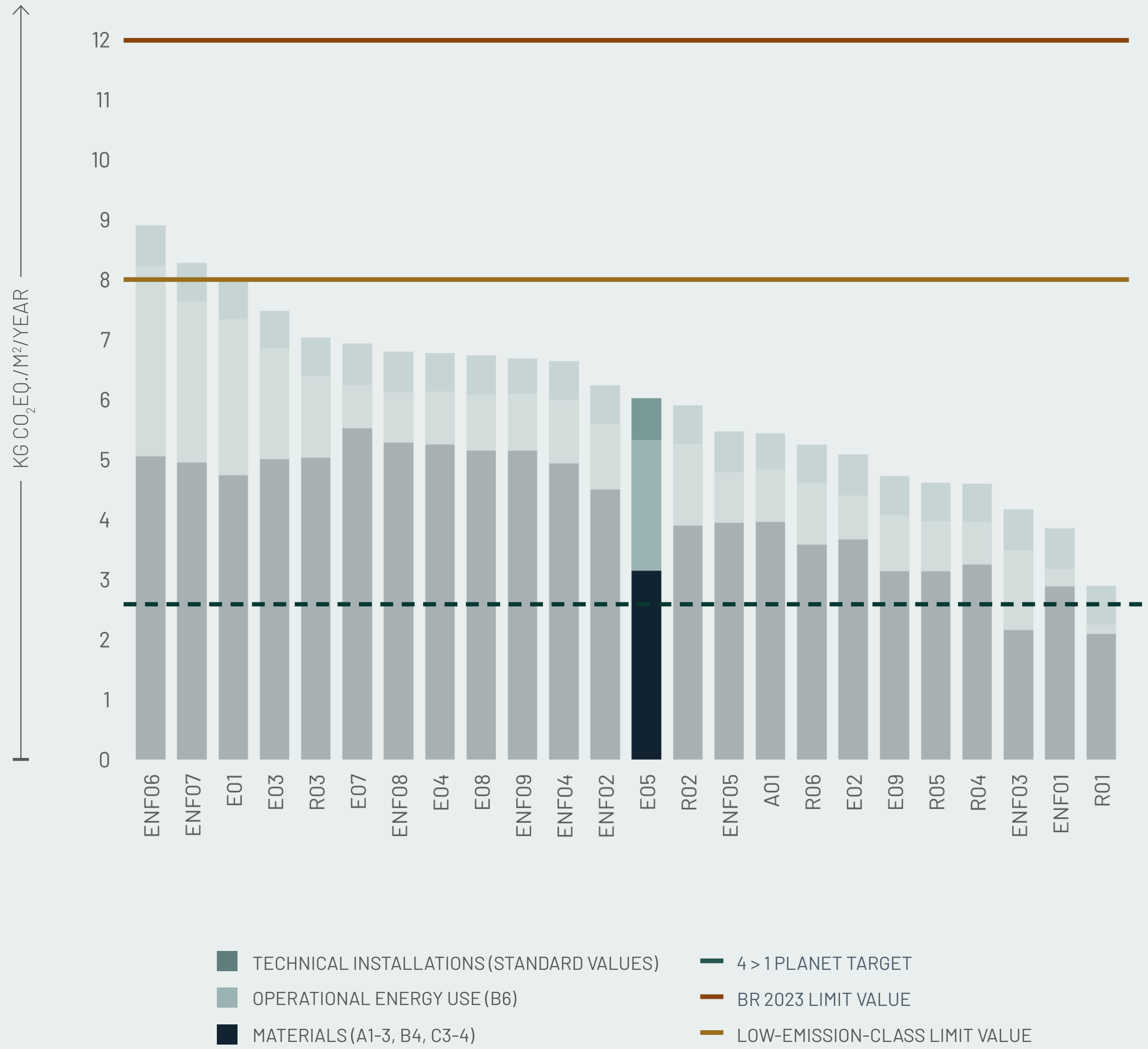


Figure E05.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m^2/year. The horizontal axis shows the 24 best practice cases.

E05: Studio [Home] Lyngby

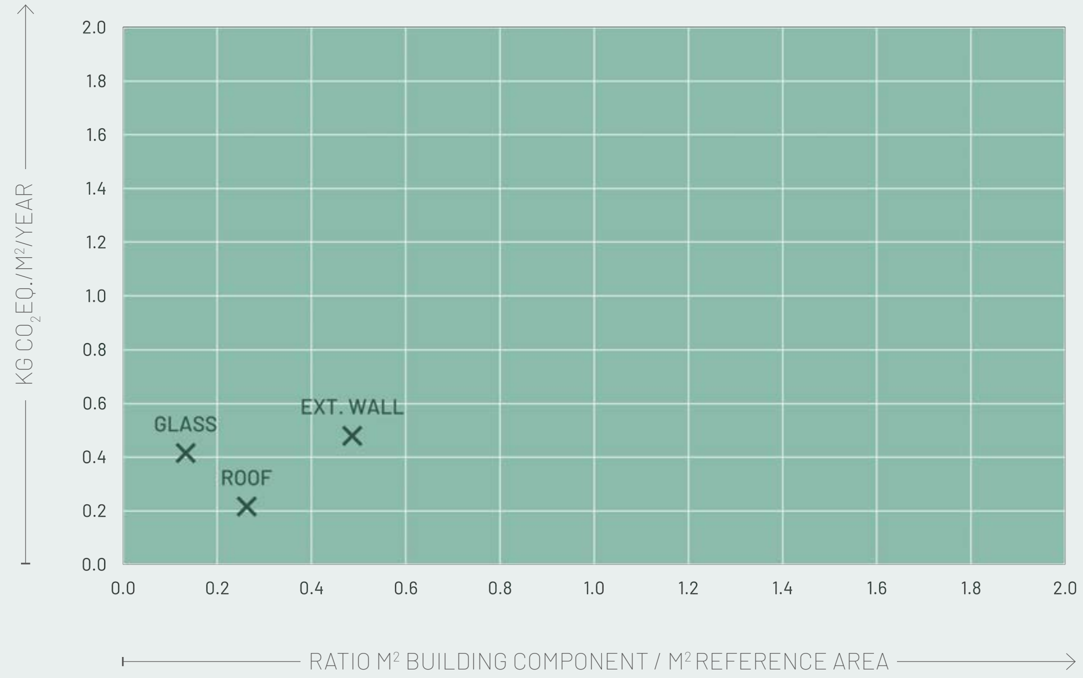
ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in CO_2eq./m^2/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is well within the fastest reduction rate: the 83% likelihood scenario.

Figure E05.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq./m^2/year, and the 'safe operating space'.

E05: Studio [Home] Lyngby

RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS



ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

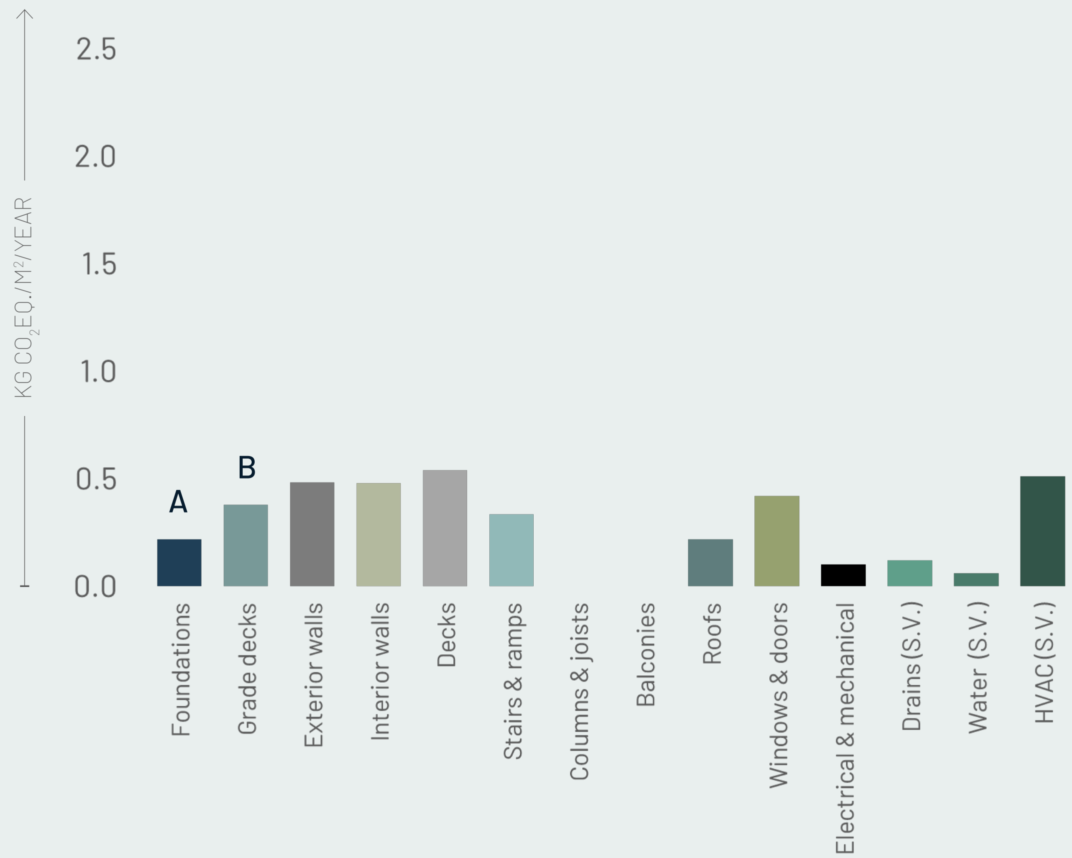


Figure E05.7: CO_2 accounting for building components
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades, electrical and mechanical systems, and technical installations (standard values).

E05: Studio [Home] Lyngby

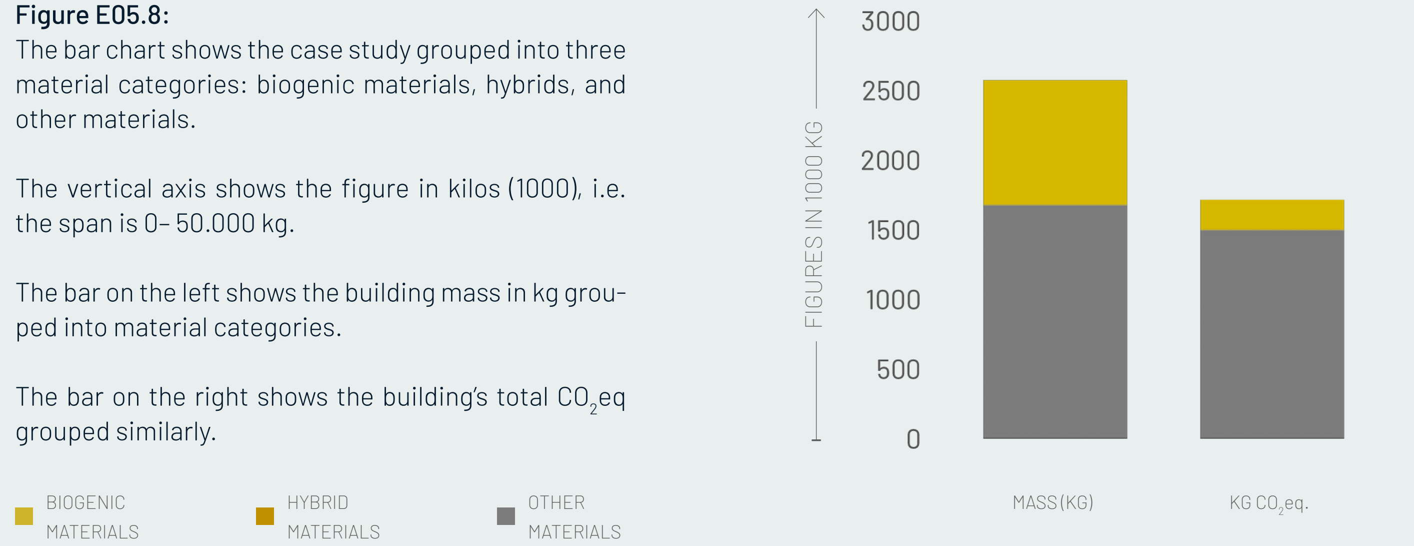
SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

Figure E05.8:
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

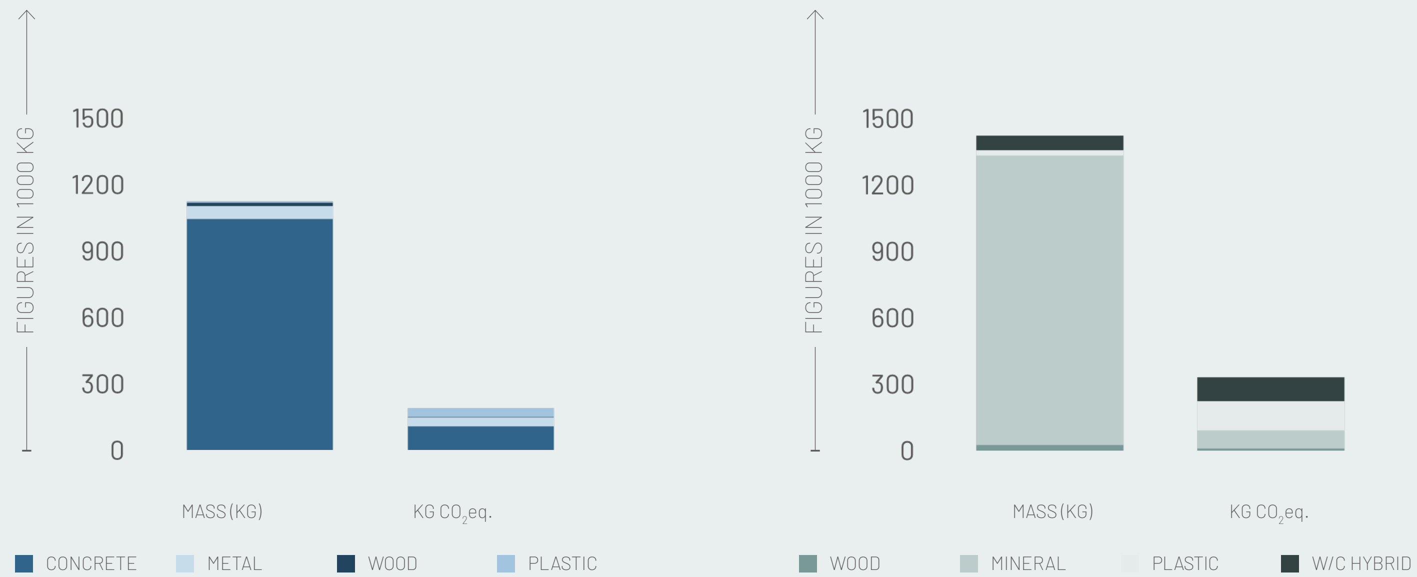
The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total CO_2eq grouped similarly.



MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG CO_2EQ.



A. FOUNDATION

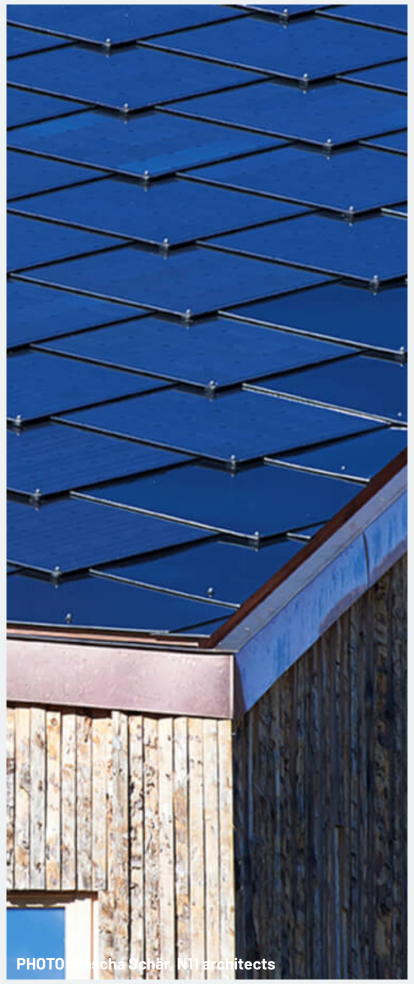
Concrete beam, reinforced
Concrete deck, doubly reinforced
PIR-foam insulated footing

64 kg material/m² ref. area

B. GRADE DECK

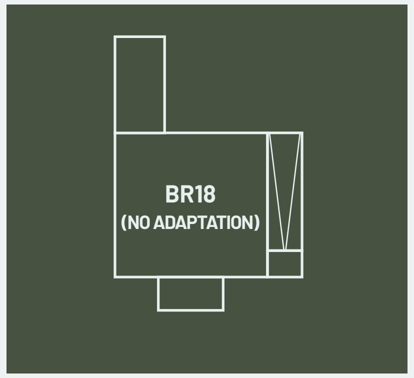
OSB sheeting
Timber frame
Mineral wool insulation
Vapour barrier
EPS insulation
Cement particle board
Gravel

E07: N11 SolarHouse



Developer:	KU Leuven
Architect:	N11 architects
Engineer:	N11 engineers

Year (built):	2014
Floor area:	536 m²
Reference area:	536 m²
Use:	Office / Residential
Occupants:	5,5 - 12
Year (calculated):	2022
Heating:	District heating
Solar cells:	Yes



DESCRIPTION

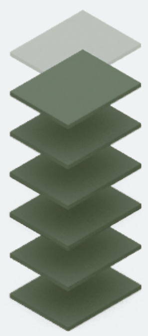
N11 Solar Direktgewinnhau translates as "solar direct-gain house", referred to as N11 SolarHouse in this report. This is a mixed-use house with the first three storeys functioning as offices and the top two as housing.

The five-storey building is built on a reinforced concrete foundation slab with a stamped clay surface. The house is built with supporting structures of glulam columns and CLT. Storey partitions are concrete and timber composites with flax insulation and anhydrite cladding. The sloping roof and exterior walls are insulated on the outside with flax fibres, and vertical surface facings are stamped clay. The roof surface is covered with photovoltaic modules.

The materials, orientation, and compact nature of the building were chosen to utilise heat emitted by people and apparatus as well as by photovoltaics. This to avoid aggregates for mechanical heating. To ensure a stable heat source, a wood-burning stove is installed in the flat.

The multi-storey housing totals 536 m² with room for 10 staff and 2 residents. The results per person will therefore show emissions per person for 12 occupants as well as for 5.5 occupants, which is a ratio of occupants/area calculated using the area per person in the residential part of building. This is approx. 45 m²/person and 98 m²/person, respectively. Both areas are on the high side in the case collection. The mixed utilisation makes it difficult to arrive at a fair representation of residents.

Hybrid



5 storeys

E07: N11 SolarHouse

6,93 kg CO_2eq./m²/year

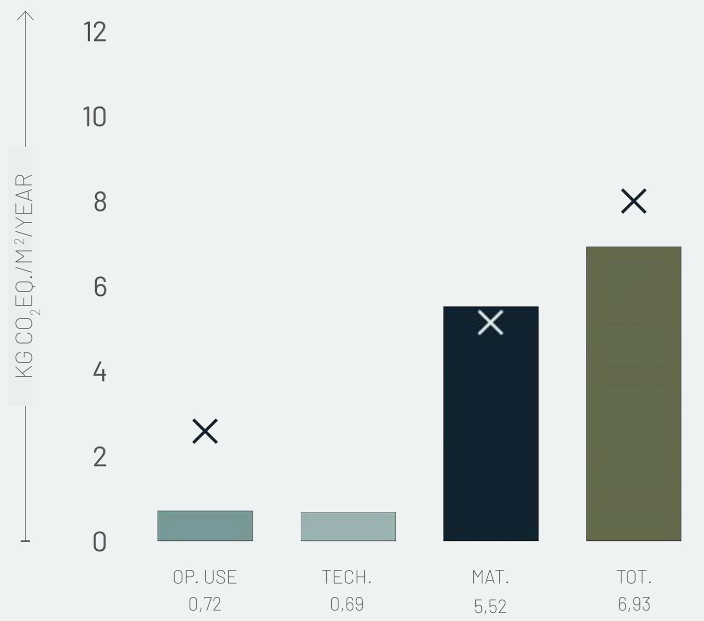


Figure E07.1: Emissions of kg CO_2eq./m²/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO_2eq./m²/year in multi-storey housing in the case collection. This case has the case collection's highest emissions of kg CO_2eq./m²/year from materials, but as it is an international case, it is not used as reference (X).

166.481 kg CO_2eq.

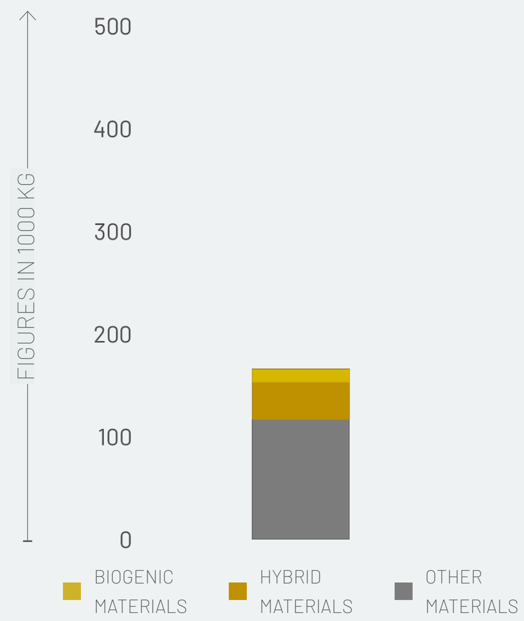


Figure E07.2: Total emission of kg CO_2eq.
The stacked bar chart shows the overall emission of kg CO_2eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

676 kg CO_2eq./person/year

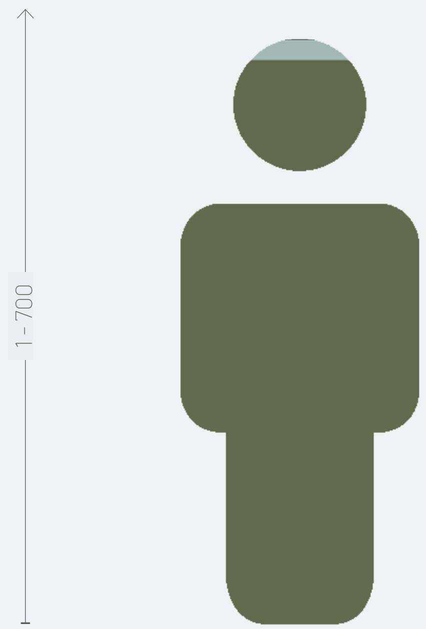


Figure E07.3: Emissions of kg CO_2eq./person/year
The span of the vertical axis is 1 to 700 kg CO_2eq./person /year

45 - 98 m²/person

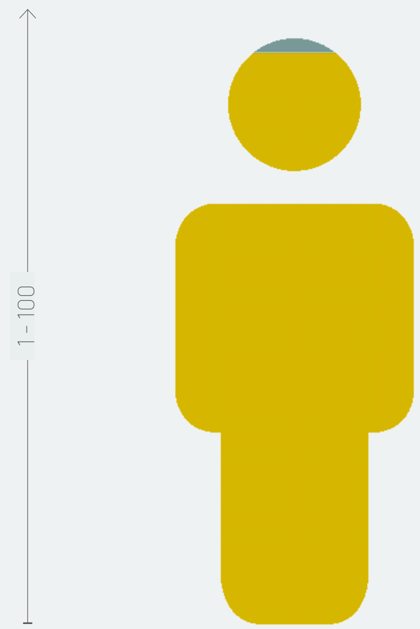


Figure E07.4: m²/person
The span of the vertical axis is 1 to 100 m²/person

E07: N11 SolarHouse

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m²/year.

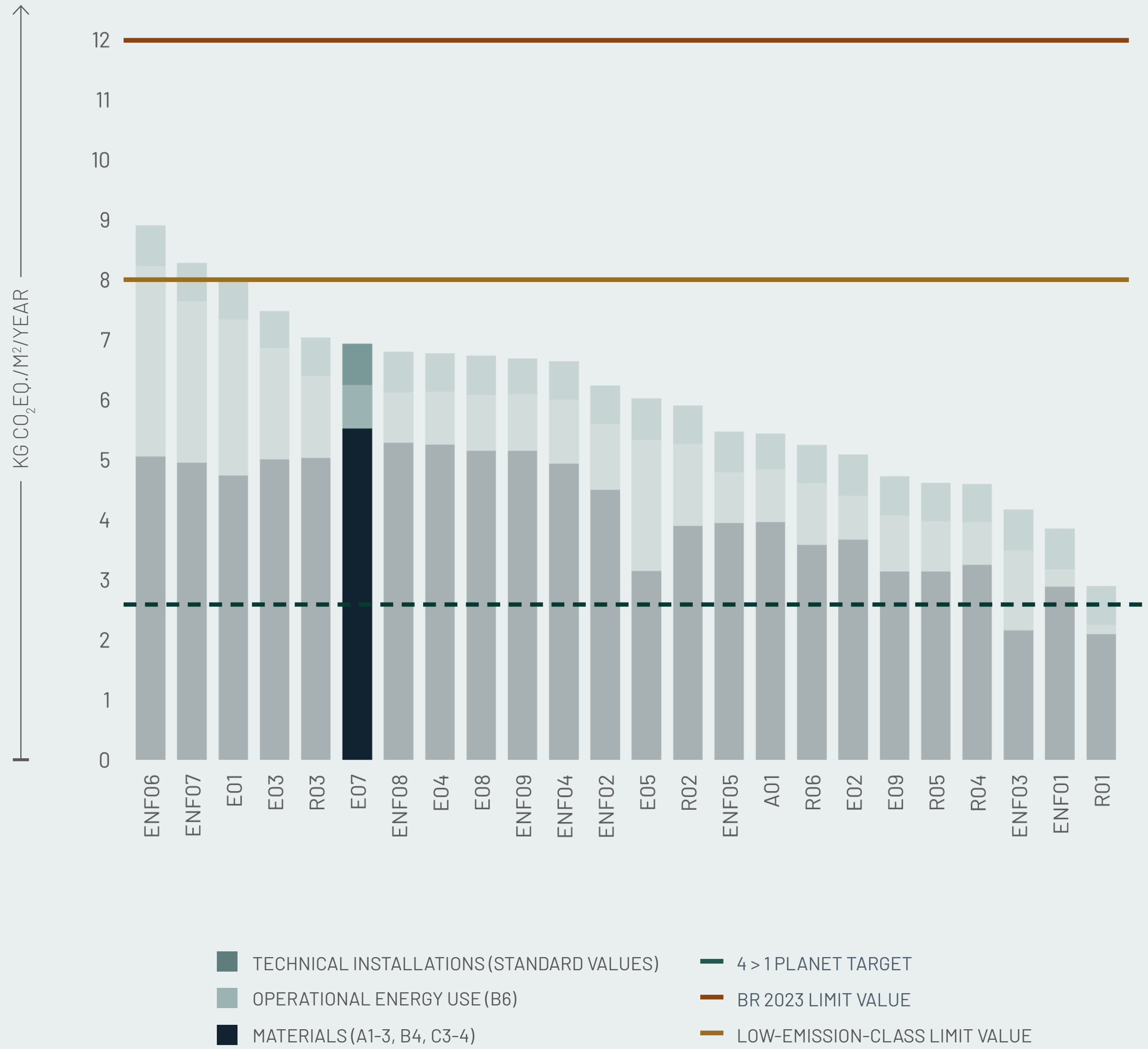


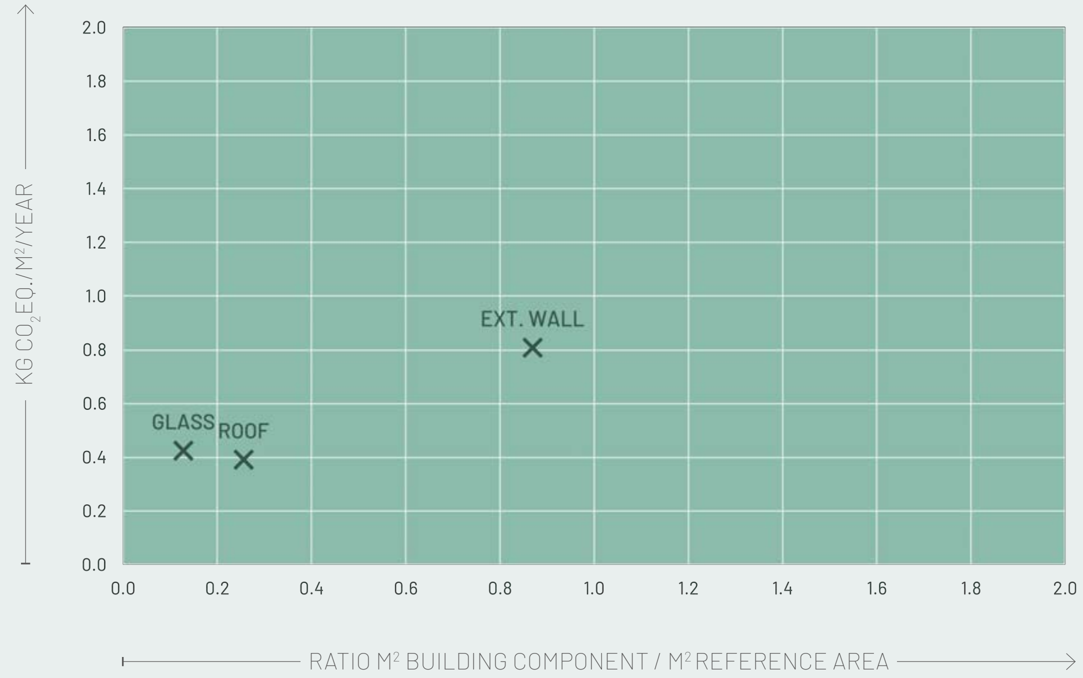
Figure E07.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m²/year. The horizontal axis shows the 24 best practice cases.

ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in CO_2eq./m²/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is well within the fastest reduction rate: the 83% likelihood scenario.

Figure E07.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq./m²/year, and the 'safe operating space'.

RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS



ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

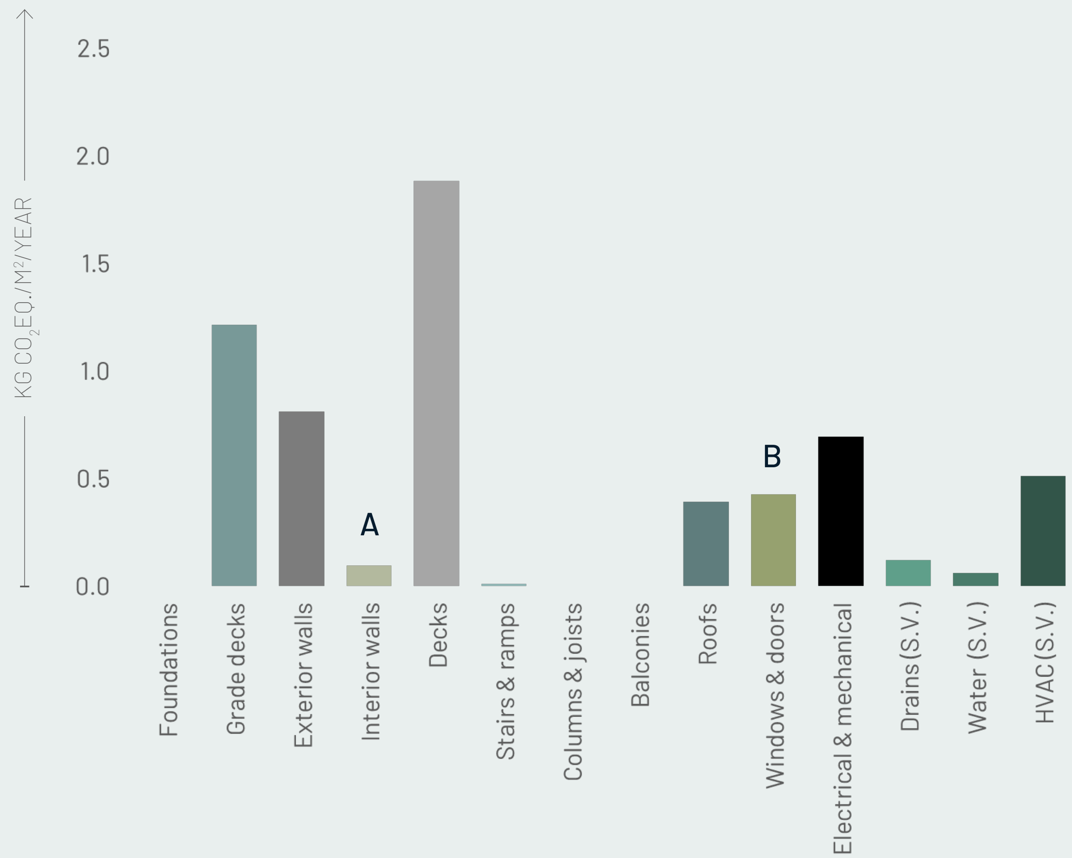


Figure E07.7: CO_2 accounting for building components
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades, electrical and mechanical systems, and technical installations (standard values).

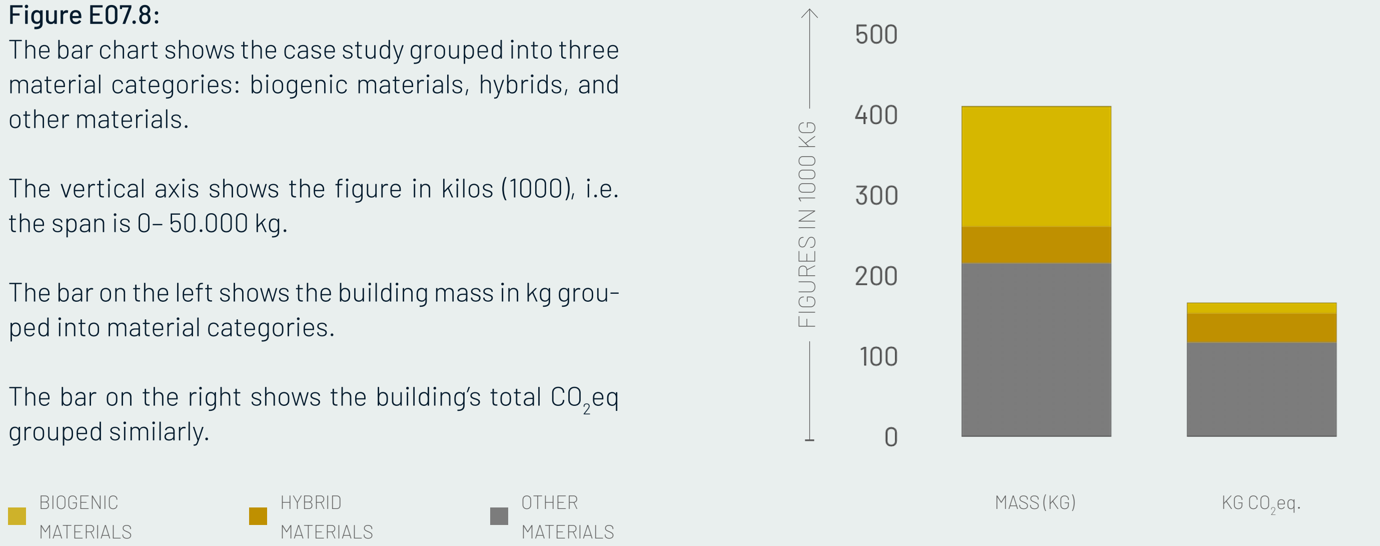
SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

Figure E07.8:
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

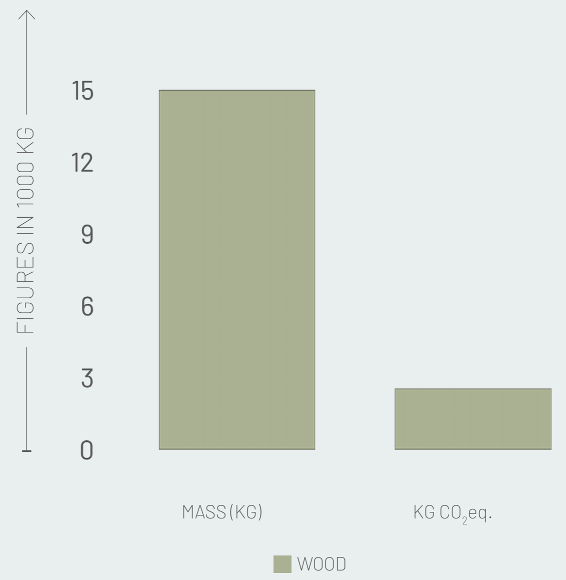
The vertical axis shows the figure in kilos (1000), i.e. the span is 0–50.000 kg.

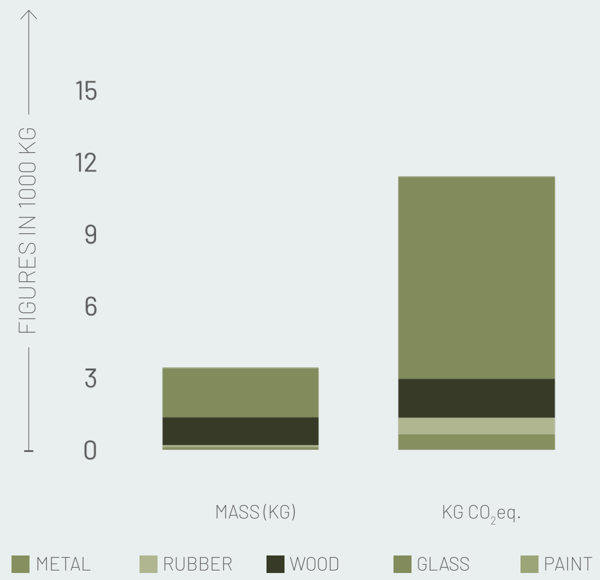
The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total CO_2eq grouped similarly.



MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG CO_2EQ.





A. INTERIOR WALLS

CLT, load bearing
CLT, non-load bearing

B. WINDOWS AND DOORS

CONSTRUCTION:

Window in wooden frame (triple glazing)
Wooden door, inside
Aluminium door, outside

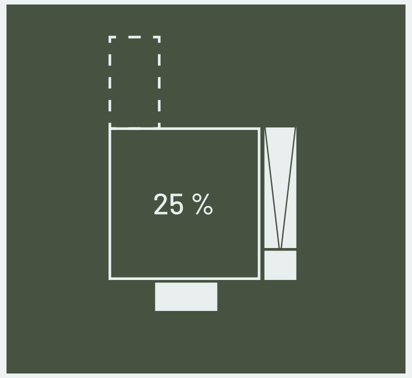
RATIO:

0.13 m² window/m² reference area

E08: CPH Village Vesterbro

Developer: CPH Village
Architect: Arcgency
Engineer: Ekolab
Contractor: Scandi Byg

Year (built): 2020
Floor area: 146 m²
Reference area: 154 m²
Use: Student housing
Occupants: 8 units / block
Year (calculated): 2022
Heating: Heat pump
Solar cells: Yes



DESCRIPTION

CPH Village Vesterbro is built as modular student housing. This is one of several projects dotted across Copenhagen applying this concept and working to build a limited square metreage per person. The product stage primarily took place at a factory, which is likely to help reduce the consumption of building materials and resources on the building site. The housing units comprise modules designed for dismantling. Modules can be dismantled, combined with other modules, and moved to other applications in the future. This flexibility facilitates changing the function of the modules according to need. The option of changing the position, size, and function of the modules challenges the limits set by standard real estate.

The two-storey housing is built on screw-pile foundations, and the grade deck is a cassette construction with an underlay of particle board and mineral wool insulation. Linoleum flooring.

The supporting structures in the house are mass timber. The exterior walls are insulated with mineral wool and the outside have timber facings. Interior walls are clad with gypsum boards. The storey partitions are constructed using timber cassettes with mineral wool insulation, and linoleum flooring and gypsum-board ceilings, respectively.

The roof is an I-beam and plywood construction insulated with mineral wool. Gypsum ceilings and bituminous felt roofing.

The multi-storey housing totals 146 m² with room for 4 persons, assuming there is one occupant per unit. This gives a space allocation of approx. 37 m²/person, which is on the high side for the case collection generally. If we calculate with 2 occupants per unit (corresponding to one primary bedroom), the result is 8 occupants and an average space allocation of 18 m²/person. This is on the low side in the case collection.

Cassette

2 storeys

E08: CPH Village Vesterbro

6,73 kg CO_2eq./m²/year

Figure E08.1: Emissions of kg CO_2eq./m²/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO_2eq./m²/year in multi-storey housing in the case collection.

44.797 kg CO_2eq.

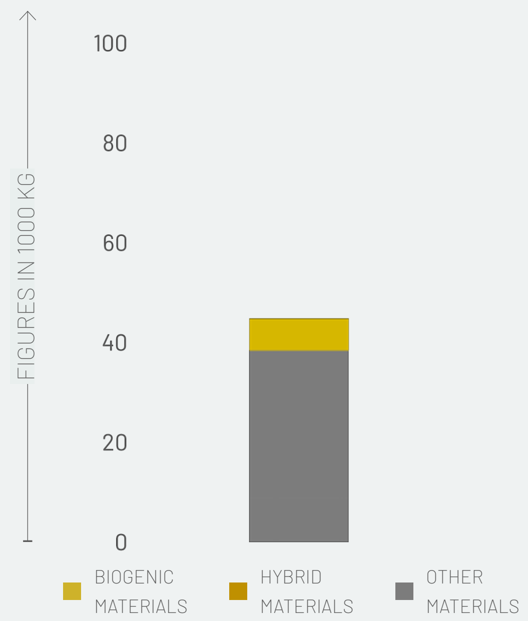


Figure E08.2: Total emission of kg CO_2eq.
The stacked bar chart shows the overall emission of kg CO_2eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

130 kg CO_2eq./person/year

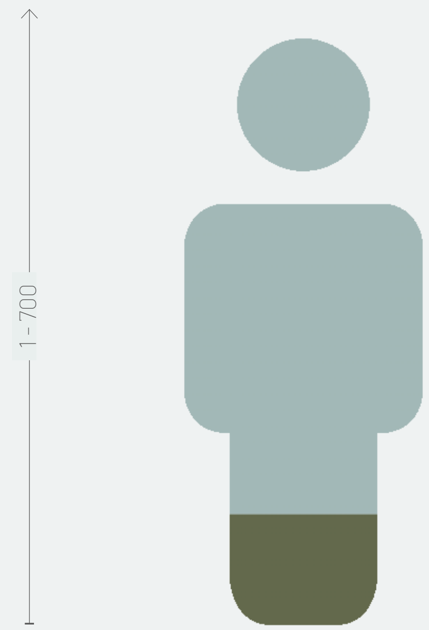


Figure E08.3: Emissions of kg CO_2eq./person/year
The span of the vertical axis is 1 to 700 kg CO_2eq./person/year

18 - 37 m²/person

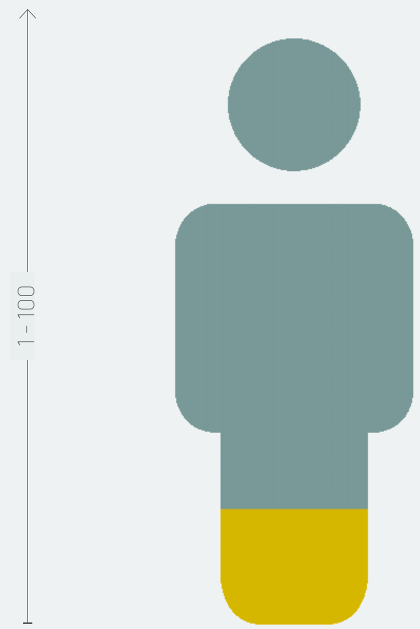


Figure E08.4: m²/person
The span of the vertical axis is 1 to 100 m²/person

E08: CPH Village Vesterbro

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m²/year.

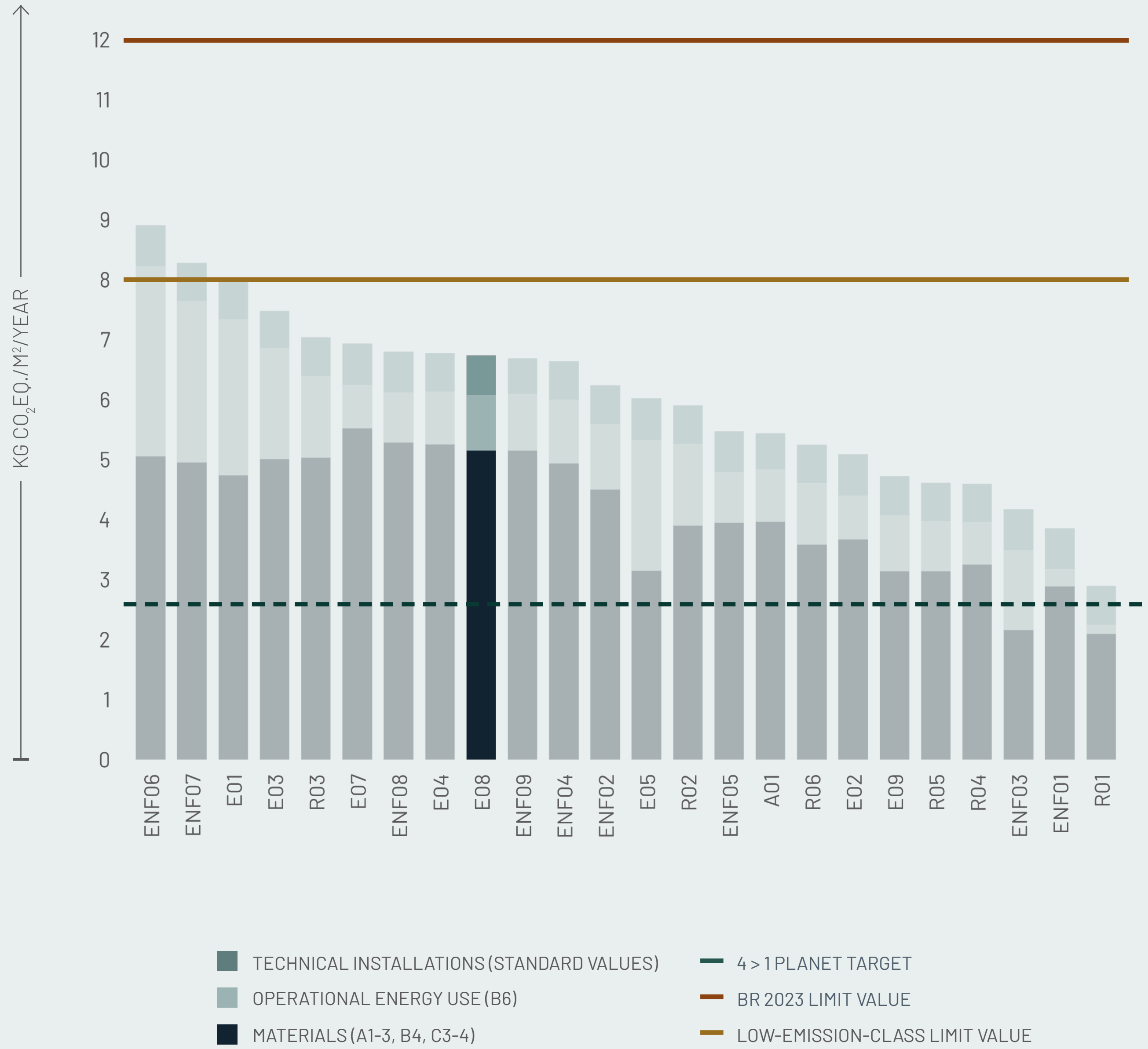


Figure E08.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m²/year. The horizontal axis shows the 24 best practice cases.

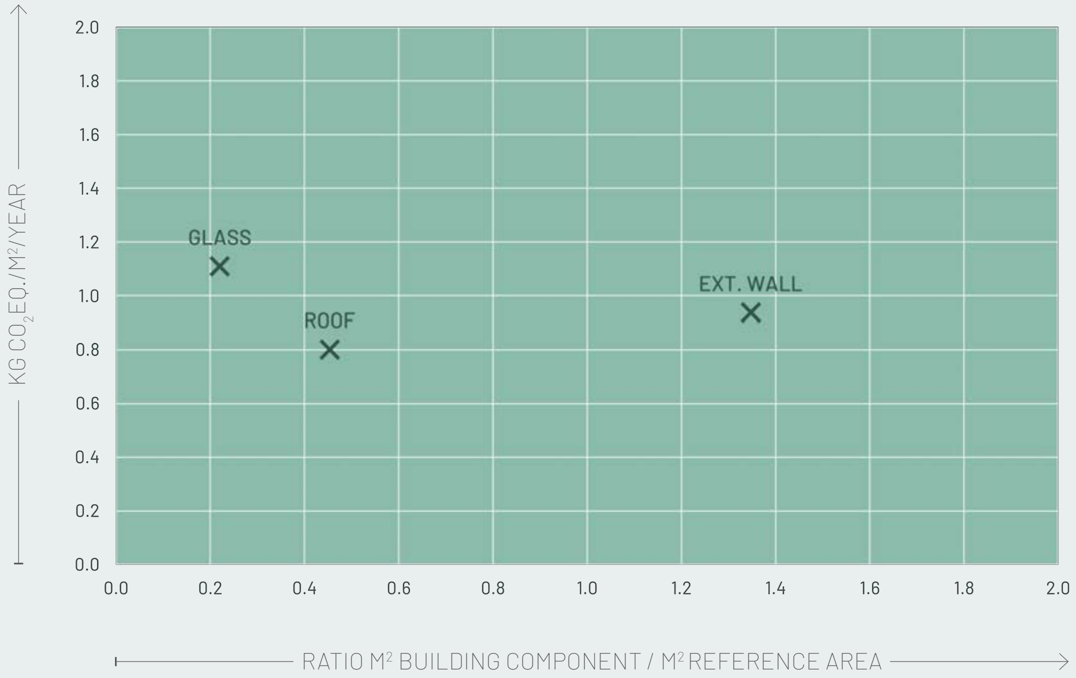
E08: CPH Village Vesterbro

ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in CO_2eq./m²/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is well within the fastest reduction rate: the 83% likelihood scenario.

Figure E08.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq./m²/year, and the 'safe operating space'.

RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS



ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

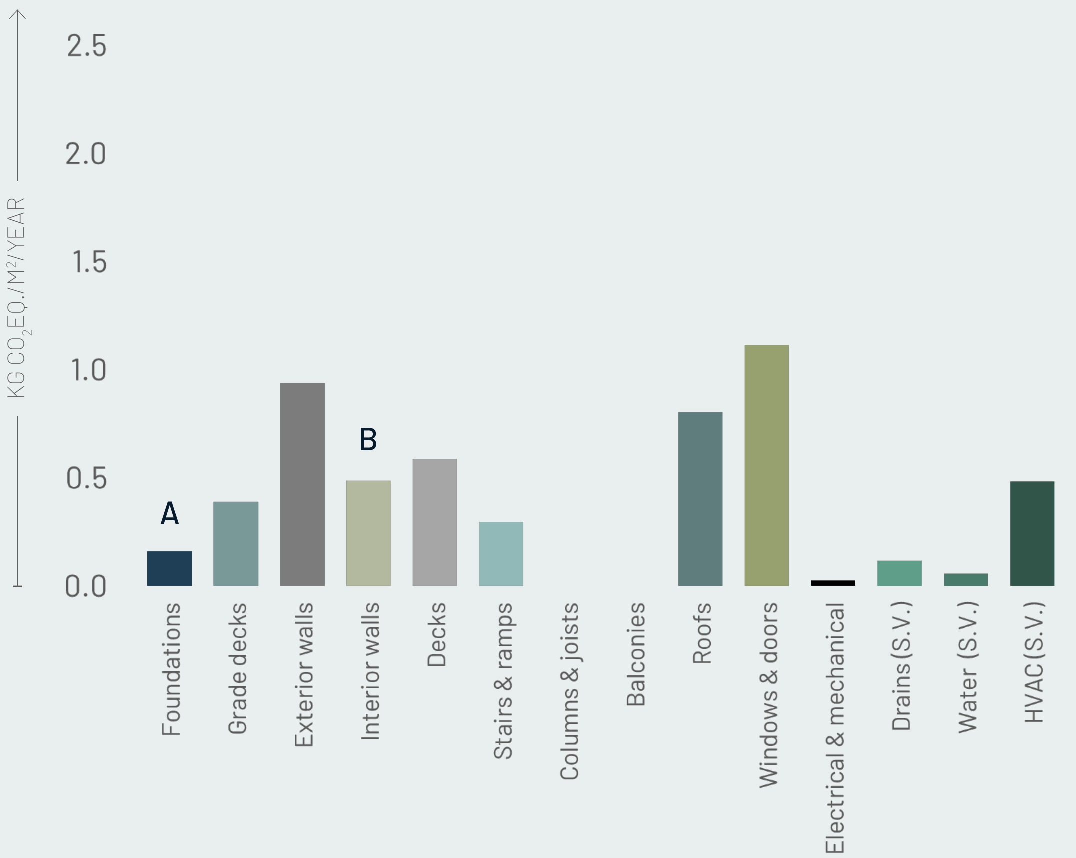


Figure E08.7: CO_2 accounting for building components
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades, electrical and mechanical systems, and technical installations (standard values).

E08: CPH Village Vesterbro

SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

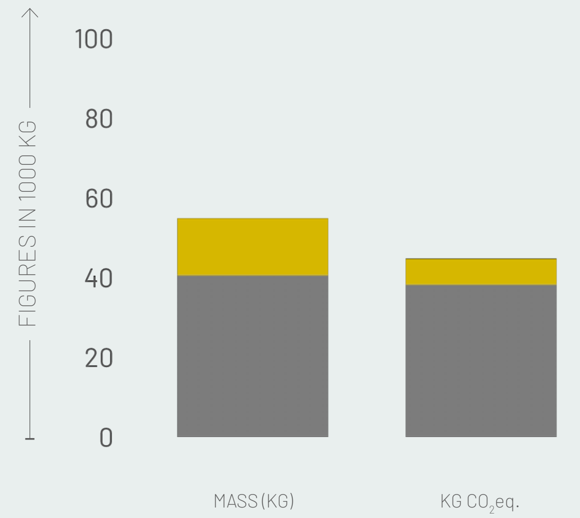
Figure E08.8:
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

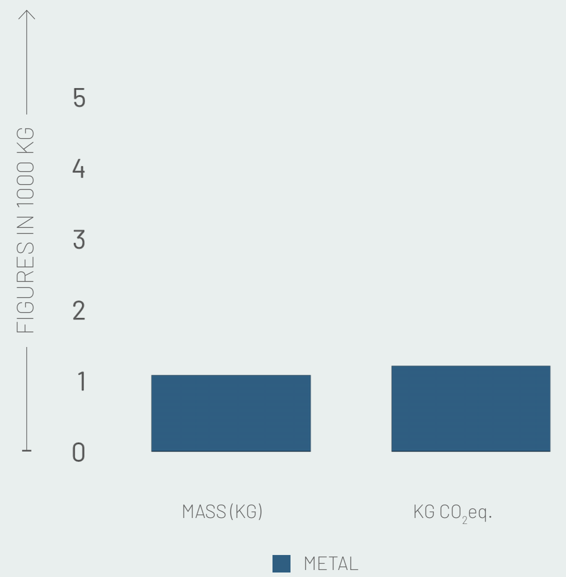
The bar on the left shows the building mass in kg grouped into material categories.

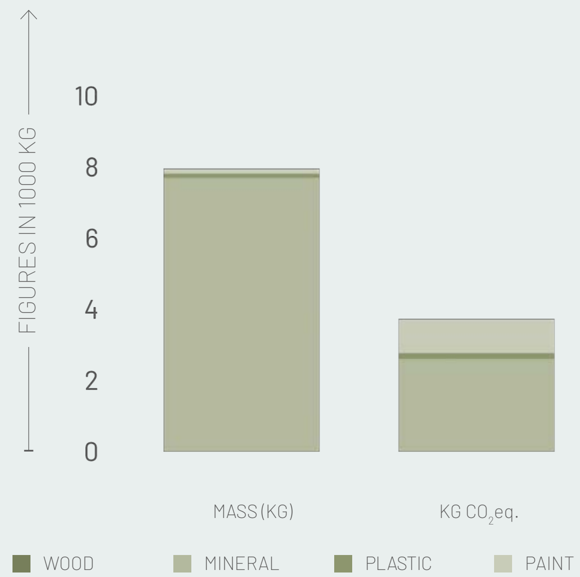
The bar on the right shows the building's total CO_2eq grouped similarly.

BIOGENIC MATERIALS — HYBRID MATERIALS — OTHER MATERIALS



MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG CO_2EQ.





A. FOUNDATION

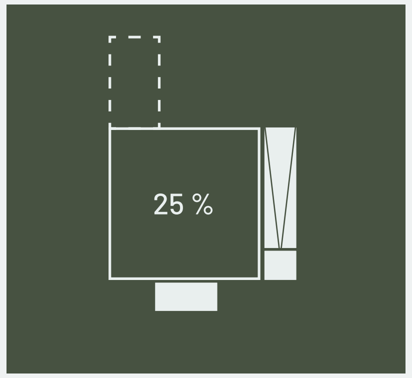
Steel screw-pile foundations

B. INTERIOR WALL

Timber cassette
Mineral wool insulation
Gypsum plasterboard
Vapour barrier
Paint

Developer: CPH Village

Year (built): 2020
Floor area: 146 m²
Reference area: 154 m²
Use: Student housing
Occupants: 8 units / block
Year (calculated): 2022
Heating: Heat pump
Solar cells: Yes



DESCRIPTION

The CPH Village Tunnelfabrikken is included as a 'pixie' case applying many of the same constructional principles as CPH Village Vesterbro, but focus has been on replacing many of the mineral materials used in insulation, for example, with bio-based materials.

The analysis is based on conservative estimates, which results in a 30% reduction of the total emissions of kg CO_2-eq/m²/year relative to case no. E08 (CPH Village Vesterbro).

The multi-storey housing accommodation totals 146 m² with room for 4 persons, assuming there is one occupant per unit. This gives a space allocation of approx. 37 m²/person, which is on the high side in the case collection. If we calculate with 2 occupants per unit (corresponding to one primary bedroom), the result is 8 occupants and an average space allocation of 18 m²/person. This is on the low side in the case collection.

Cassette

2-3 storeys

E09: CPH Village Tunnelfabrikken PIXIE CASE

4,72 kg CO_2eq./m²/year

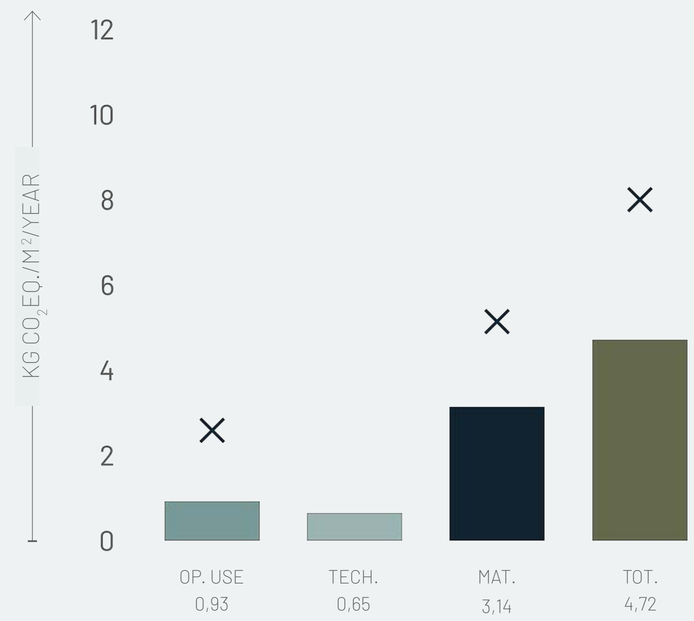


Figure E09.1: Emissions of kg CO_2eq./m²/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO_2eq./m²/year in multi-storey housing in the case collection.

29.282 kg CO_2eq.

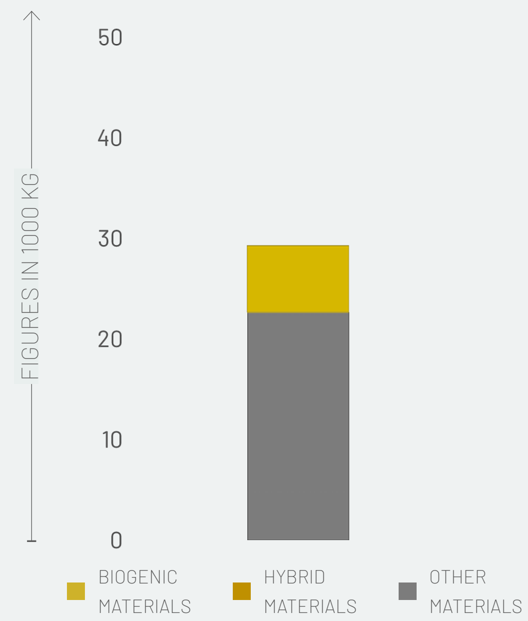


Figure E09.2: Total emission of kg CO_2eq.
The stacked bar chart shows the overall emission of kg CO_2eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

91 kg CO_2eq./person/year

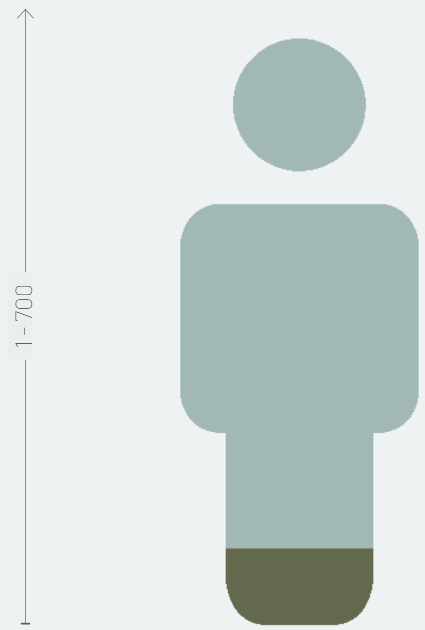


Figure E09.3: Emissions of kg CO_2eq./person/year
The span of the vertical axis is 1 to 700 kg CO_2eq./person/year

18 - 37 m²/person

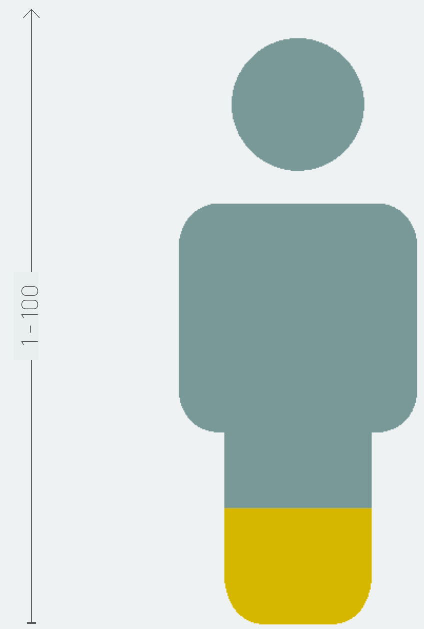


Figure E09.4: m²/person
The span of the vertical axis is 1 to 100 m²/person

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m²/year.

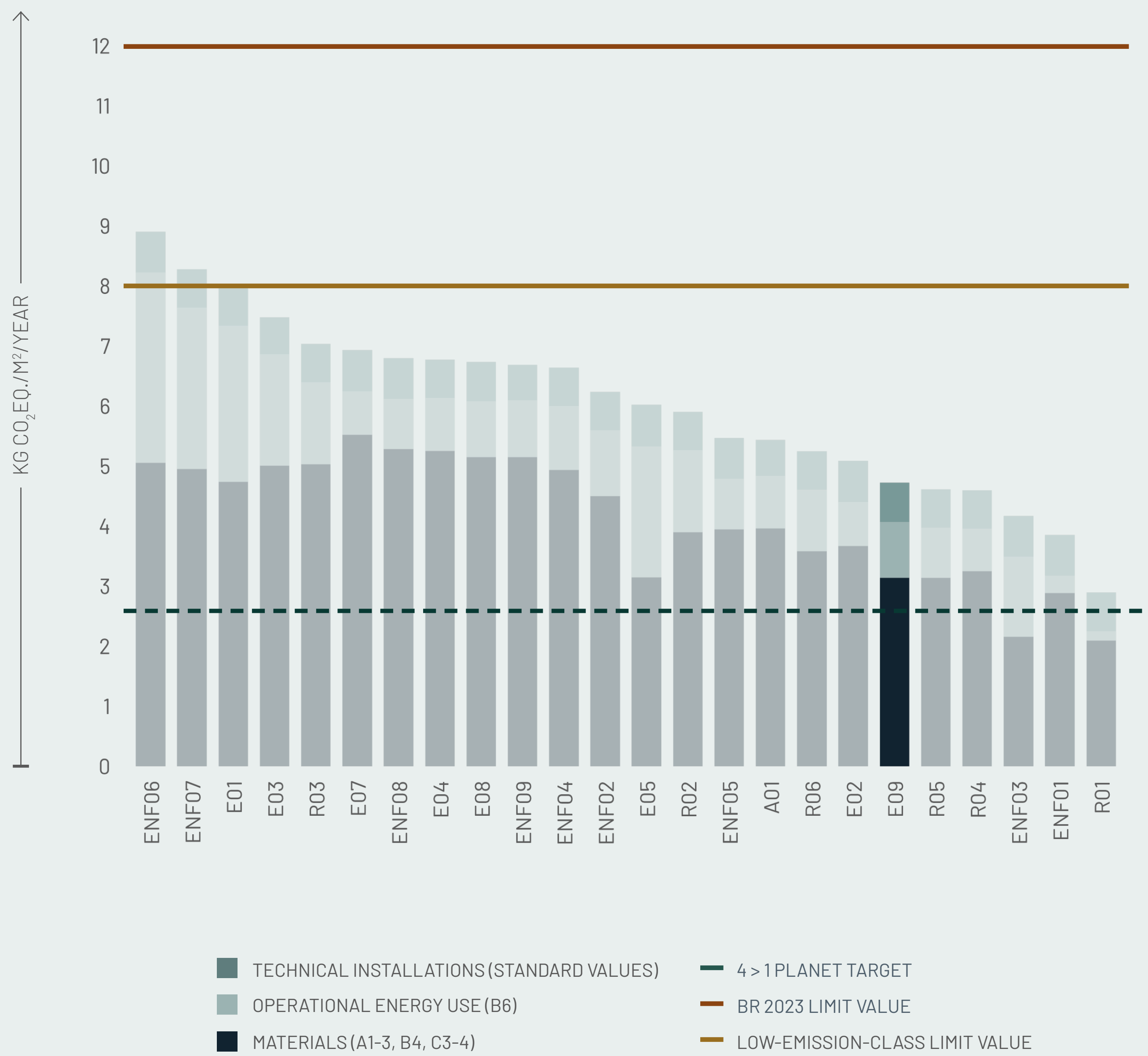


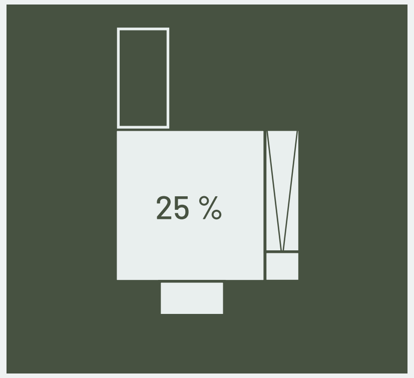
Figure E09.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m²/year. The horizontal axis shows the 24 best practice cases.

ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in CO_2eq./m²/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is well within the fastest reduction rate: the 83% likelihood scenario.

Figure E09.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq./m²/year, and the 'safe operating space'.

Developer:	AP Pension
Architect:	Henning Larsen Architects
Engineer:	Rambøll
Partners:	Teknologisk Institut Dansk Beton Unicon Aalborg Portland Realdania
Use:	Other
Year (BUILT):	2023
Floor area:	143 m^2
Reference area:	162 m^2
Occupants:	4 (calc. as single-family house)



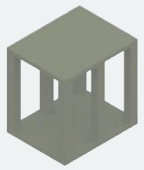
DESCRIPTION

The community centre Kanalbyen, Fredericia, is a new community centre, built to evolve new standards for the use of concrete. A chief focal point in the project has been to reduce the quantity of concrete and to test a mix of materials with reduced CO_2 emissions. An example of an innovative approach is the fact that the load-bearing concrete columns are produced by 3D printing, so that they can be made hollow rather than massive.

This one-storey building is built on screw-pile footings and continuous foundations. The grade deck is a mix of concrete and EPS insulation.

The supporting structures are concrete columns produced by 3D printing combined with steel girders. The lightweight storey deck is mass timber with , and the exterior walls are also wood-fibre insulated lightweight timber-framed walls supporting the glazed areas. Head and window frames are wooden and the panes are double-glazed. Interior walls are steel-framed and eelgrass functions as acoustic panelling. The roof is a concrete shell cast on site.

Since the building has not yet been constructed and is not a dwelling, a series of assumptions were made to render the results comparable with the other housing projects in the case collection. The operational energy use is average for the case collection, and the technical installations are standard values for single-family housing. To calculate the kg CO_2-eq/m^2/year, the estimated number of occupants is set at 4.



Hybrid

1 storey

A01: Aktivitetshus i Kanalbyen PIXIE CASE

5,43 kg CO_2eq./m^2/year

Figure A01.1: Emissions of kg CO_2eq./m2/year
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO_2eq./m^2/year in multi-storey housing in the case collection. In this particular case study, operational energy use is an average value from the single-family housing in the case collection and hence not a final result.

37.052 kg CO_2eq.

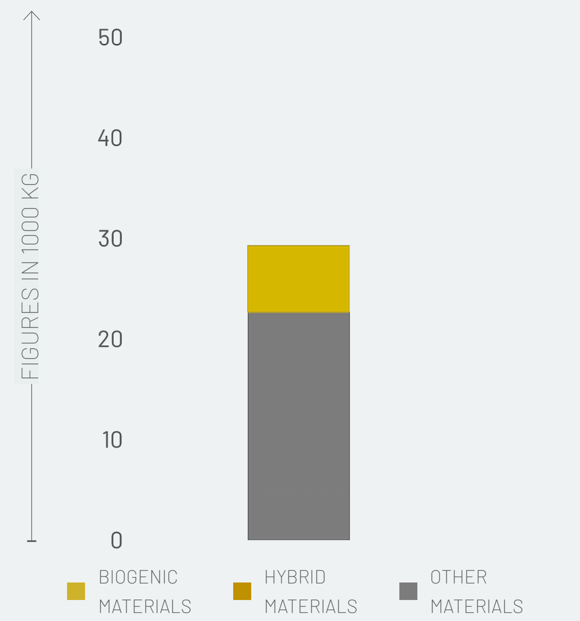


Figure A01.2: Total emission of kg CO_2eq.
The stacked bar chart shows the overall emission of kg CO_2eq in the study grouped into the three material categories: other, hybrids, and biogenic.

220 kg CO_2eq./person/year

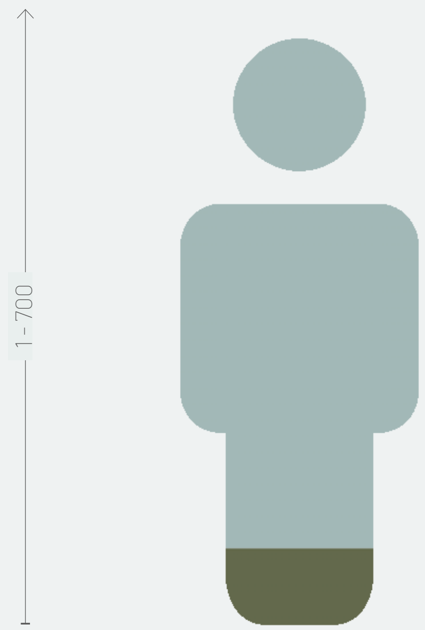


Figure A01.3: Emissions of kg CO_2eq./person/year
The span of the vertical axis is 1 to 700 kg CO_2eq./person/year

36 m^2/person

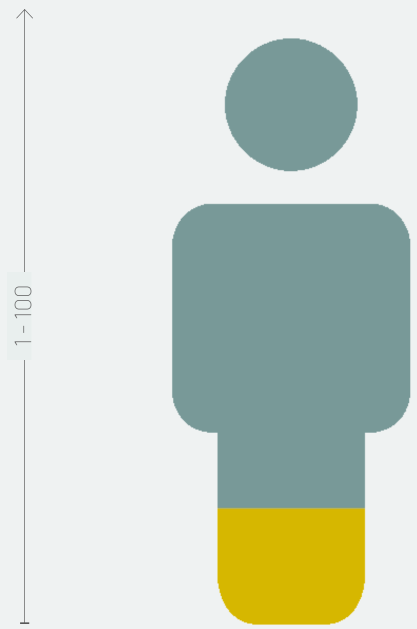


Figure A01.4: m^2/person
The span of the vertical axis is 1 to 100 m^2/person

ENVIRONMENTAL IMPACT IN RELATION TO OTHER BEST PRACTICE CASES

The specific case study is emboldened in the diagram, which shows emissions from the best practice cases, going from the highest to the lowest emission of kg CO_2eq./m^2/year.

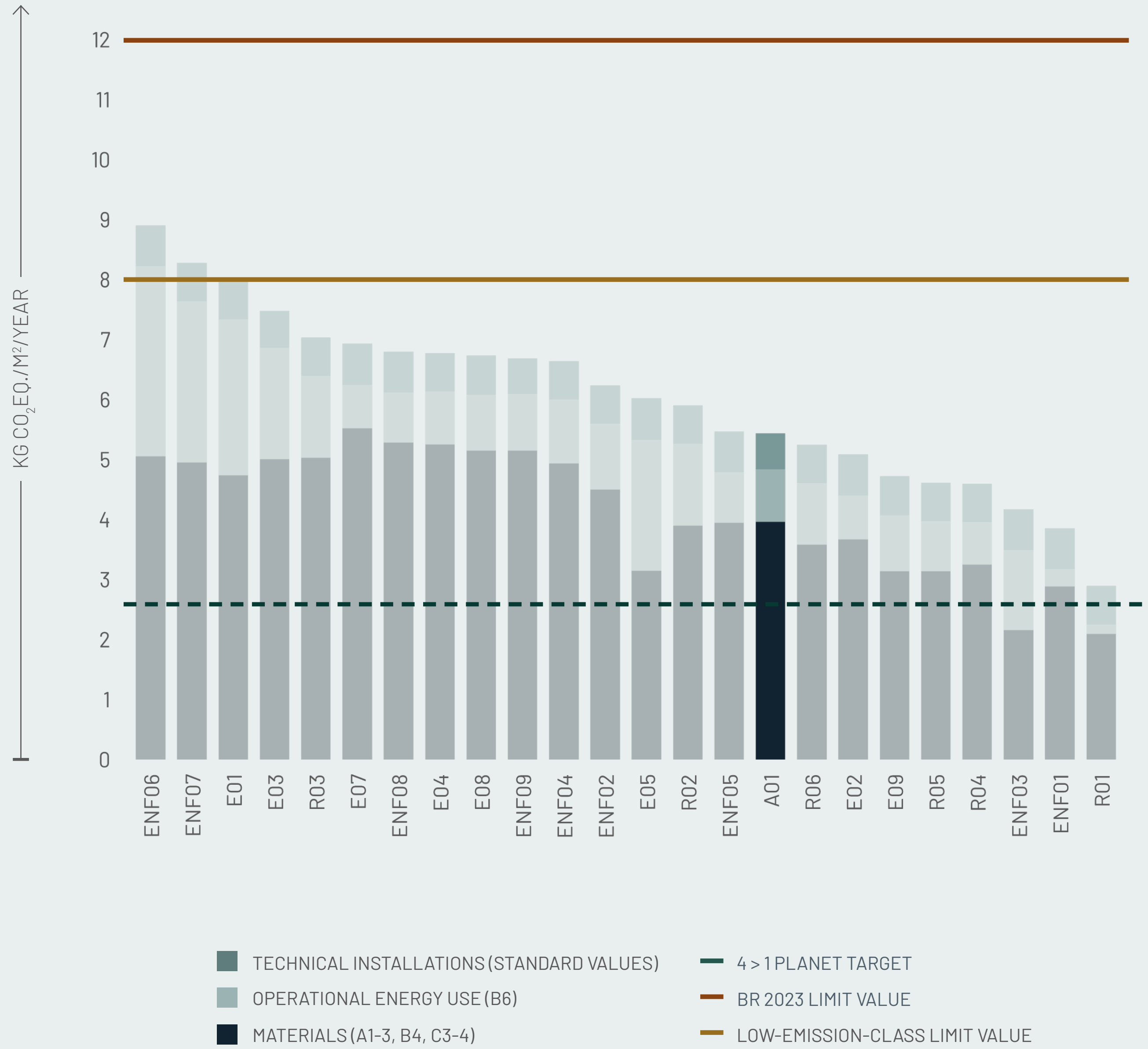


Figure A01.5: Housing case studies
The vertical axis shows the emission of CO_2eq./m^2/year. The horizontal axis shows the 24 best practice cases.

A01: Aktivitetshus i Kanalbyen PIXIE CASE

ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in CO_2eq./m^2/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is well within the fastest reduction rate: the 83% likelihood scenario.

Figure A01.6: Reduction Roadmap
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg CO_2eq./m^2/year, and the 'safe operating space'.

FINDINGS

CONCLUSION

ENVIRONMENTAL IMPACT RELATIVE TO LIMIT VALUES

This report presents life-cycle assessments of 24 best practice cases. Of these, the findings of 19 of the case studies are complete whereas the findings of the 5 pixie case studies are preliminary with a high degree of detail.

Of the 24 case studies, 22 meet the limit value of 8 kg CO_2eq/m²/year in the low-emission class. In half of the housing projects, inclusive of the collection's oldest project from 2010, environmental impact is halved relative to the applicable limit value of 12 kg CO_2eq/m²/year in the Building Regulations (Figure 25). One single study is outside the three probability scenarios in the Reduction Roadmap (Figure 15) and 22 come within the 83% likelihood scenario.

ENVIRONMENTAL IMPACT FROM MATERIALS

Most of the housing in this case collection is constructed with a large proportion of biogenic materials. Traditionally, heavy building components such as foundations, grade deck, and decks are redesigned, in several studies, from conventional concrete and steel solutions to material-reducing structures, solutions with biogenic materials or other material combinations that would reduce CO_2 emissions.

Emission of kg CO_2eq from materials total 78% of the total environmental impact from single-family housing in the case collection, 81% from terraced housing, and 79% from multi-storey housing.

In overall terms, the biogenic materials constitute 25% of the building mass and 15% of the environmental impact from the housing in the case collection (Figures 27–28). Other materials constitute approx. 75% of the building mass and are responsible for 85% of the environmental impact. Emissions from other materials occur here and now in connection with the Product stage (A1–3), whereas the emissions from the biogenic materials to a very large extent occur beyond the End-of-Life stage. This implies that emissions from the biogenic materials could potentially be less than indicated by the findings in this report, depending on which waste-processing method is used (p. 20).

There is a clear tendency in the report that the proportion of biogenic materials diminishes in tandem with the construction project getting more extensive (Figure 28). For example, the share of biogenic insulation materials in single-family housing appears predominant, whereas in larger-scale terraced and multi-storey housing, this appears to be supplemented or replaced with insulation materials common in conventional construction.

Among the more recent terraced and multi-storey housing, there are examples of grade decks and housing unit partitions (vertical and horizontal) constructed as timber frames and insulated with biogenic materials, indicating that changes in the use of materials in large-scale construction projects are underway.

ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

Foundations, grade decks, exterior walls, interior walls, decks, and roofs are those building components with the greatest environmental impact and are outlined briefly in the following section on structures. Windows play a significant role in the environmental impact of housing but will not be addressed from a structural perspective.

For single-family housing, foundations are responsible for 5.8%, grade decks for 14.3%, exterior walls for 18.2%, interior walls for 4.6%, decks for 2.3%, and roofs for 18.9% of environmental impact from materials. Windows are responsible for 18.8%.

For terraced housing, foundations are responsible for 9.2%, grade decks for 14.7%, exterior walls for 10.2%, interior walls for 10%, decks for 11.9%, and roofs for 11.4% of environmental impact from materials. Windows are responsible for 13%.

For multi-storey housing, foundations are responsible for 6.3%, grade decks for 9.9%, exterior walls for 13.2%, interior walls for 8%, decks for 14%, and roofs for 12,7% of environmental impact from materials. Windows are responsible for 11.5%.

THE THREE HOUSING TYPES: FINDINGS AND TENDENCIES

The best practice case collection shows the same trend in terms of environmental impact as conventional construction within the three housing types: single-family, terraced, and multi-storey housing (Figures 17–24).

In the case collection, single-family housing is built in materials with low CO_2 emissions, but many resources are still used for relatively few square metres, and as typology, single-family housing therefore has a high environmental impact, calculated both per square metre and per person. As in conventional construction, there is also a tendency to build more square metres per person than in other typologies (pp. 40–41).

As typology, terraced housing has the lowest environmental impact per square metre and per person. Further, this typology shows the smallest differences in the various findings, which might indicate that work to define a methodology to construct environmentally sustainable terraced housing has progressed further than for the other two typologies.

Multi-storey housing shows a greater variation in the different results than the other typologies, which might indicate that it is more difficult to optimise multi-storey housing and that a methodology to facilitate this is at an early developmental stage.

The amount of material per square metre is greater in single-family housing than in terraced housing (Figure 28). For single-family housing, the report concludes that this could be due to the large climate envelope where the building components with the highest emissions are found.

As for the multi-storey housing in the case collection, it is harder to draw conclusions across the eight cases. In some of the cases responsible for the highest emissions, we note a large material consumption, which should prompt considerations about how many storeys should be built, which materials to use and, not least, in which subsoil conditions multi-storey housing should be built.

BUILDING COMPONENTS

FOUNDATIONS

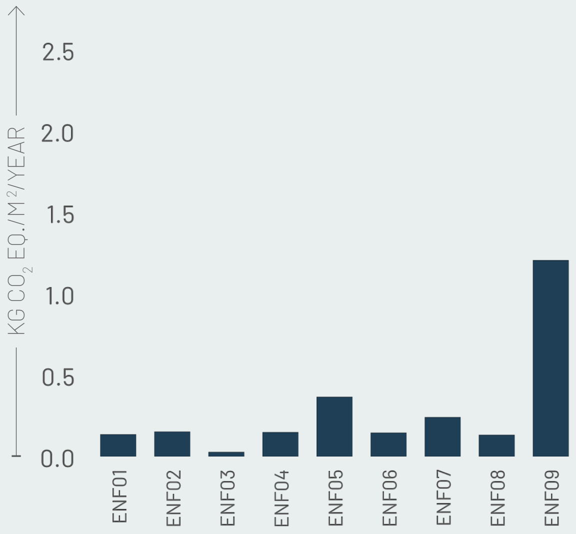
SINGLE-FAMILY HOUSING

Screw-pile foundations (ENF01)

Continuous foundations under concrete basement (ENF02)

Screw-pile foundations (ENF: 03, 04, 05, 06, 07, 08)

Continuous foundations in concrete with lightweight aggregate blocks and EPS insulation (ENF09)



TERRACED HOUSING

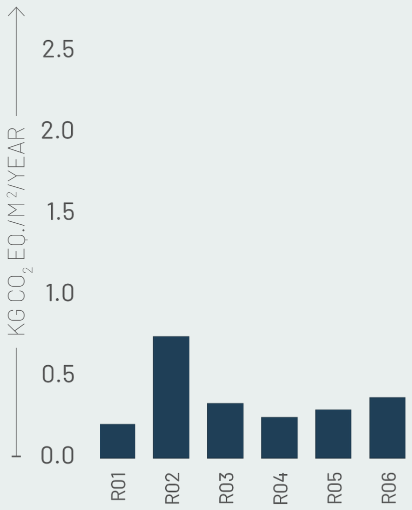
Continuous foundations in concrete with lightweight aggregate blocks (R01)

Reinforced concrete pile foundations and continuous foundations in lightweight aggregate blocks and PIR foam insulation (R02)

Point foundations in concrete with steel girders (R03)

Continuous and pile foundations in concrete with EPS and foamed glass insulation (R04)

Continuous foundations in concrete with lightweight aggregate blocks (R:05, 06)



MULTI-STOREY HOUSING

Pile foundations and foundation slab in reinforced concrete (E01)

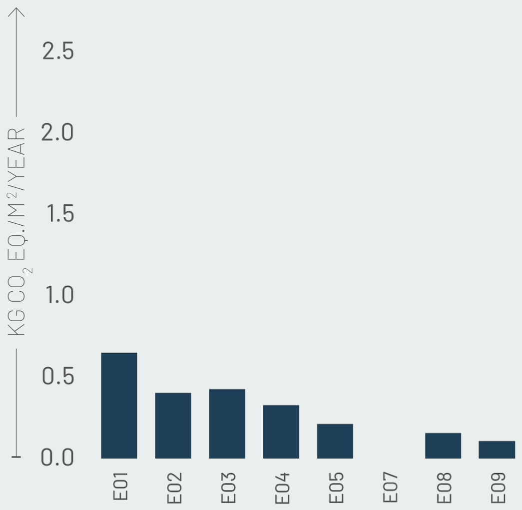
Concrete, lightweight aggregate blocks, and EPS (E02)

Wall and continuous foundations in concrete insulated with EPS (E03)

Continuous concrete foundations (E04)

Concrete with PIR insulation E05)

Screw-pile foundations (E:08, 09)



GRADE DECKS

SINGLE-FAMILY HOUSING

Lightweight timber cassettes insulated with cellulose (ENF01)

Reinforced concrete deck insulated with EPS (ENF02)

Timber-frame structure insulated with wood-fibre and eelgrass (ENF03)

Timber module insulated with blown-in wood-fibre (ENF04)

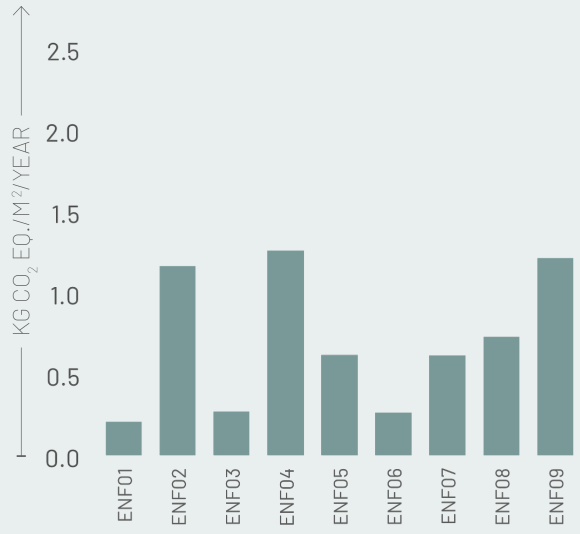
Timber cassettes insulated with wood-fibre (ENF05)

Steel structure insulated with wood-fibre and cellulose (ENF06)

Timber frame structure insulated with recycled EPS (ENF07)

Timber-frame structure insulated with wood-fibre and straw-bale (ENF08)

Reinforced concrete deck insulated with EPS (ENF09)



TERRACED HOUSING

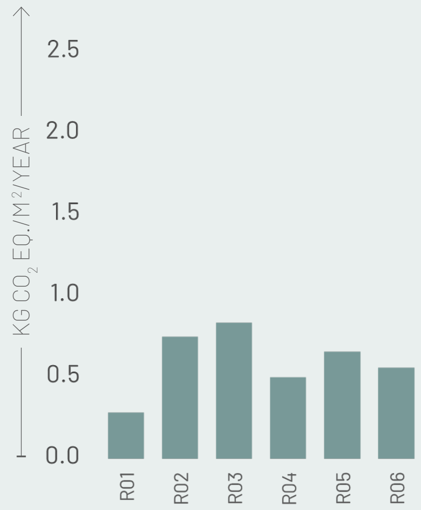
Reinforced concrete deck of low-emission cement insulated with stone wool (R01)

Concrete deck and EPS (R02)

Modules of prefabricated glulam and pressure-resistant plywood insulated with mineral wool (R03)

Timber cassettes insulated with mineral wool and EPS (R04)

Timber frame insulated with cellulose on an underlay of EPS (R05, R06)



MULTI-STOREY HOUSING

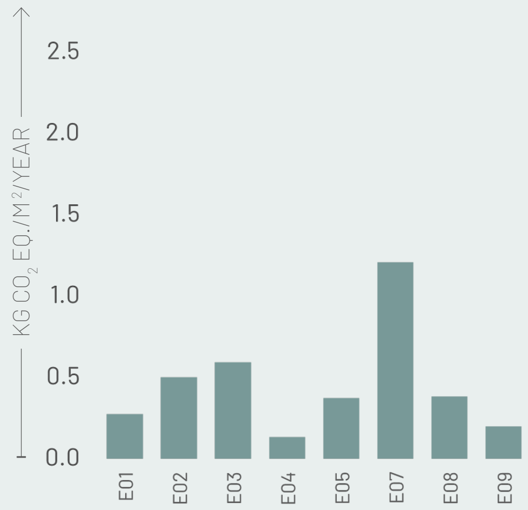
Concrete deck and EPS (E: 01, 02)

Timber structure insulated with mineral wool and EPS with fibre-cement cladding (E03)

Timber modules insulated with mineral wool (E04) Concrete deck and EPS (E05)

Reinforced concrete foundation slab with a stamped-clay surface of (E07)

Timber cassettes insulated with mineral wool (E:08, 09)



EXTERIOR WALLS

SINGLE-FAMILY HOUSING

Facade cassettes and supporting structures in glulam insulated with cellulose and wood fibre (ENF01)

Mass timber and CLT insulated with cellulose and wood fibre (ENF02)

Timber-frame walls insulated with eelgrass (ENF03)
Timber cassette modules insulated with wood-fibre (ENF04)

Timber-frame walls insulated with wood-fibre (ENF05)

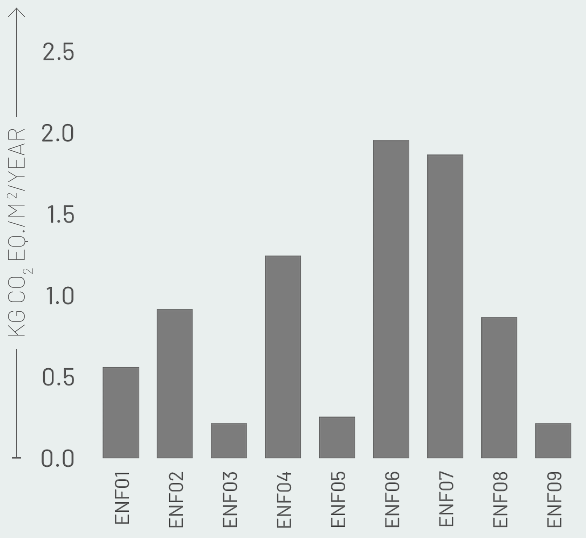
Timber and steel structure insulated with cellulose and wood-fibre, facade cladding of brick, wood, and cork (ENF06)

Frame structures in timber and reused materials from steel containers insulated with cellulose (ENF07)

Timber-frame structure insulated with wood fibre and straw bales (ENF08)

Timber-frame walls with wood-fibre insulation (ENF09)

Timber facade cladding (ENF:01, 02, 03, 04, 05)



TERRACED HOUSING

Facade cassettes and supporting structures in glulam insulated with cellulose and mineral wool (R01)

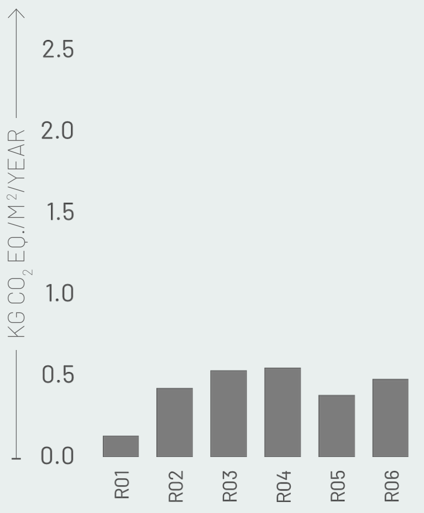
CLT timber modules insulated with glass wool (R02)

Timber cassette modules insulated with mineral wool (R03)

Timber modules insulated with mineral wool and slate and cedar wood facade cladding (R04)

Timber cassettes with cellulose and mineral wool insulation (R: 05, 06)

Timber facade cladding (R: 01-02-03-05, 06)



MULTI-STOREY HOUSING

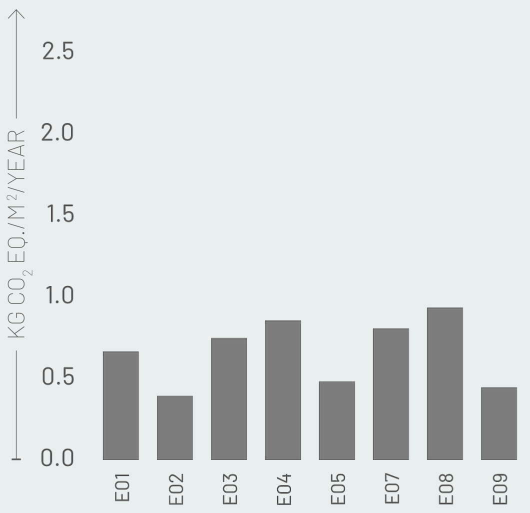
Load bearing structures in CLT, glulam, and steel, lightweight timber-frame walls insulated with wood fibre and mineral wool (E01)

Lightweight structures as supporting and lightweight exterior walls insulated with mineral wool with a facing of fibre-gypsum boards and timber (E02)

Timber cassette module insulated with:
(A) mineral wool – slate and timber facing (E03)
(B) mineral wool – timber facing (E08)
(C) wood fibre – timber facing (E09)

Timber cassette module insulated with mineral wool:
(A) with a black-painted timber facing (E04)
B) with slate facing (E05)

Glulam columns and CLT – insulated on the outside with flax fibres and stamped clay (E07)



INTERIOR WALLS

SINGLE-FAMILY HOUSING

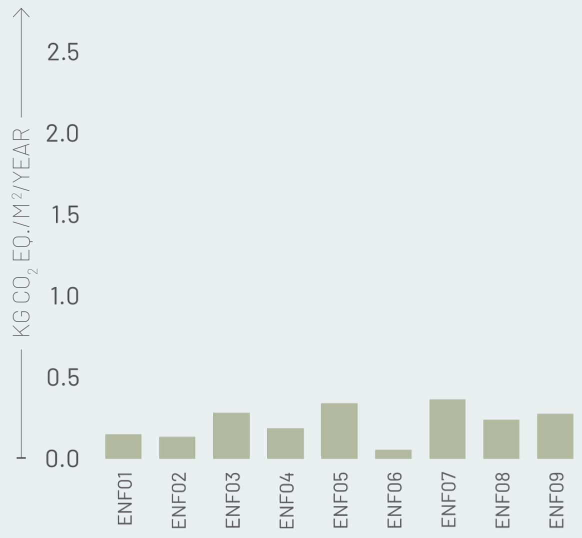
Timber-frame walls insulated with wood fibre – plywood and fibre gypsum facing (ENF:01, 09)

Timber-frame walls with cellulose insulation – gypsum facing (ENF02)

Timber-frame walls with eelgrass insulation – plywood facing (ENF03)

Timber-frame walls with wood-fibre insulation – gypsum facing (ENF: 04, 05, 06)

Frame structures in timber and reusables from steel containers insulated with cellulose (ENF07)



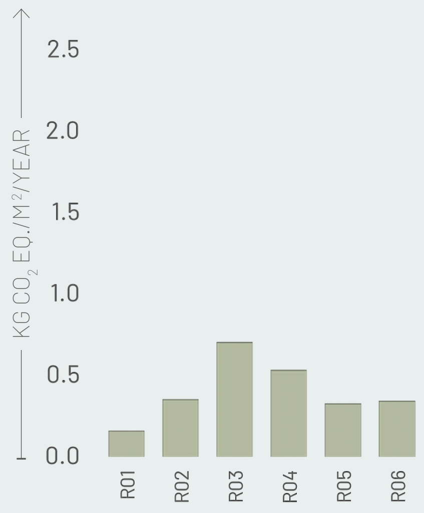
TERRACED HOUSING

CLT and timber-frame walls insulated with mineral wool – gypsum facing (R01)

CLT walls insulated with mineral wool – gypsum facing (R02)

Timber cassettes insulated with mineral wool (R:03, 04)

Timber cassette modules and timber-frame walls insulated with cellulose and mineral wool – gypsum facing (R: 05, 06)



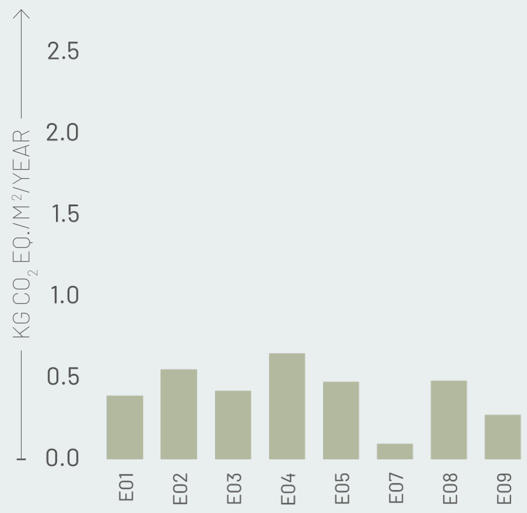
MULTI-STOREY HOUSING

Load bearing structures in CLT, glulam and steel, lightweight timber-frame walls – insulated with wood-fibre and mineral wool, fibre gypsum facing (E01)

Aerated concrete and timber-frame walls with mineral wool insulation – fire-rated gypsum facing (E02)

Timber-frame structures with cement particle board and mineral wool insulation – fire-rated gypsum facing (E03)

Cassette module with supporting structures in timber, insulated with mineral wool and a facing of:
(A) gypsum and timber (E04)
(B) gypsum (E: 05, 08, 09) (09 with wood-fibre insulation)



DECKS

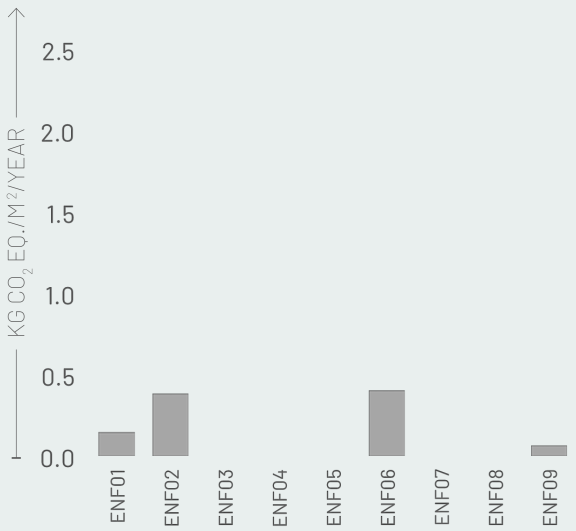
SINGLE-FAMILY HOUSING

Ribbed deck in mass timber with footfall insulation membrane and plywood (ENF01)

CLT deck with cellulose and wood-fibre insulation (ENF02)

Grade deck covering:
(A) integral flooring (ENF: 03, 04, 05, 07, 08)
(B) wooden flooring and terrace (ENF09)

Timber and steel structure with plywood and wood-fibre insulation (ENF06)



TERRACED HOUSING

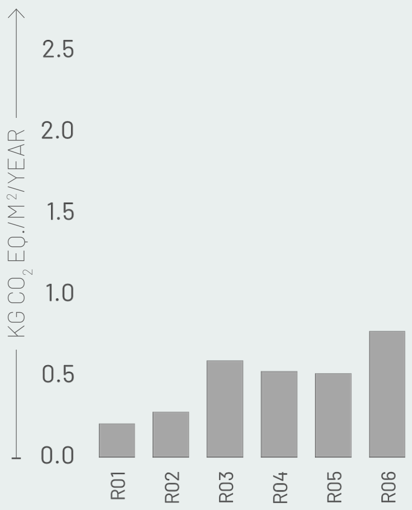
Ribbed deck construction in mass timber with footfall insulation membrane and plywood (R01)

CLT deck (R02)

Timber structures with mineral wool insulation, sound-dampening profile and felt (R03)

Timber cassettes with mineral wool insulation and fire-rated gypsum boards (R04)

Supporting timber frames with cavities and cement particle board – insulated with cellulose (R:05, 06)



MULTI-STOREY HOUSING

Ribbed deck with CLT and glulam – insulated with cellulose (E01)

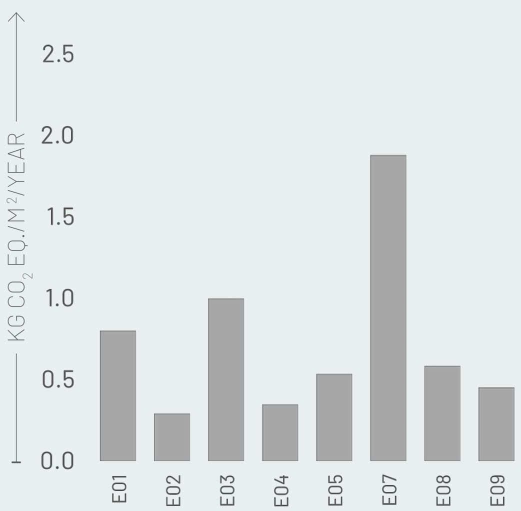
Timber-frame structure and steel and concrete structure – insulated with mineral wool, fire-rated gypsum facing (E02)

Frame structures in timber with cement particle board, mineral wool insulation, and fire-rated gypsum (E03)

Timber cassette module insulated with:
(A) mineral wool (E:04, 05)
(B) vertical and horizontal stone wool (fire stop) (E05)

Structure with cement-bonded wood wool and flax insulation (E07)

Timber cassette with particle board – insulated with mineral wool (E08) and wood fibre (E09)



ROOFS

SINGLE-FAMILY HOUSING

Timber cassette structure insulated with cellulose – zinc-magnesium-coated sheeting and bituminous felt (ENF01)

Timber structure insulated with cellulose and covered with integral photovoltaic modules (included in "electrical and mechanical systems") (ENF02)

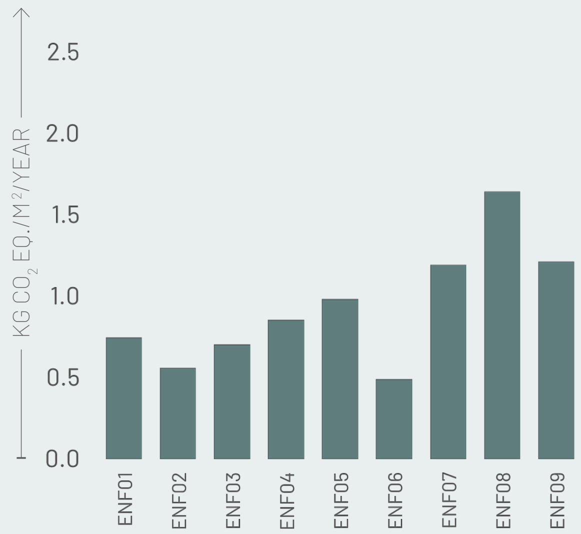
Timber-frame structure insulated with eelgrass (ENF03)

Timber structure with wood-fibre insulation (ENF: 04, 05, 09)

Timber and steel structure with plywood and wood-fibre insulation (ENF06)

Timber and steel structure with reusables from steel containers – insulated with cellulose (ENF07)

Bituminous felt (ENF:03)
Sedum roof (ENF: 04, 09)
Steel sheeting (ENF: 05, 06 (reuse))



TERRACED HOUSING

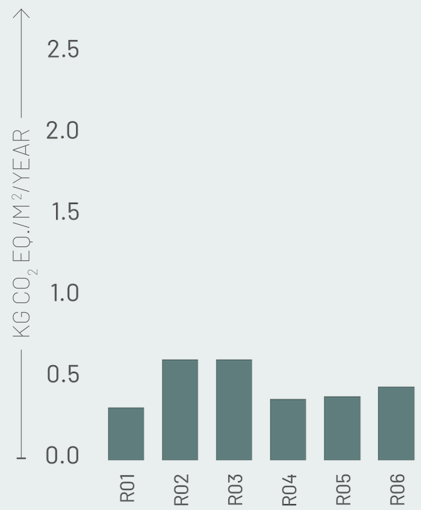
Timber cassette structure insulated with cellulose – slate and bituminous felt facing (R01)

Timber cassette structure with plywood – insulated with mineral wool and clad with bituminous felt (R02)

Glulam structure with mineral wool insulation, sedum and bituminous felt roofing (R03)

Timber cassettes insulated with mineral wool and a facing of bituminous felt, roof overhang (R04)

Supporting timber frames with cavities – insulated with cellulose and bituminous felt (R:05, 06)



MULTI-STOREY HOUSING

Timber beam and rafter structure with OSB and fibre gypsum boards – insulated with mineral wool. Steel sheet facing (E01)

Timber lattice-truss structure with roof overhang, mineral wool insulation, and a sedum roof (E02)

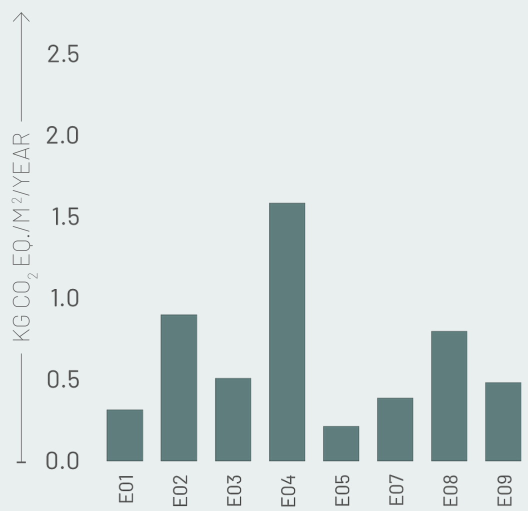
Glulam structure with vented cavity space and fire-rated gypsum – insulated with pressure-resistant mineral wool. Sedum and bituminous felt roofing (E03)

Glulam structure with a facing of clear polycarbonate (E04)

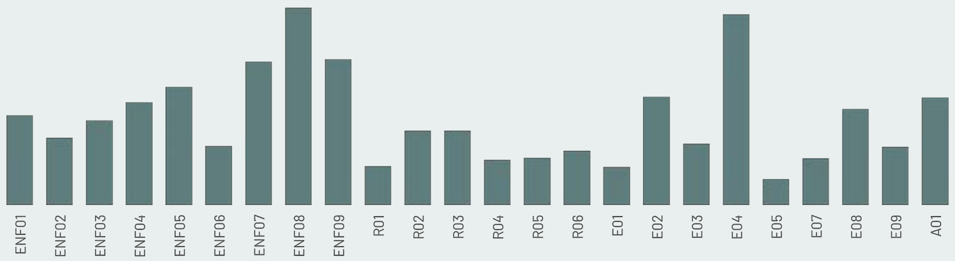
Timber cassette module insulated with:
(A) mineral wool with a facing of bituminous felt (E:04, 05)
(B) part of the roof doubling as roof terrace (E05)

CLT structure, interior insulation of flax fibres, stamped clay – brick facing (E07)

I-beams, plywood with a bituminous felt facing – insulated with:
(A) mineral wool (E08)
(B) wood fibre (E09)



SUMMARY

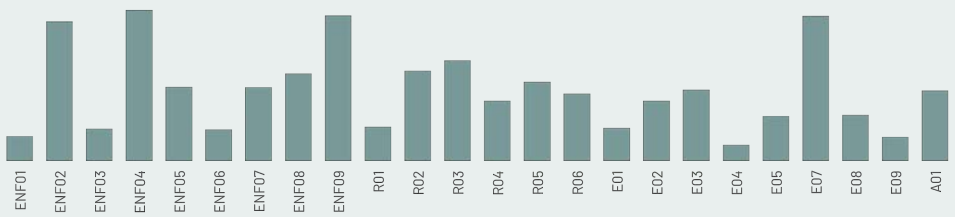


FOUNDATIONS:

Construction types vary among the typologies in the case collection. Screw-pile foundations are preferred in the single-family housing category.

For non-prototype housing, other types of foundations tend to be preferred, possibly indicating barriers experienced by, for example, clients.

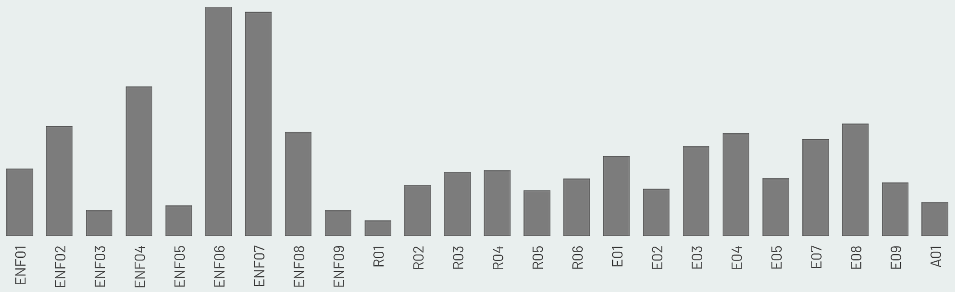
Concrete foundations and lightweight aggregate blocks are the commonest solutions for terraced and multi-storey housing.



GRADE DECKS:

Timber structures feature frequently in the case collection typologies.

Insulation materials vary from eelgrass, wood fibre, cellulose, mineral wool, and EPS – tending to be "less biogenic" in larger construction projects – in particular, the case collection's single-family housing uses biogenic insulation materials in grade decks.



EXTERIOR WALLS:

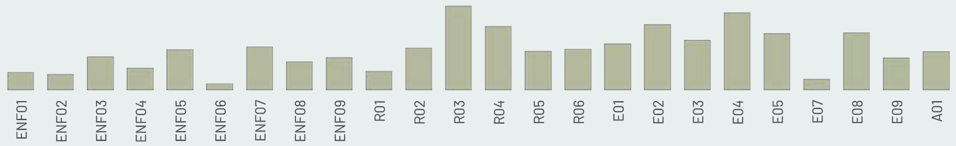
Timber-frame walls feature frequently in the case collection as both exterior and interior walls.

Insulation materials in timber-framed walls are often bio-based; cellulose and wood-fibre insulation being a very frequent choice.

In large-scale construction, prefabricated modules are frequently used, often timber with mineral wool insulation.

Timber and slate are the preferred facing materials.

SUMMARY

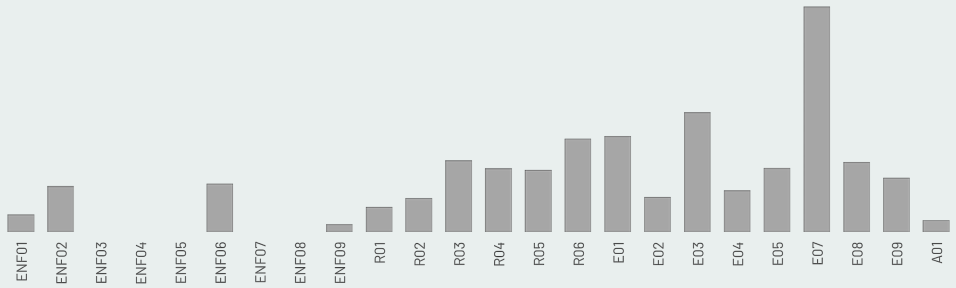


INTERIOR WALLS:

Timber-frame walls are the predominant construction type for interior walls in single-family housing, usually with bio-based insulation materials.

Timber-frame and CLT walls are the predominant construction type for interior walls in terraced housing with a mixed use of bio-based and mineral insulation materials.

Mineral wool and gypsum are commonly used in partitions (water and vertical boundaries) Few occurrences of concrete, however, a significant occurrence of cement-based particle board.

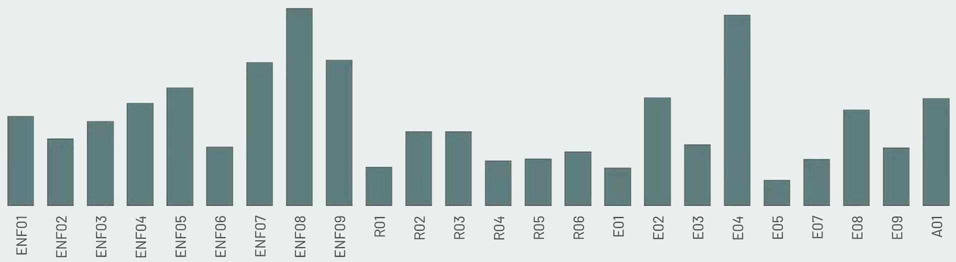


DECKS:

The case collection's most innovative solutions occur in storey partitions, timber structures with wood fibre, sound-dampening membranes, cavity spaces.

Quite a few hybrid structures but no pure concrete decks.

Numerous examples in the case collection of structures using cassette modules, often separated by layers of mineral insulation materials.



ROOFS:

Often construction principles identical to those in the rest of the building; solutions with breathable constructions occur frequently.

The preferred facing material in the case collection is bituminous felt, but there are also steel roofing and a couple of sedum roofs.

Many cases have photovoltaic modules installed on the roof.

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Figur 05a: Planetary boundaries (April 22, as seen in 1st DK edition of this report)
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