BUILD
REPORT

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# Housing construction from **4 to 1 planet:**

# 25 Best Practice Cases

Agnes Garnow, Buket Tozan, Lea Hasselsteen Nielsen, Liv Kristensen Stranddorf,
Kin Sun Tsang, Camilla Ernst Andersen, Christian Grau Sørensen og Harpa Birgisdóttir

# Housing construction from 4 to 1 planet:
# 25 Best Practice Cases


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# 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.


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.


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 $CO_2$eq./m$^2$/year to 2.5. kg $CO_2$eq./m$^2$/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 25 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 25 case studies, 19 are complete, i.e. the underlying data set is sufficient to present an aggregate result of the environmental impact. The remaining six, 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.

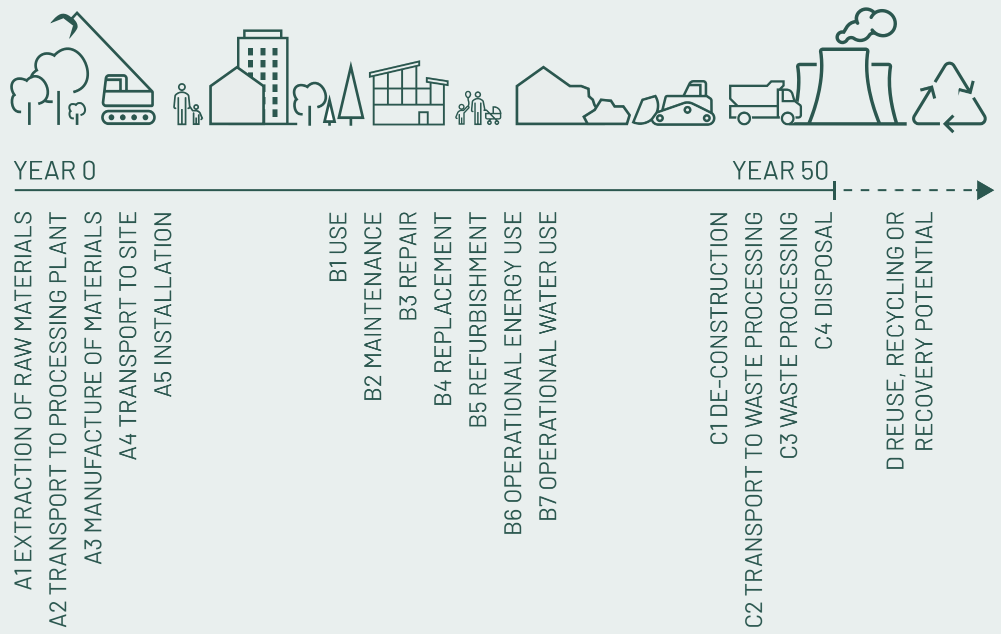



**Figure 02: Life-cycle stages and related modules**
Whole Life Carbon Impact from: 45 Timber Buildings (Andersen, C. M. E. et al., 2023)

# 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 $CO_2$eq. (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.

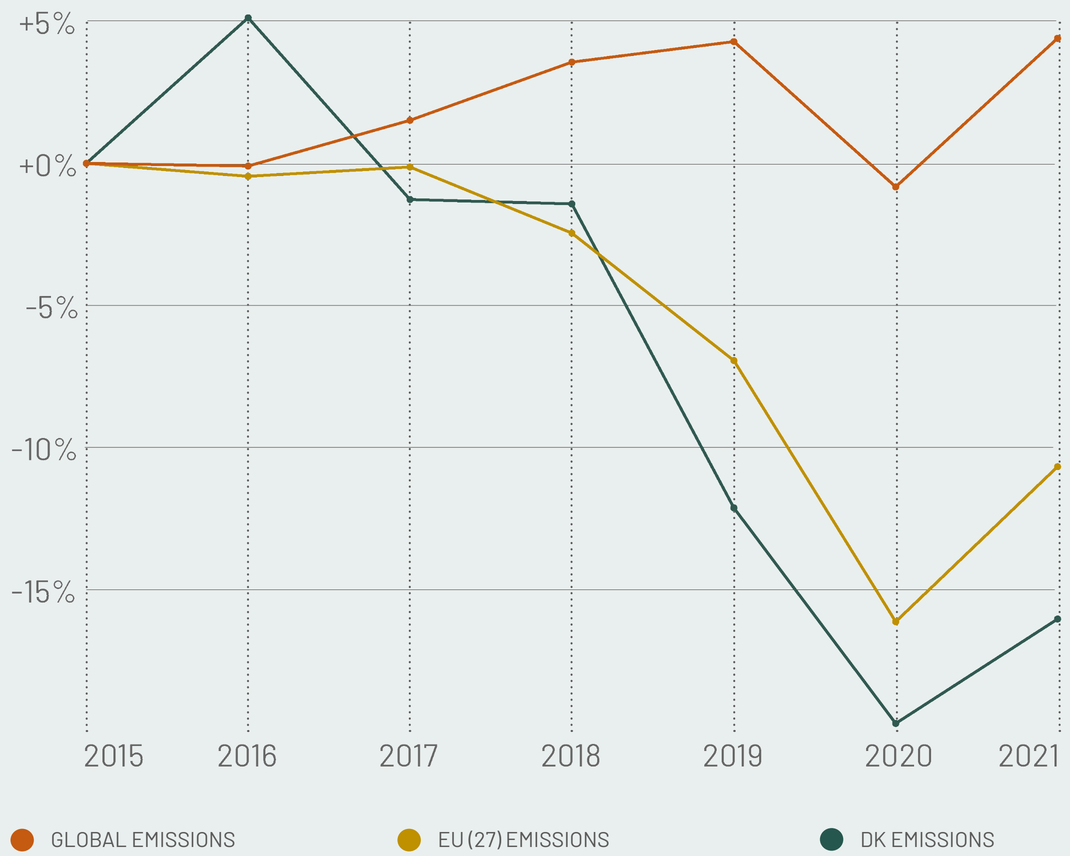



**Figure 03: Global emission trends 2015–2021 (Global Carbon Budget, 2022)**
Rises and reductions in emissions are shown in the vertical axis as percentages. Years are shown in the horizontal axis.



# 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 $CO_2$eq./$m^2$/year, whereas the voluntary low-emission class is 8 kg $CO_2$eq./$m^2$/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.

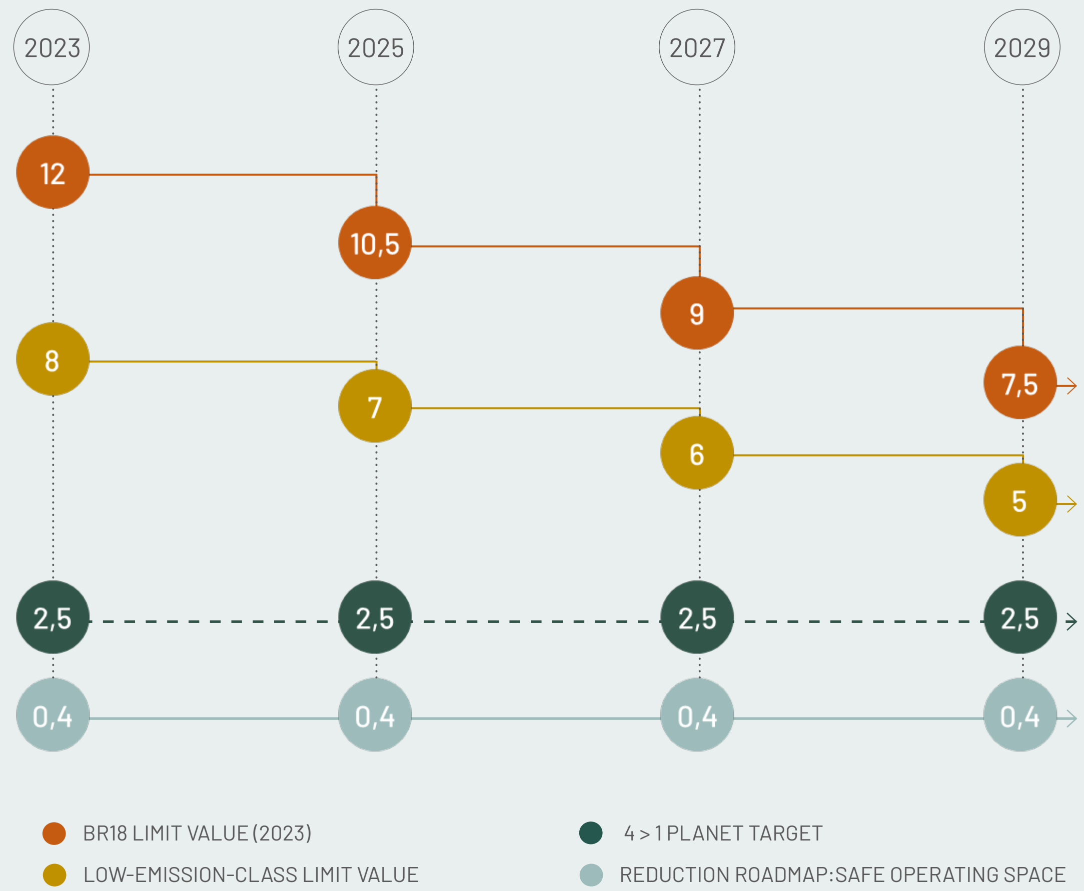



**Figure 04: Time schedule for climate targets and limit values for emissions of kg $CO_2$eq./$m^2$/year**

# 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 $CO_2$eq.) is a value denoting emission of several greenhouse gases, whose contribution to global warming is calculated relative to carbon dioxide ($CO_2$).

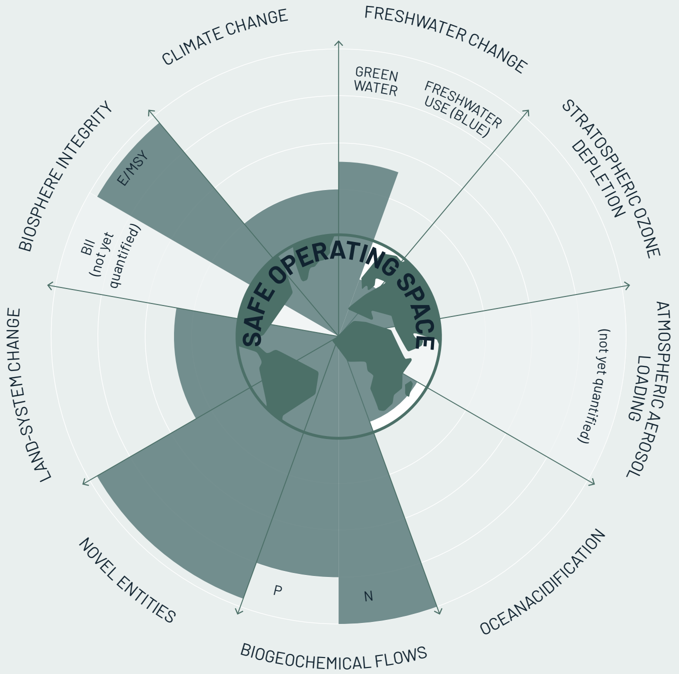



**Figure 05a: Planetary boundaries (April 22, as seen in 1st DK edition of this report)**
Azote for Stockholm Resilience Centre, based on analysis in Wang-Erlandsson et al. 2022

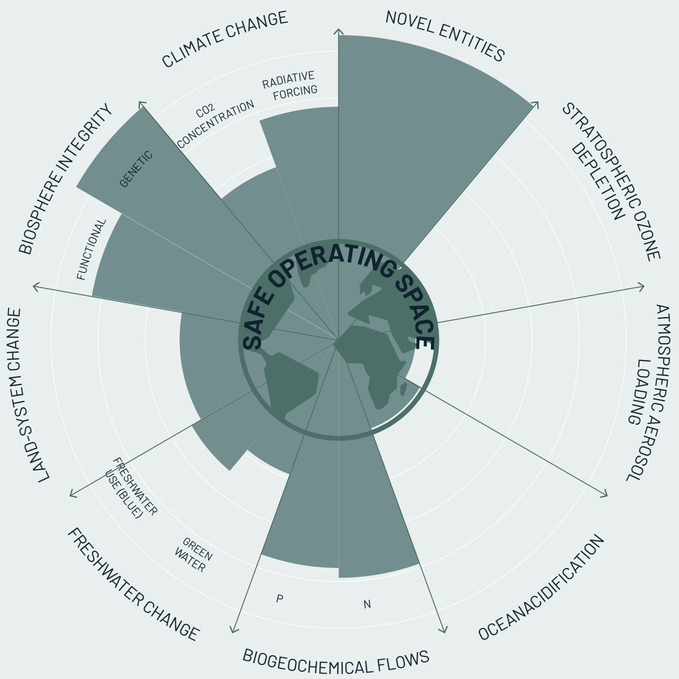



**Figure 05b: Planetary boundaries (Sept 23, updated in 2nd edition and translation)**
Azote for Stockholm Resilience Centre, based on analysis in Richardson et al. 2023



# REDUCTION ROADMAP

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 $CO_2$eq./m$^2$/year (Tozan, B. et al., 2021), ending – with the current rate of building activities – with a reduction target of 0.4 kg $CO_2$eq./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.

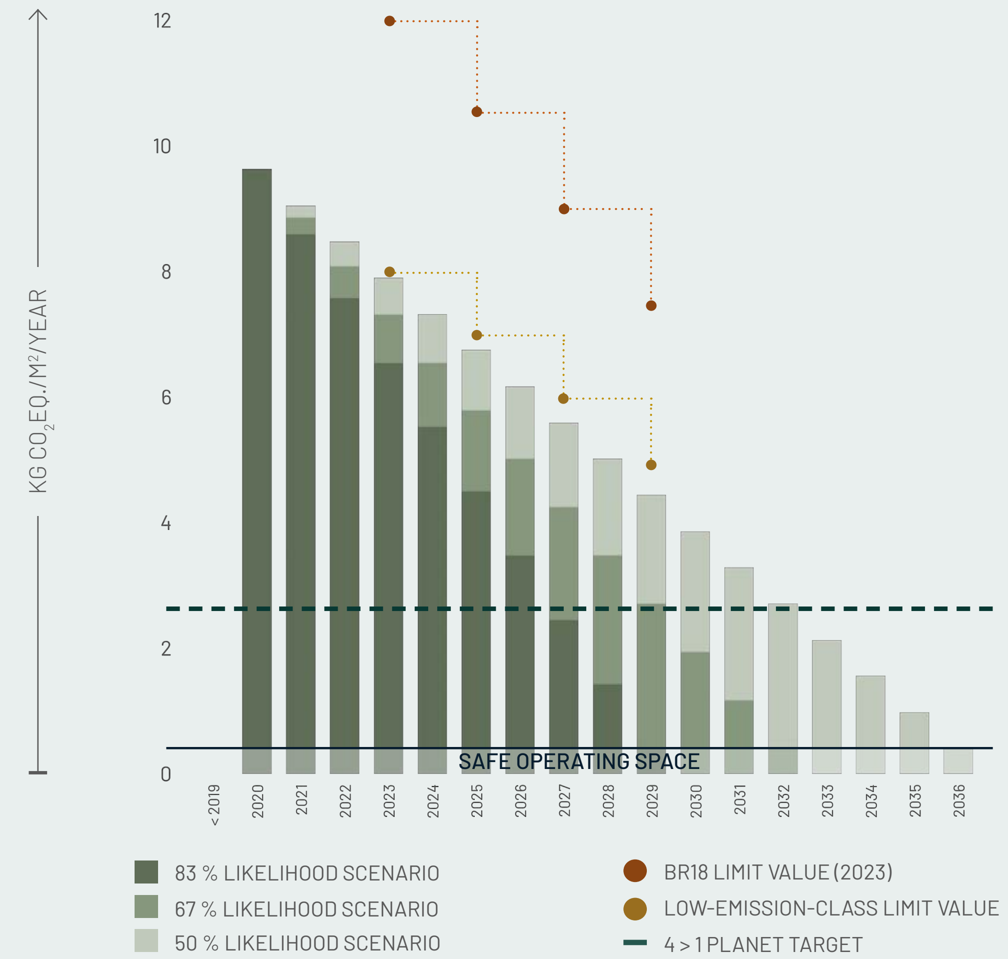



**Figure 06: Reduction Roadmap**
Reduction Roadmap, 2022

# 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 (16 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
- Winter 2023: 2nd edition of danish report published
- Winter 2023: 1st edition of english report published

# 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 25 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%.

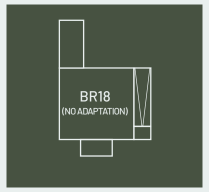



**Figure 08. BR18 (2023) without adaptations**

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

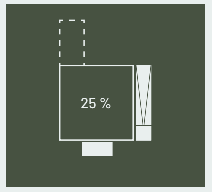



**Figure 09. 25%**

Cases adapted relative to 2 and/or 4.

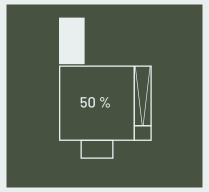



**Figure 10. 50%**

Cases adapted relative to 3.

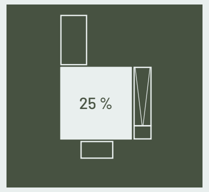



**Figure 11. 25%**

Cases adapted relative to 5.

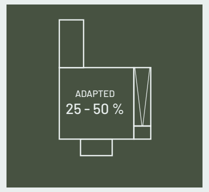



**Figure 12. 25 - 50 %**

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 for 24 of the 25 case studies.

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.

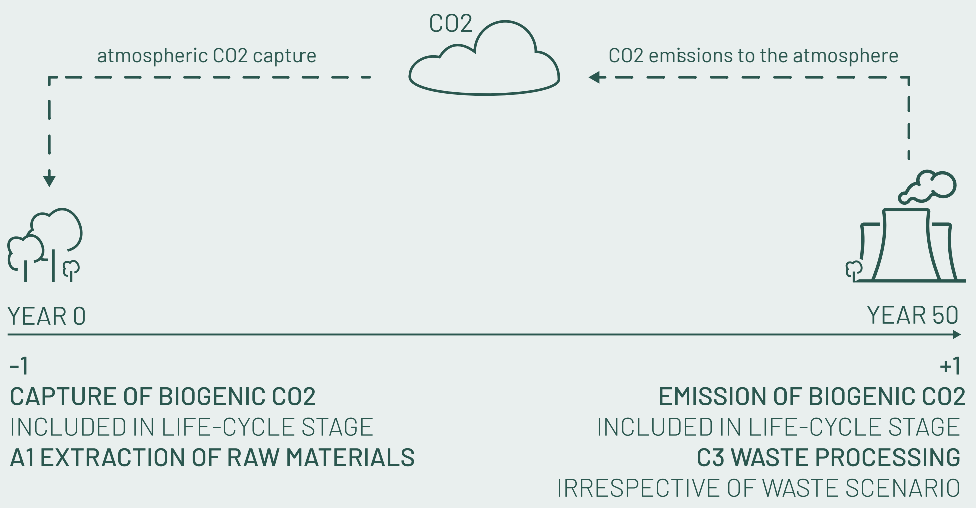



**Figure 13: Biogenic $CO_2$**
Whole Life Carbon Impact from 45 Timber Buildings (Andersen, C. M. E. et al., 2023)





## REUSE

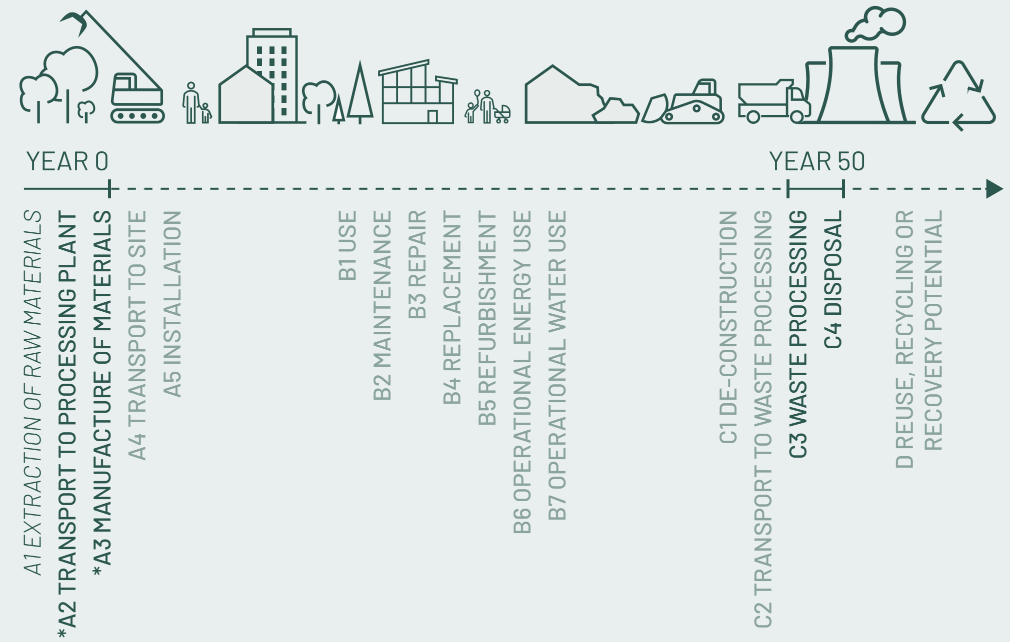
According to the Building Regulations (BR18), environmental data from the generic data set or from environmental product declarations (EPDs) should be used to describe the environmental impact from materials used in a building. At present, no data exists on reusable materials in the BR18 generic data 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 se-ction 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 housing (single-family, terraced, and multi-storey) in 24 of the 25 case studies.

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 $CO_2$eq./$m^2$/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 $CO_2$eq./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 $CO_2$eq 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 $CO_2$eq 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

**E06 (MULTI-STOREY)**
FJORDUDSIGTEN
BUILT 2021
335 $m^2$
2 STOREYS
8 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 25 case studies, 22 come within the 83% likelihood scenario.

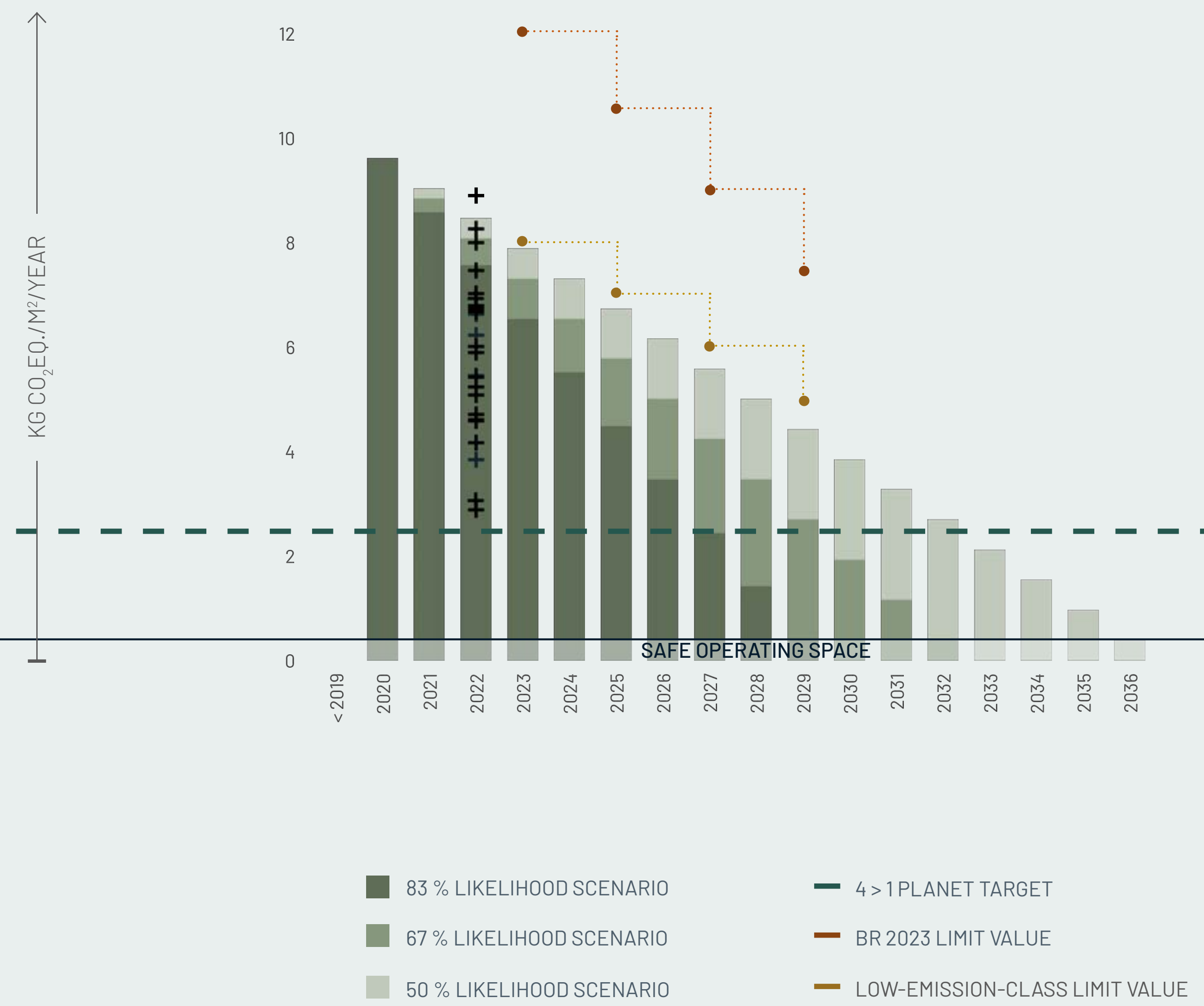



**Figure 15: Reduction Roadmap**
The 25 best practice cases are shown with 2022 as year start and in relation to the Reduction Roadmap and 4 t 1 planet goal of 2.5 kg $CO_2$eq./m²/year shown here.



# BPC > ACTUAL YEAR OF CONSTRUCTION

This shows the 25 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 $CO_2$eq./m²/year, and the results for two cases built in 2014 and 2019, respectively, are around 5 kg $CO_2$eq./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 $CO_2$eq./m²/year below the limit value of 12 kg $CO_2$eq./m²/year.

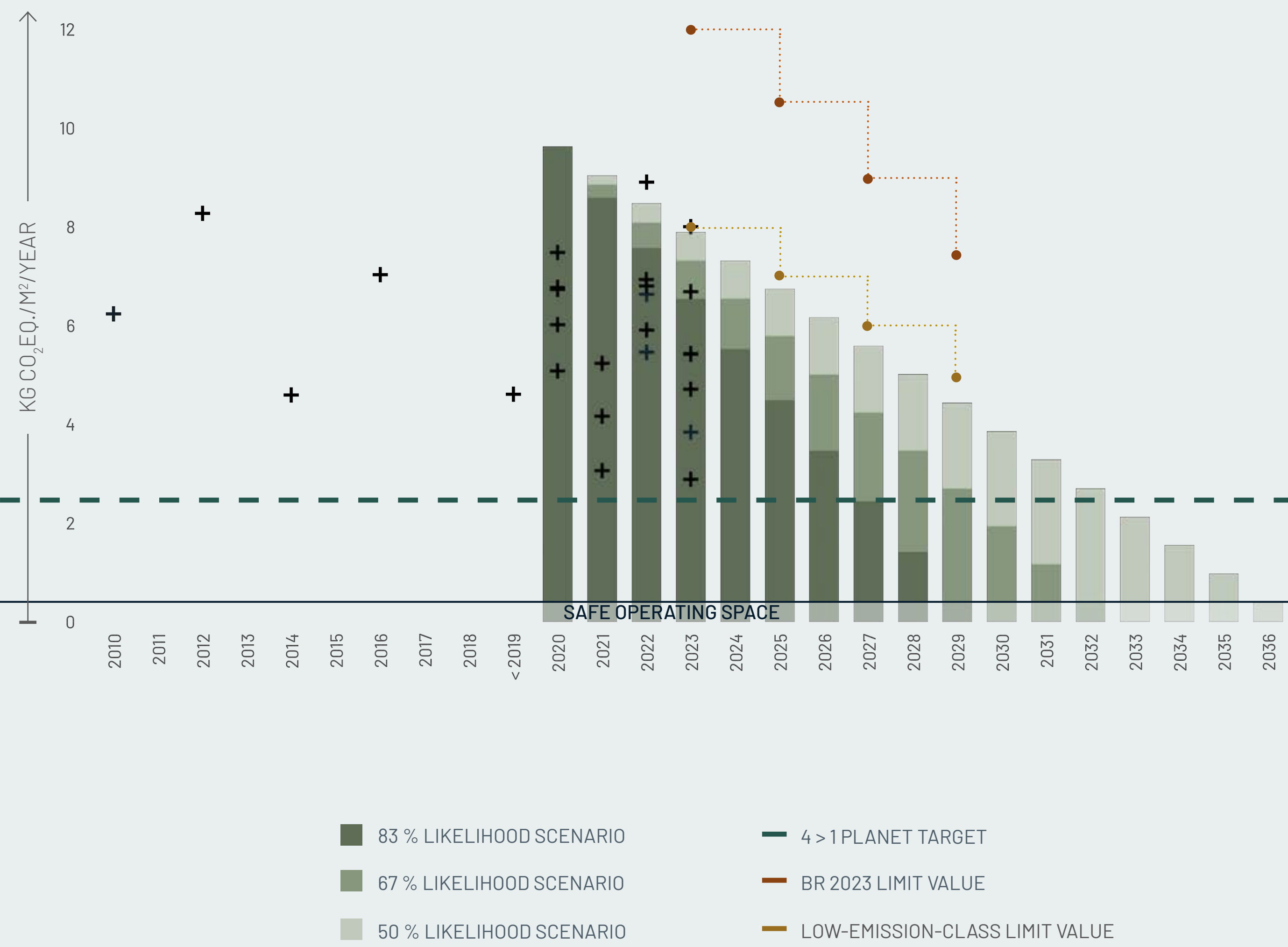
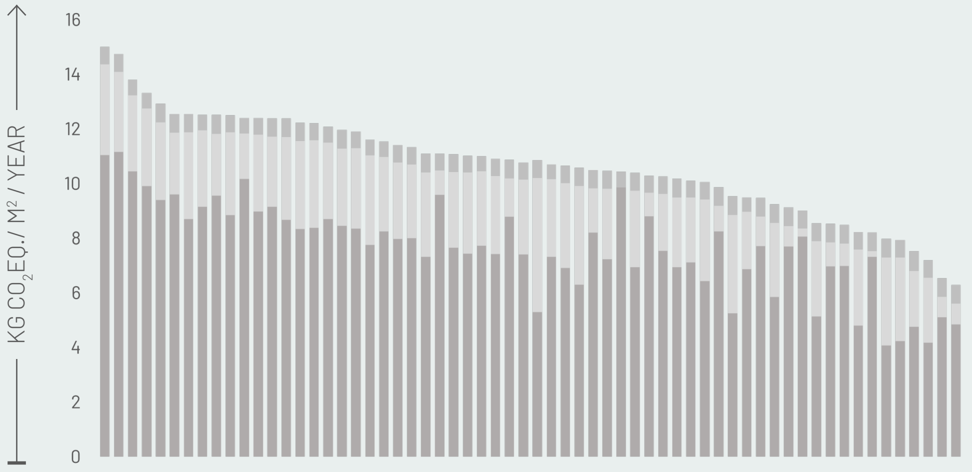


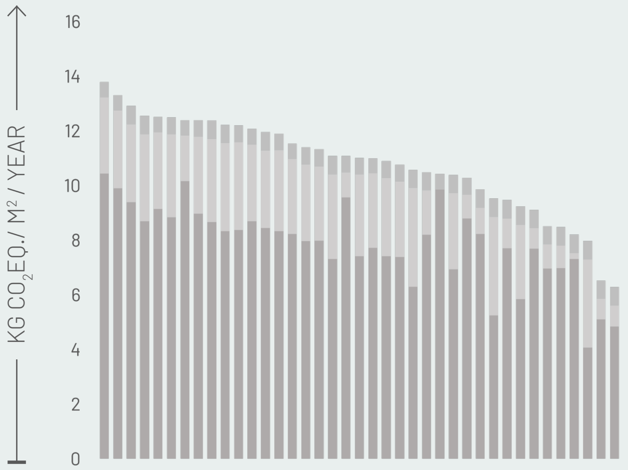

**Figure 16: Reduction Roadmap**
The 25 best practice cases are shown with their actual year of construction in relation to the Reduction Roadmap and to the 4 to 1 planet goal of 2.5 kg $CO_2$eq./m²/year.

# 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 $CO_2$eq./m²/year and is further subdivided into typology with a variable median. Single-family housing has the highest median of 11.1 kg $CO_2$eq./m²/year, terraced housing the lowest median of 9.5 kg $CO_2$eq./m²/year, whereas with a median of 10.5 kg $CO_2$eq./m²/year, multi-storey housing comes closest to the median for housing generally.




MEDIAN ALL HOUSING (SPC): 10,8 KG $CO_2$EQ./M²/YEAR



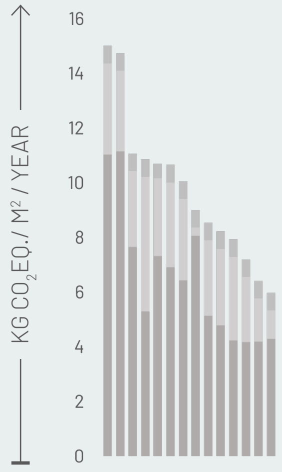

MEDIAN SINGLE-FAMILY HOUSING (SPC): 11,1 KG $CO_2$EQ./M²/YEAR

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

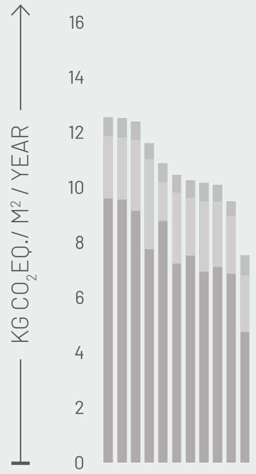
**Figures 17 - 18: Standard Practice Cases**
The horizontal axis shows BUILD's existing housing case collection. The vertical axis shows the emission of $CO_2$eq./m²/year.



# STANDARD PRACTICE CASES




MEDIAN TERRACED HOUSING (SPC): 9,5 KG $CO_2$EQ./M²/YEAR



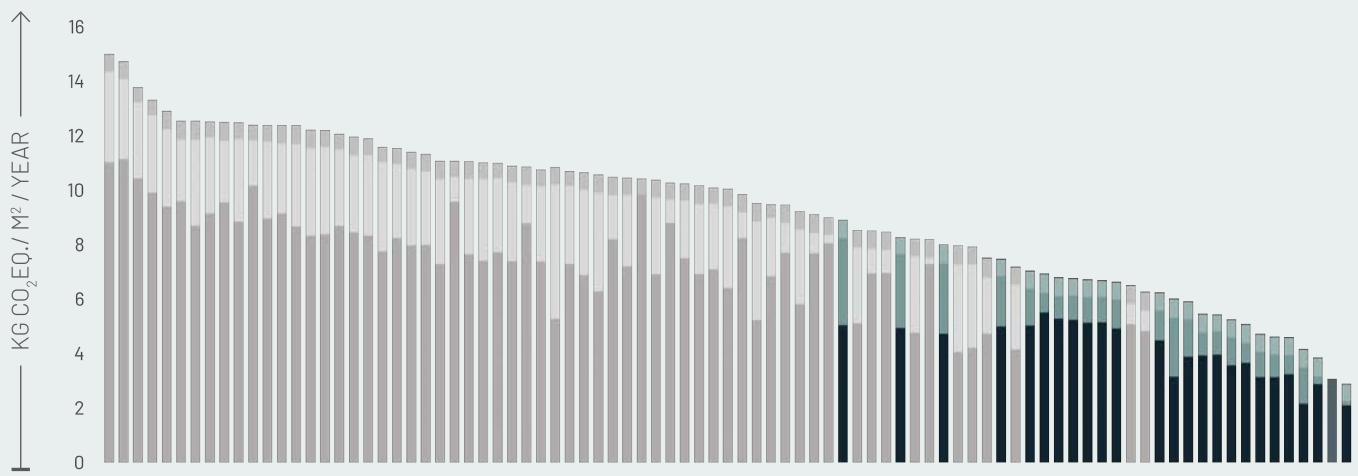

MEDIAN MULTI-STOREY HOUSING (SPC): 10,5 KG $CO_2$EQ./M²/YEAR

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

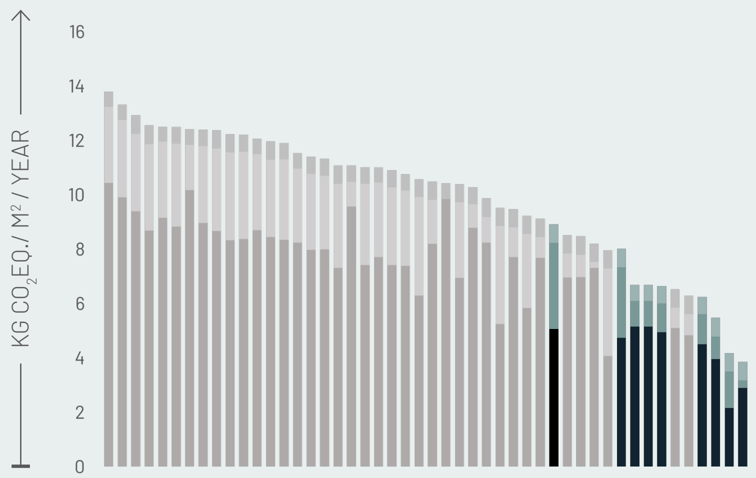
**Figures 19 - 20: Standard Practice Cases**
The horizontal axis shows BUILD's existing housing case collection. The vertical axis shows the emission of $CO_2$eq./m²/year.

# 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 6.2 kg $CO_2$eq./m²/year, and the variation for each typology shows the same trend as in the standard practice cases: the median for single-family housing is higher (6,7 kg $CO_2$eq./m²/year), the median for terraced housing is lower (4,9 kg $CO_2$eq./m²/year), and the median for multi-storey housing is identical to the median for housing generally (6.2 $CO_2$eq./m²/year).




MEDIAN ALL BEST PRACTICE CASES: 6,2 $CO_2$EQ./M²/YEAR



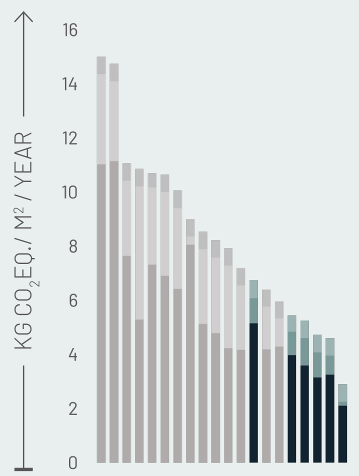

MEDIAN BEST PRACTICE SINGLE-FAMILY HOUSING: 6,7 KG $CO_2$EQ./M²/YEAR

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)

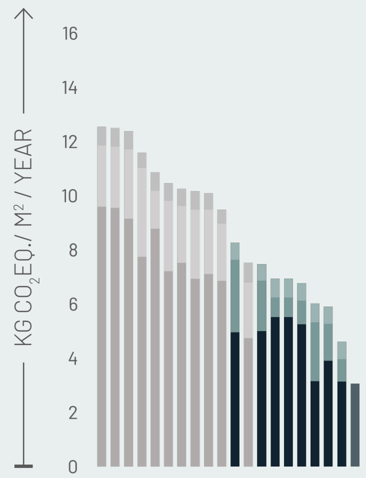
**Figures 21–22: Best Practice Cases**
The horizontal axis shows BUILD's existing housing case collection and cases from the 4 to 1 planet case collection. The vertical axis shows the emission of $CO_2$eq./m²/year.



# STANDARD + BEST PRACTICE CASES




MEDIAN BEST PRACTICE TERRACED HOUSING: 4,9 KG $CO_2$EQ./M²/YEAR




MEDIAN BEST PRACTICE MULTI-STOREY HOUSING: 6,2 KG $CO_2$EQ./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 $CO_2$eq./m²/year.

# RESULTS RELATIVE TO LIMIT VALUES

The axis represents the unit kg $CO_2$eq./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 $CO_2$eq./m²/year.

The case-study results show a variation of around 5 kg $CO_2$eq./m²/year from the lowest to the highest emission rate. All 25 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 $CO_2$eq./m²/year, i.e. less than half of the current limit value stated in the Building Regulations.

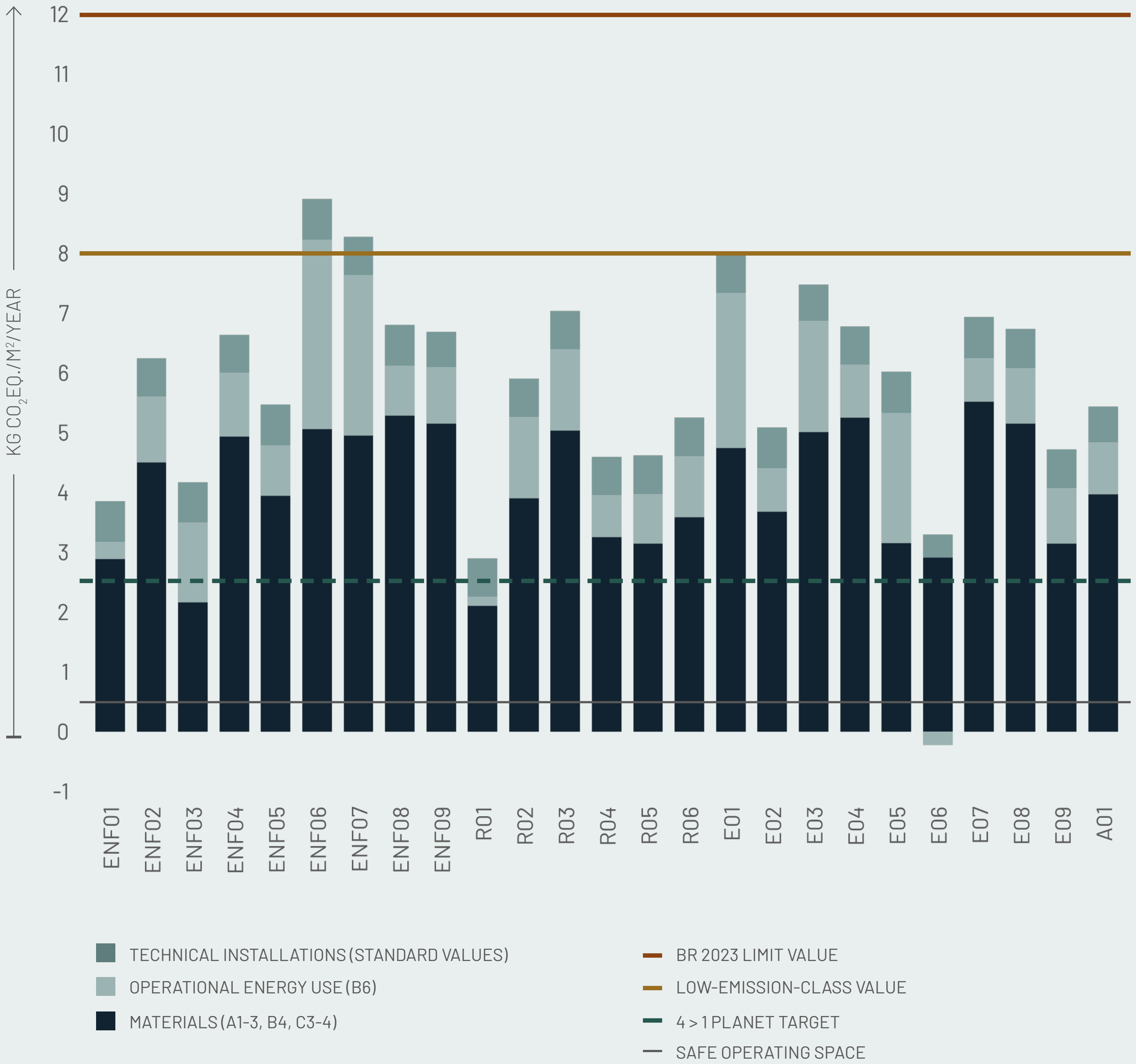



**Figure 25. Limit values**
The 25 cases in relation to BR2023 limit values, the voluntary $CO_2$ class, the 4 to 1 planet goal of 2.5 kg $CO_2$eq./m²/year, and the "safe operating space".



# SELECTED RESULTS

The axis represents the unit kg $CO_2$eq./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 $CO_2$eq./m²/year.

The five 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 $CO_2$eq./m²/year in the studies R01 and E02, whereas total emissions are lower in the studies ENF01 and R05. Case E06 features with specific listings of technical installations throughout the report, and the results are therefore unchanged.

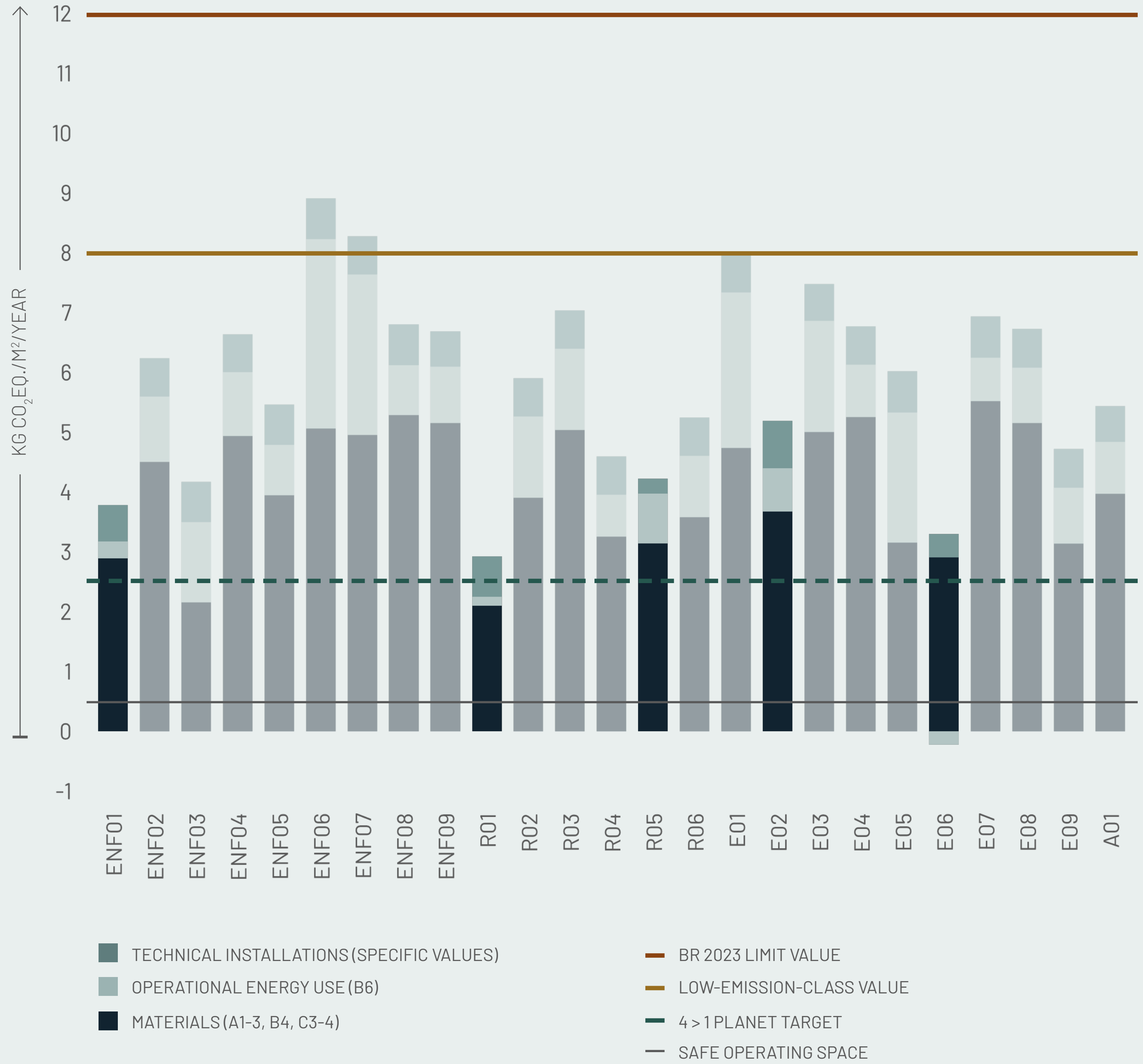



**Figure 26. Selected case studies with specific listings of technical installations**
The 25 cases in relation to BR2023 limit values, the voluntary $CO_2$ class, the 4 to 1 planet goal of 2.5 kg $CO_2$eq./m²/year, and the "safe operating space". The selected cases are written in bold.

# BIOGENIC SHARE: GWP

The axis represents the unit kg $CO_2$eq./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.

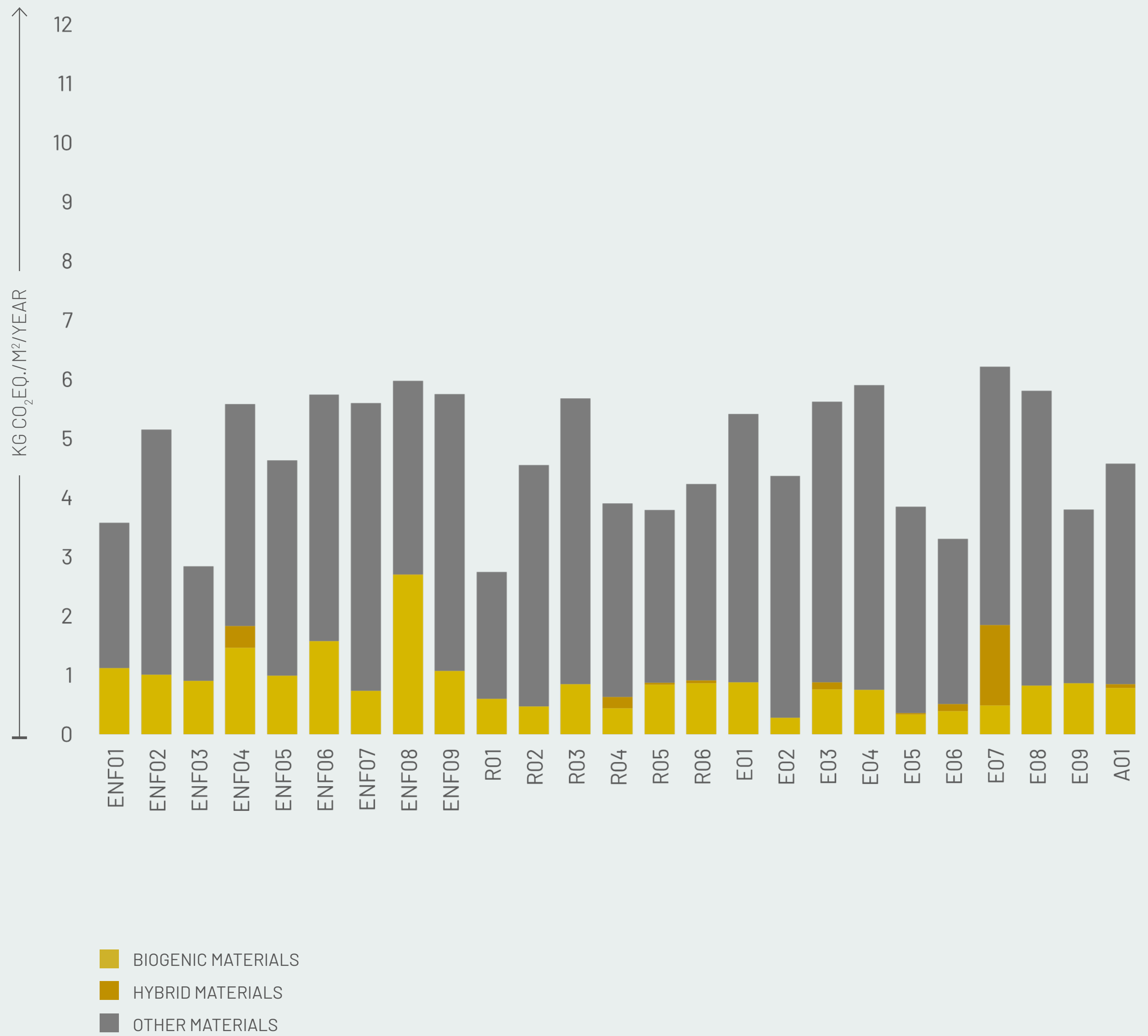



**Figure 27: Biogenic share: GWP**
The figure shows $CO_2$eq./m²/year emissions from the 25 buildings in three overall categories: biogenic materials, hybrids, and other materials.

# 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.

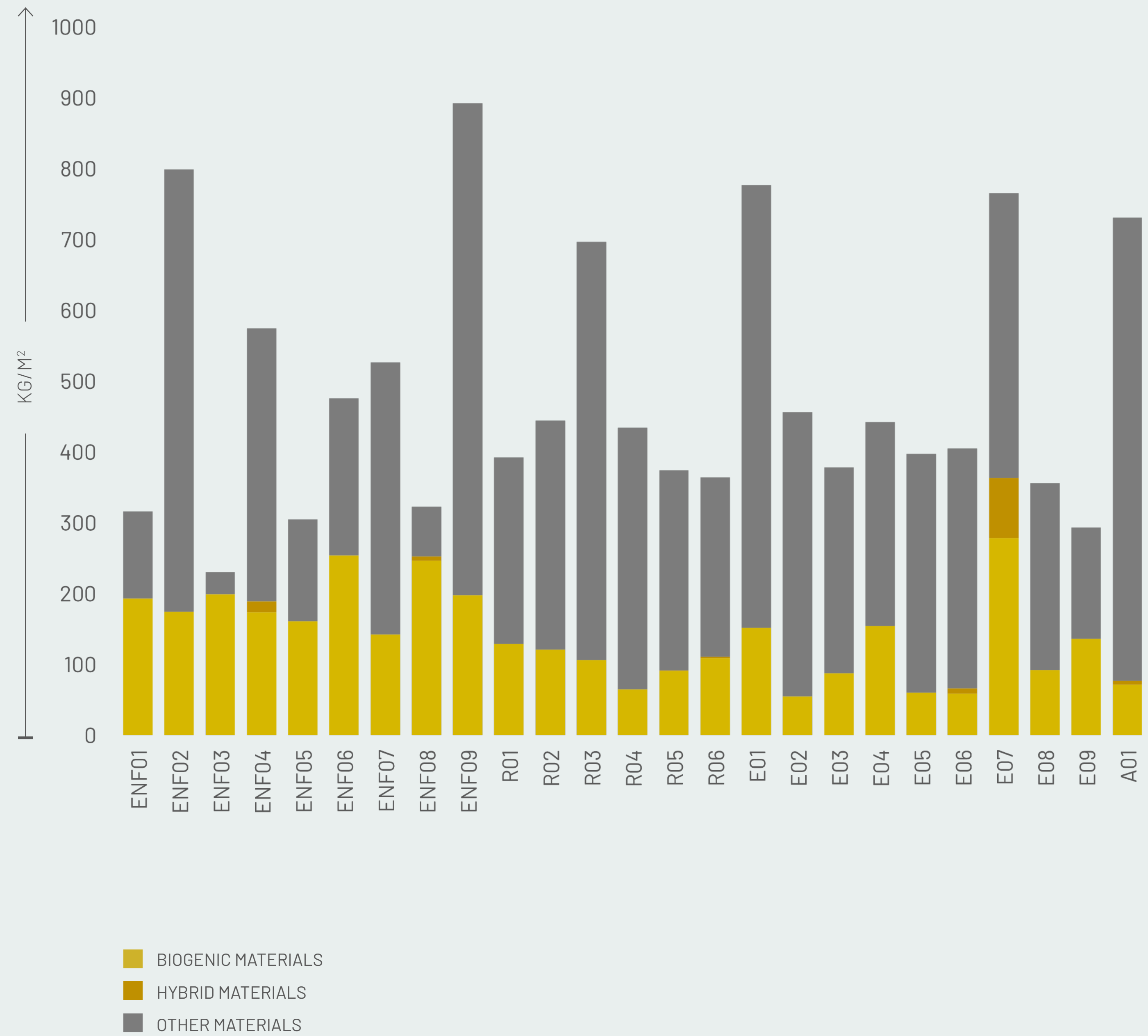



**Figure 28: Biogenic share: MASS**
The figure shows kg material/m² from the 25 buildings in the study subdivided into three overall categories: biogenic materials, hybrids, and other materials.

# BUILDING COMPONENTS

The axis represents the unit kg $CO_2$eq./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.

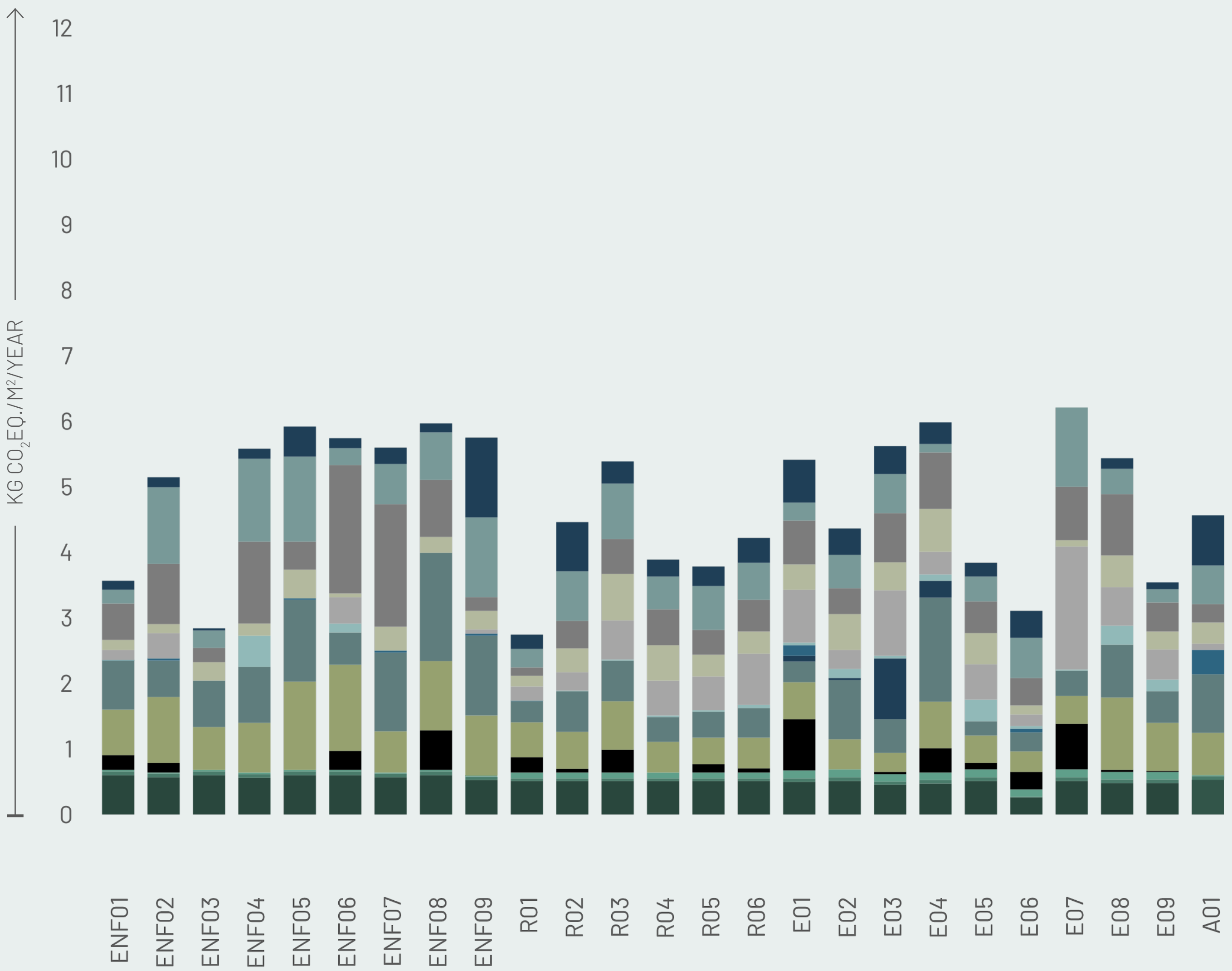



**Figure 29: $CO_2$ accounting: building components**
The horizontal axis shows the 25 buildings in the report and the emissions from the various building components. The vertical axis shows the emission of $CO_2$eq./m²/year.



# BUILDING COMPONENTS + OPERATIONAL ENERGY USE

The axis represents the unit kg $CO_2$eq./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.

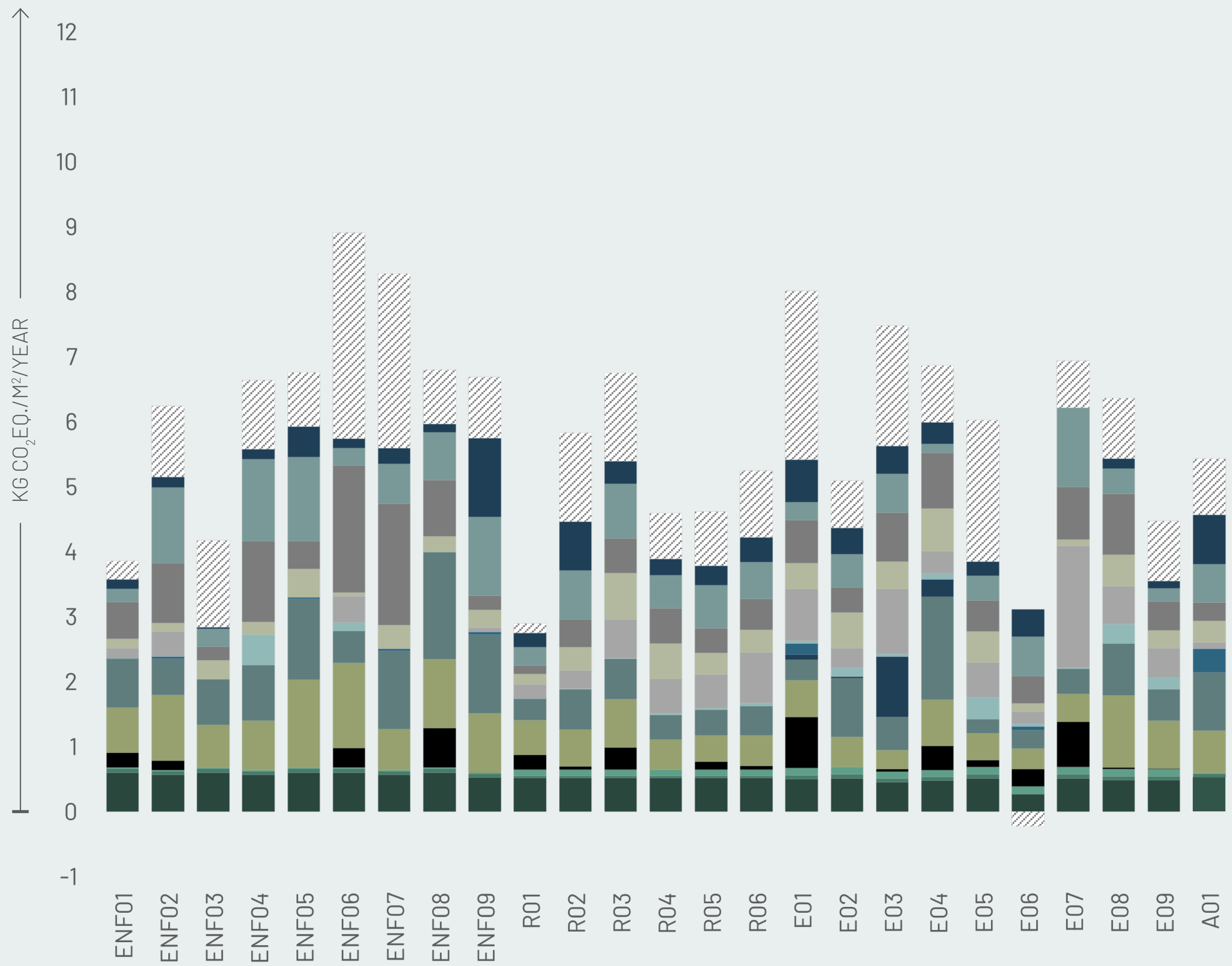



**Figure 30: $CO_2$ accounting: building components including operational use**
The horizontal axis shows the 25 buildings in the study and the emissions from the various building components with operational energy use added at the top. The vertical axis shows the emission of $CO_2$eq./m²/year.

# HUMAN SHARE

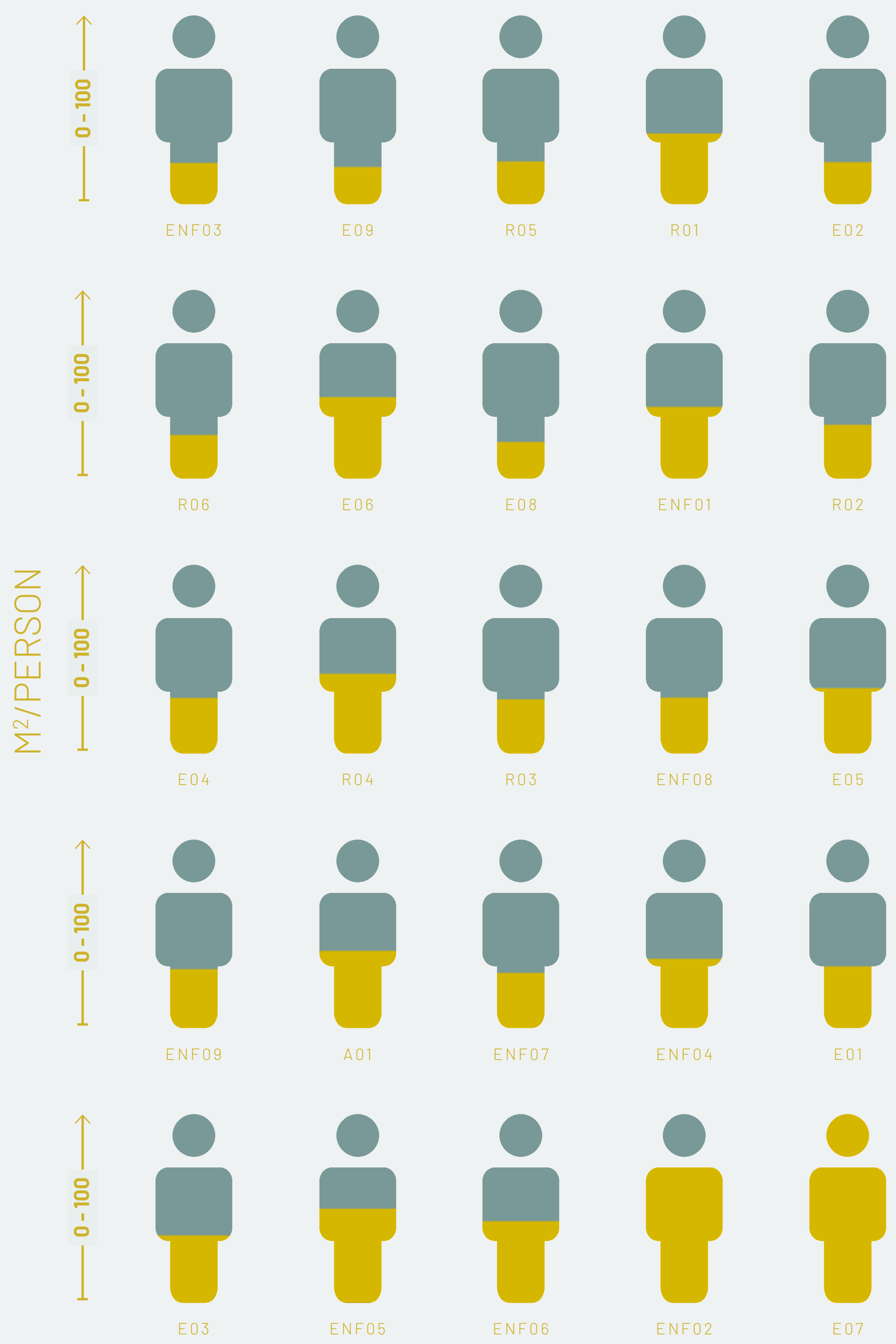
The green axis represents the unit kg $CO_2$eq./person/year, and the yellow axis the unit $m^2$ of floor space/person and looks at the connection between occupant and emissions per occupant. The case studies are sorted according to kg $CO_2$eq./person/year, starting with the project with the lowest emissions.




# HUMAN SHARE

The case collection applies the rule that space per occupant is significant for the emission of $CO_2$eq./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 $CO_2$eq./person/year than $m^2$ of floor space/person.



# HUMAN SHARE

The axis represents both the unit kg $CO_2$eq./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 $CO_2$eq./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.

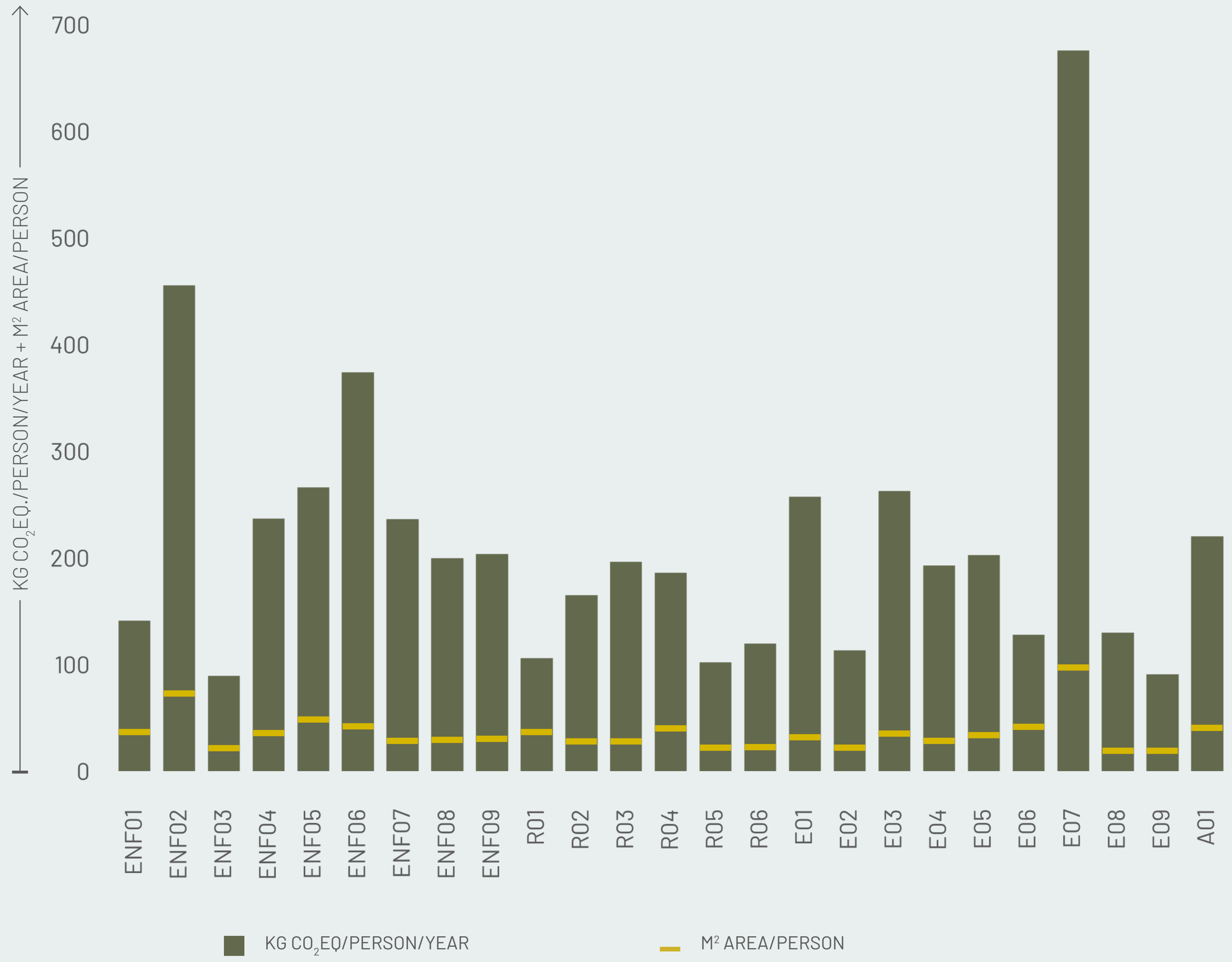



Figure 31: Best practice case emissions of kg $CO_2$eq./person/year and m²/person

# 3 SCENARIER: kg $CO_2$eq./person/year

The basis of this analysis is the case collection housing, where reference area and number of occupants from the 25 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 $CO_2$eq./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 $CO_2$eq./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 $CO_2$eq./m²/year.

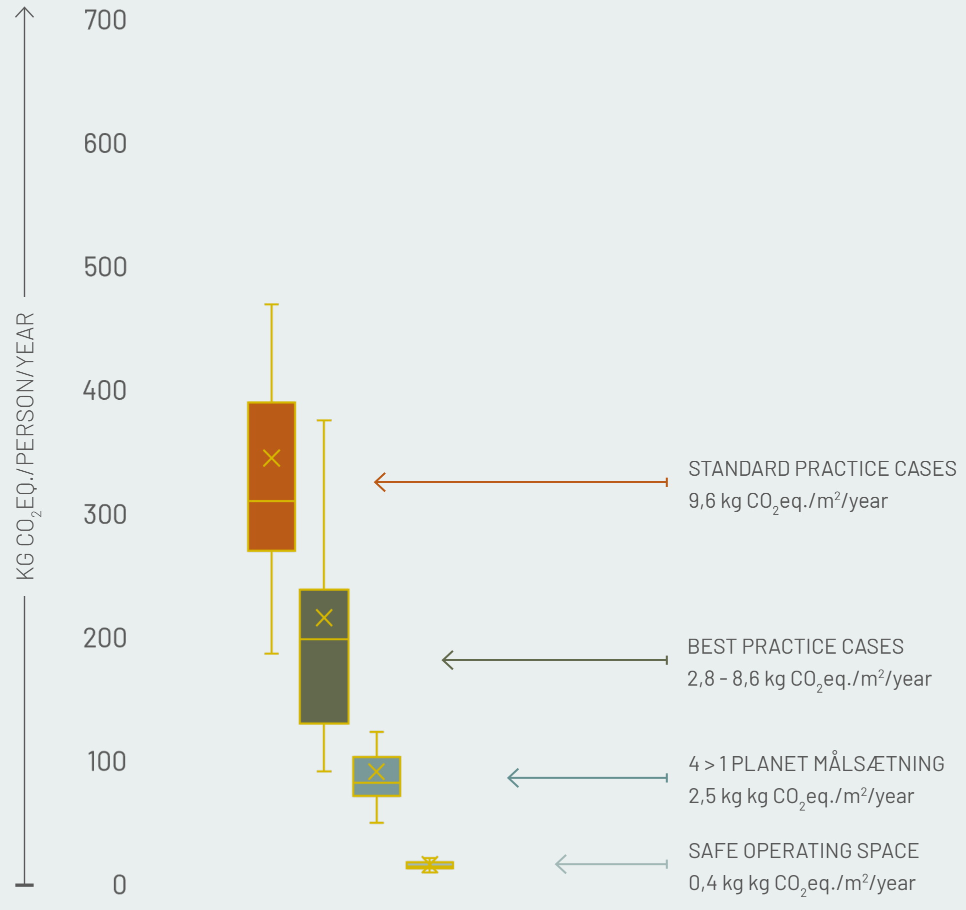



Figure 32: Scenarios for the building's emission of kg $CO_2$eq./person /year

# RATIO / ENVIRONMENTAL IMPACT

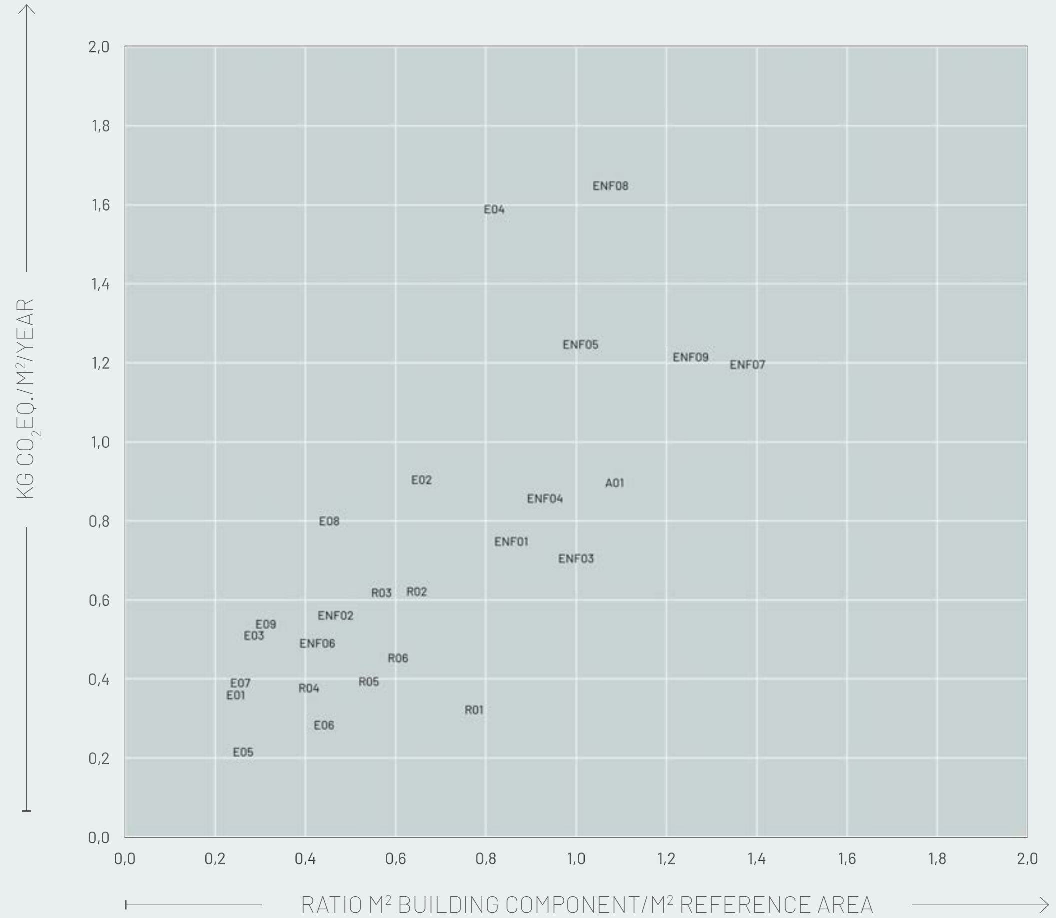
The analysis couples the relationship of the ratio of a building component to its emission to examine the correlation between emissions and occurrence. In this context, ratio is the square metreage of a specific building component spread over the building's reference area, for example, 1 $m^2$ of exterior 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 $CO_2$eq./$m^2$/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.

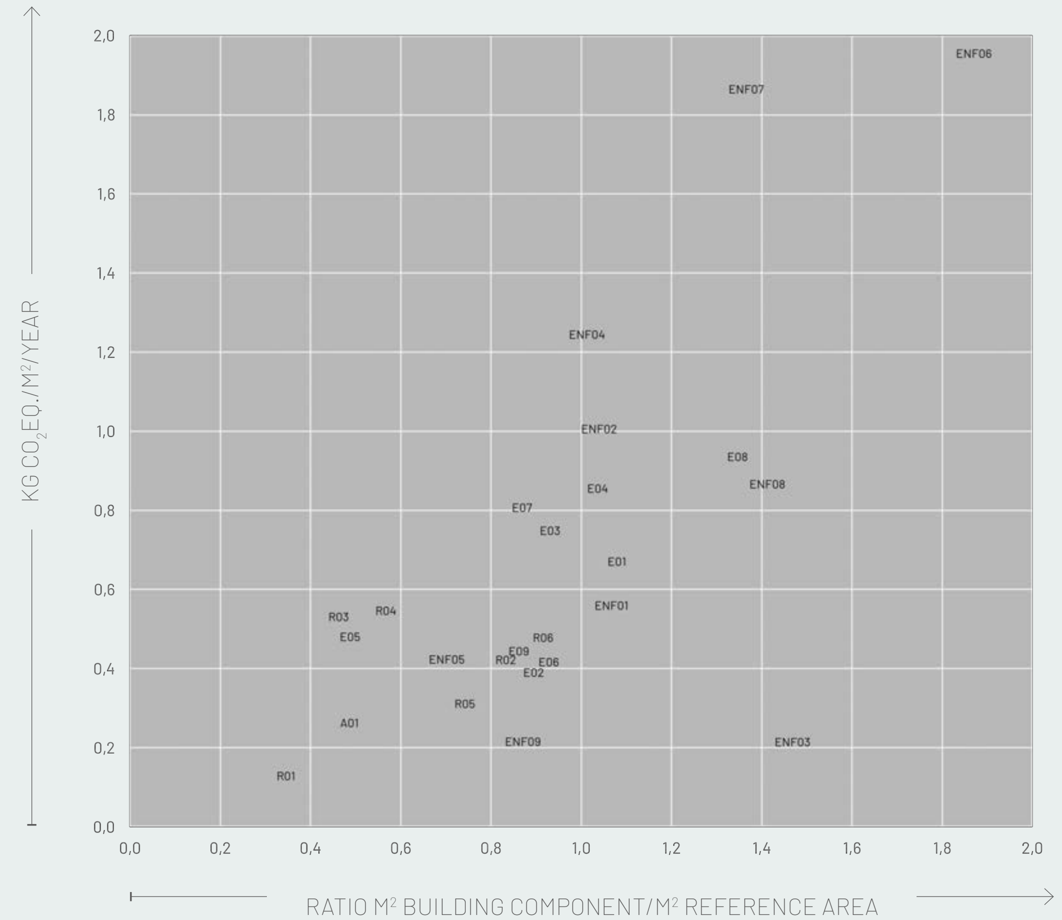
The picture is different for exterior walls, showing a larger span both in terms of emission and ratio. This confirms that material choice is significant for the building component, since it is evident that some exterior walls with relatively low emissions still have a high ratio. In line with the results 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.

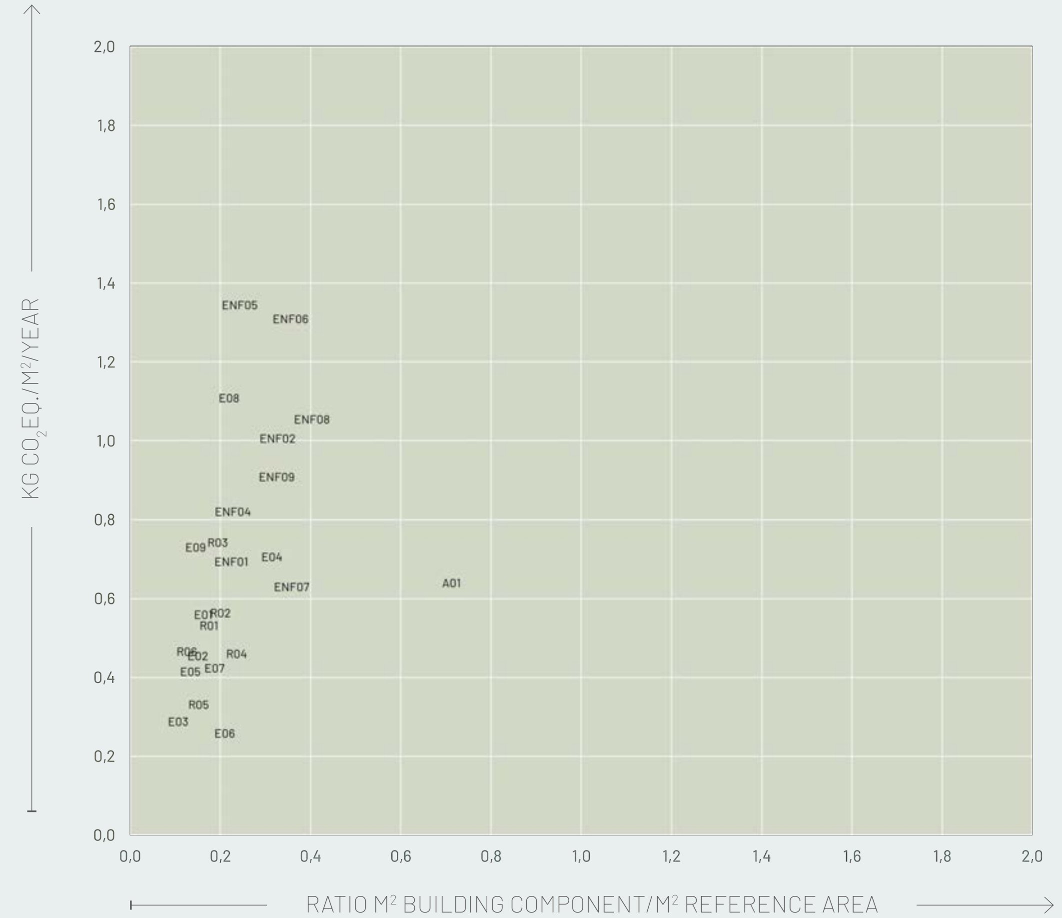
## BUILDING COMPONENT: ROOF




## BUILDING COMPONENT: EXTERIOR WALL




## BUILDING COMPONENT: WINDOW, DOOR AND GLASS FACADE



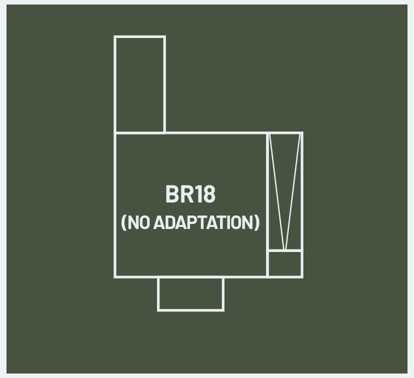
# 25 CASES

# 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

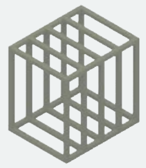
Living Places is a demo project, challenging the idea of "business as usual" with a holistic approach to building, pointing the building trade in new directions for the benefit of both people and the planet. The project is implemented via a strategic partnership, showing that by exclusively making use 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 $CO_2$eq./m²/year

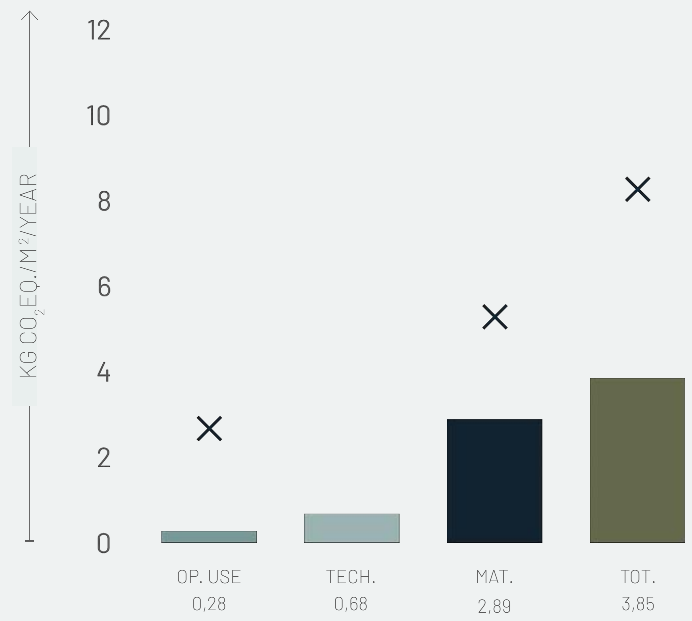



**Figure ENF01.1: Emissions of kg $CO_2$eq./m²/year**
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg $CO_2$eq./m²/year in single-family housing in the case collection.

26.229 kg $CO_2$eq.

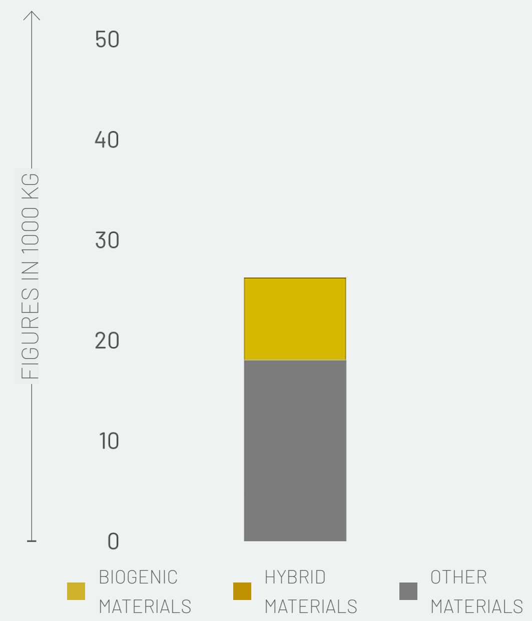



**Figure ENF01.2: Total emission of kg $CO_2$eq.**
The stacked bar chart shows the overall emission of kg $CO_2$eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

142 kg $CO_2$eq/person/year

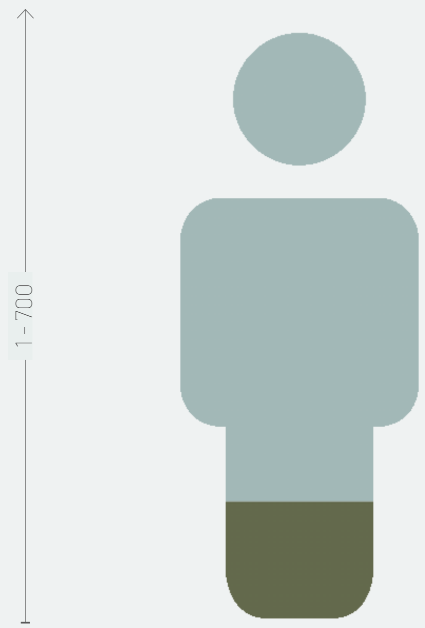



**Figure ENF01.3: Emissions of kg $CO_2$eq./person/year**
The span of the vertical axis is 1 to 700 kg $CO_2$eq./person/year

37 m²/person

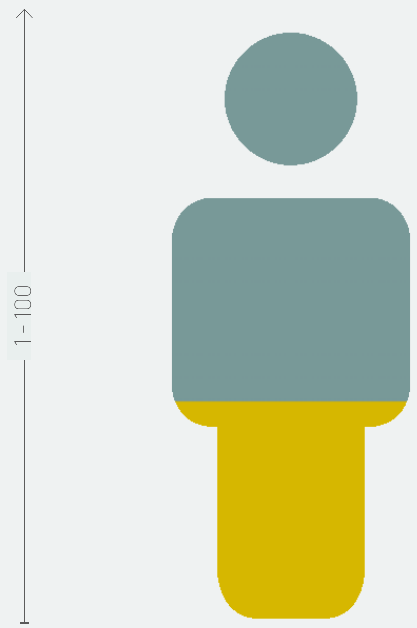



**Figure ENF01.4: m²/person**
The span of the vertical axis is 1 to 100 m²/person.

## 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 $CO_2$eq./m²/year.

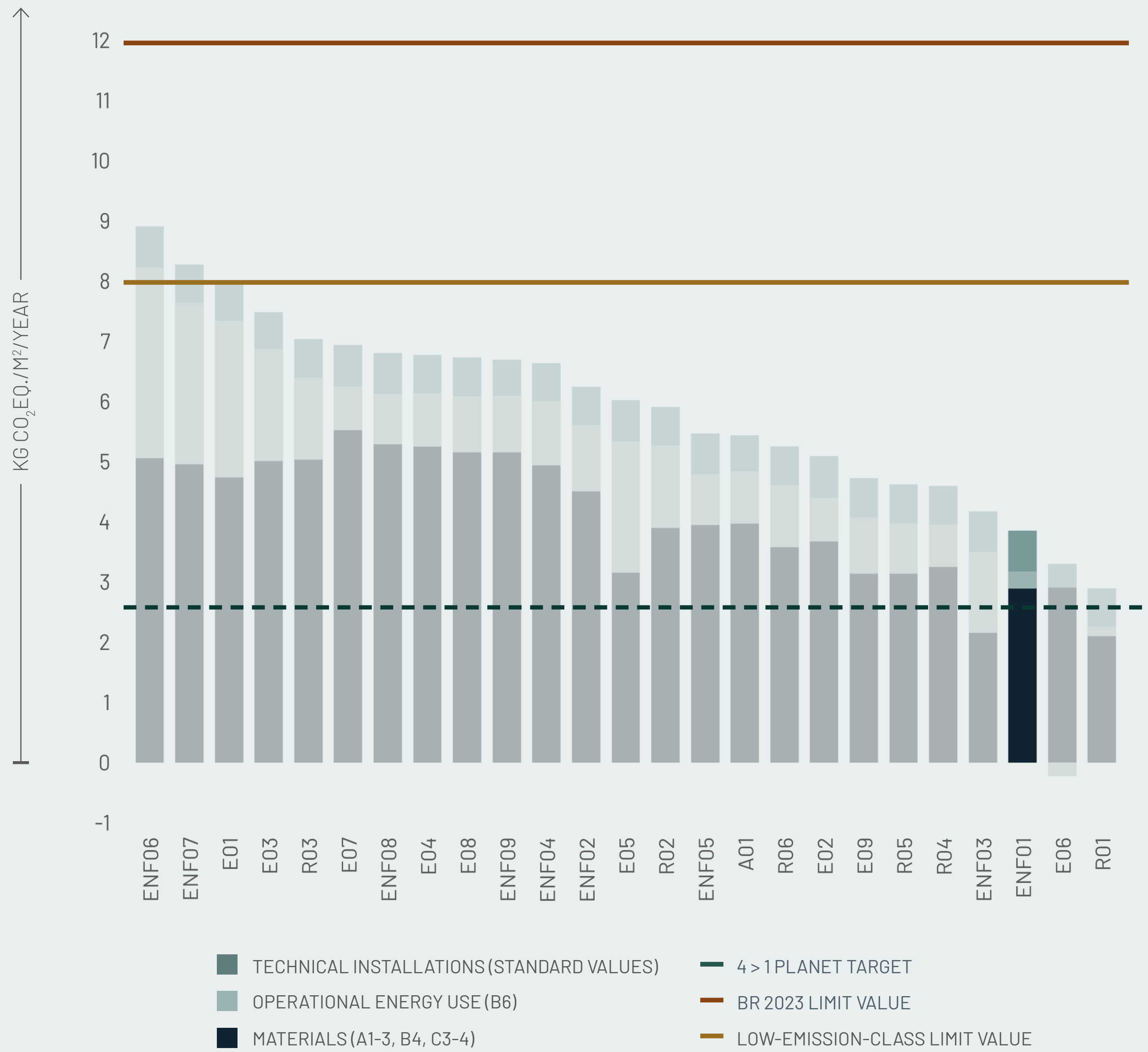



**Figure ENF01.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.



ENF01: Living Places I

## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in $CO_2$eq./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.

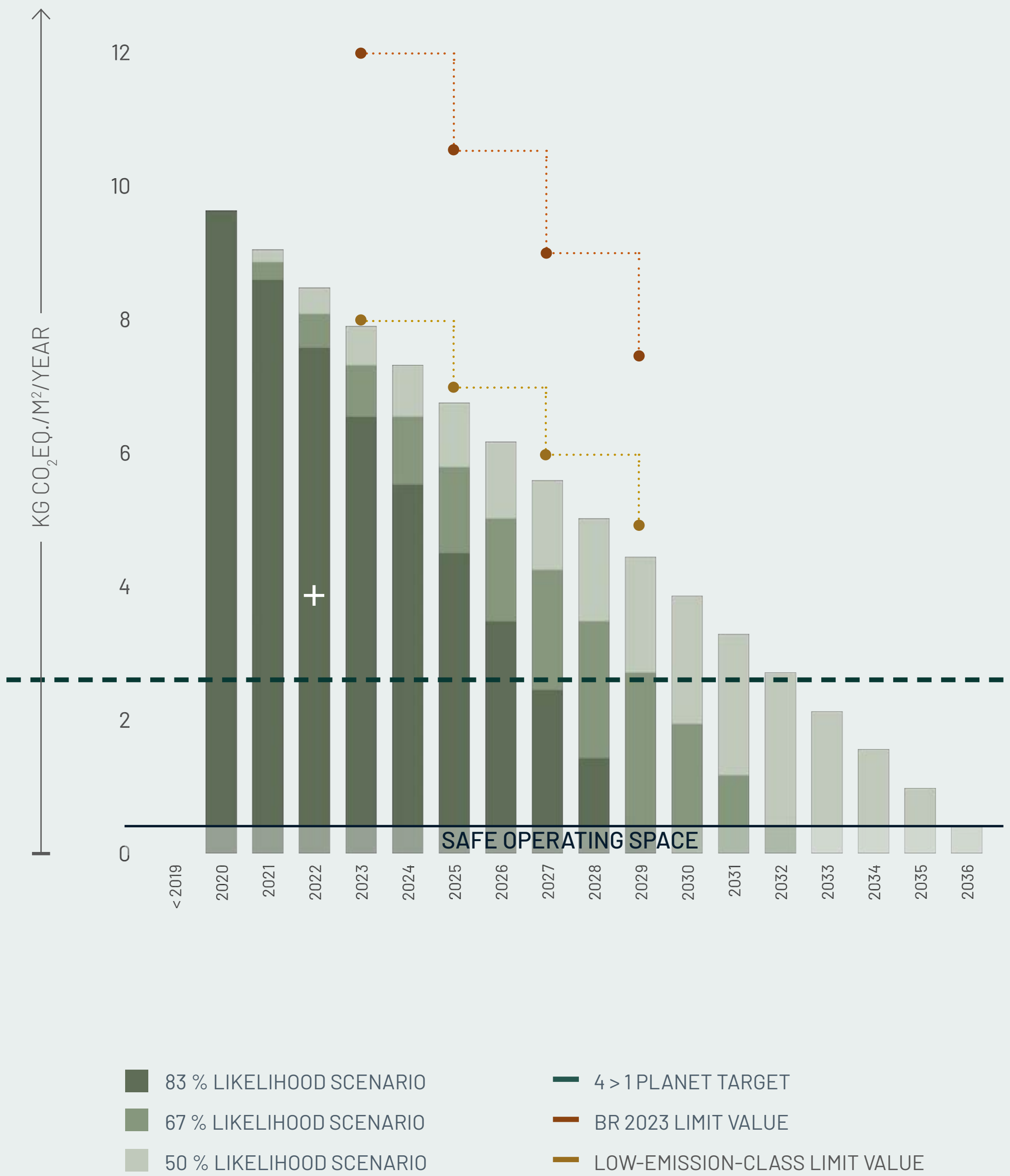
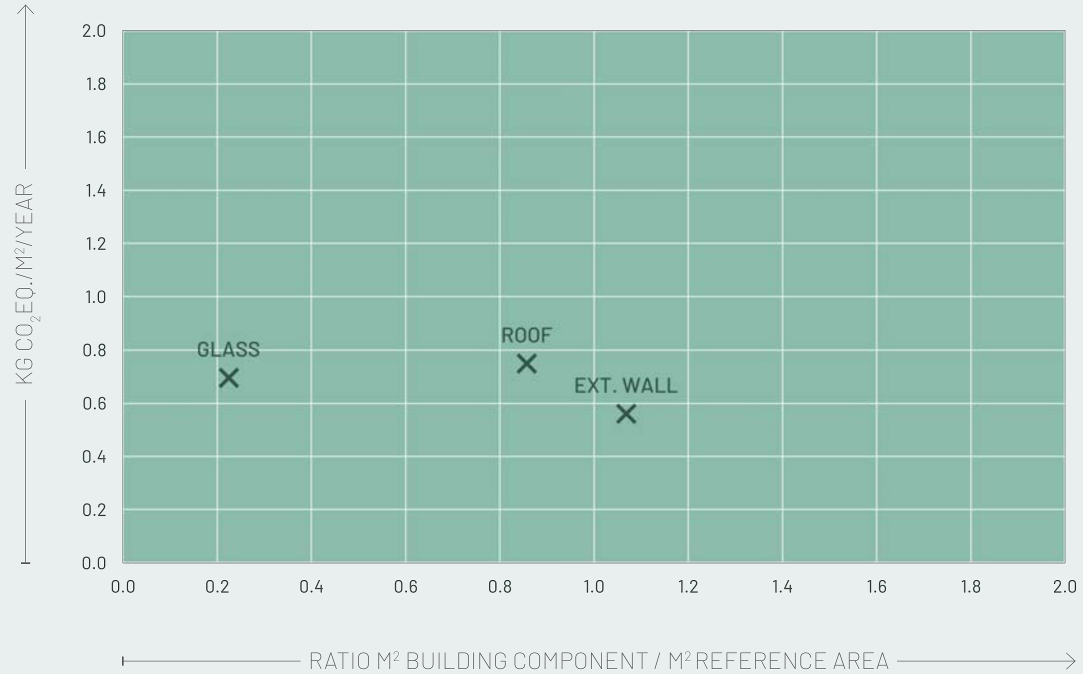



**Figure ENF01.6: Reduction Roadmap**
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg $CO_2$eq./m²/year, and the 'safe operating space'.

## RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS




## ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

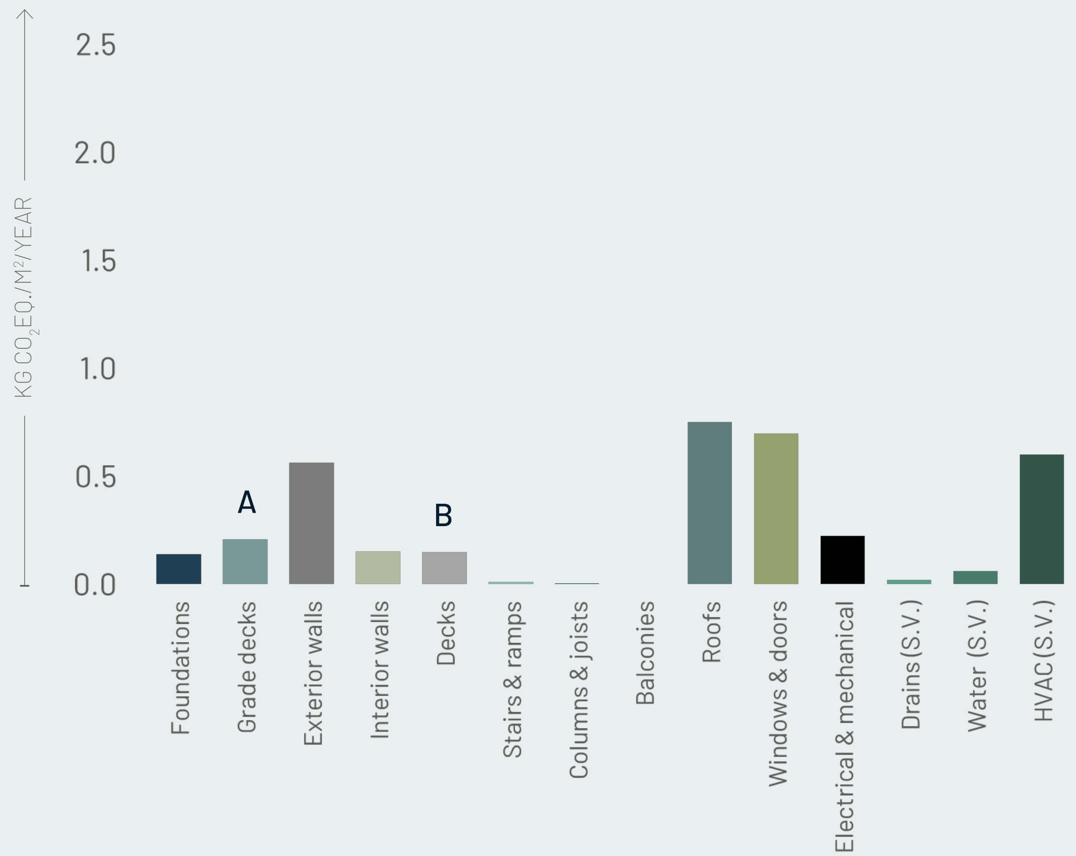



**Figure ENF01.7: $CO_2$ accounting for building components**
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades,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



# ENF01: Living Places I

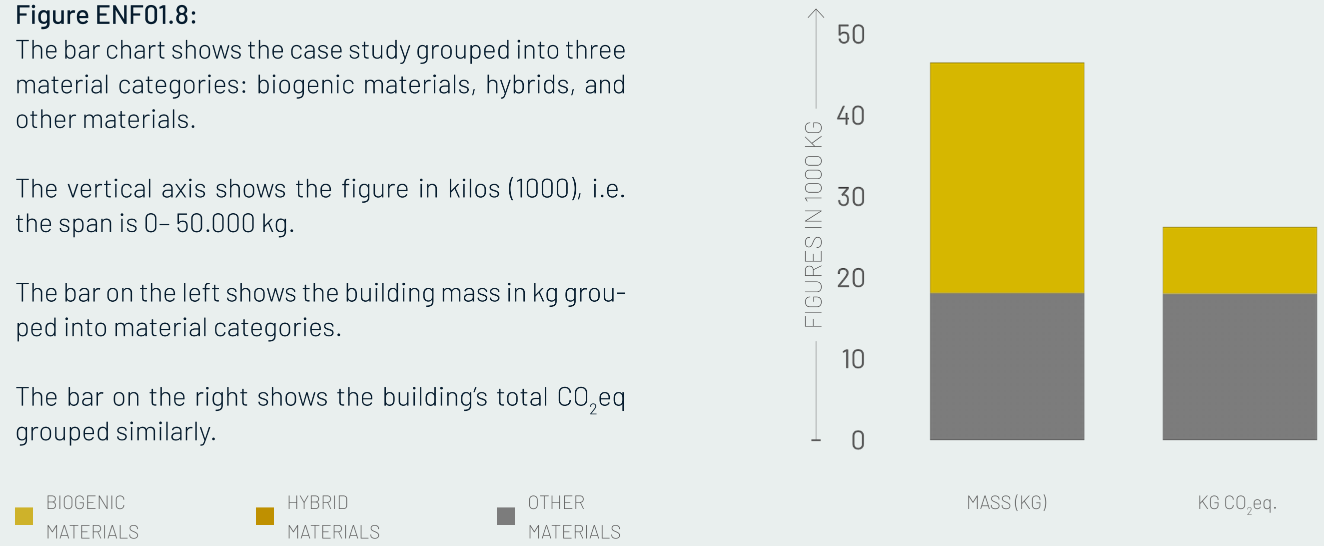
## SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

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

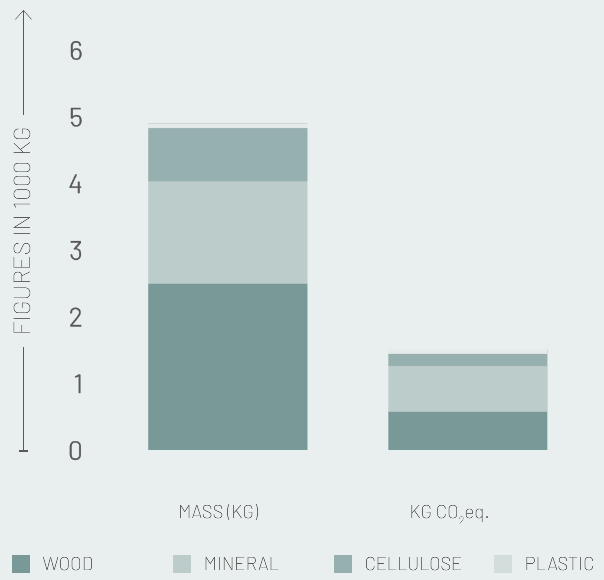
The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

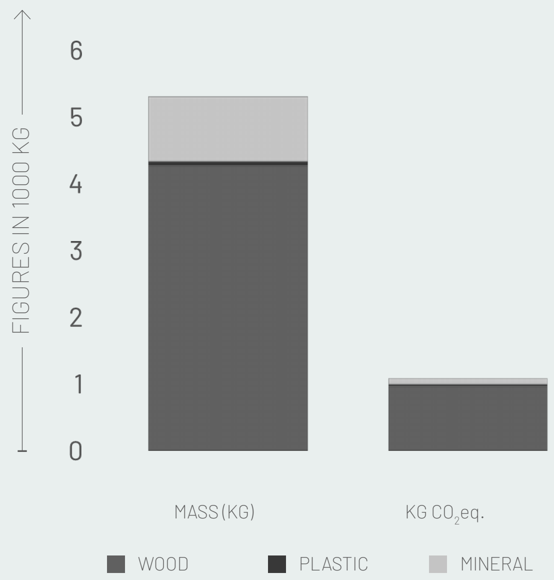
The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total $CO_2$eq grouped similarly.




## MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG $CO_2$EQ.




### A. GRADE DECK

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

### B. DECK

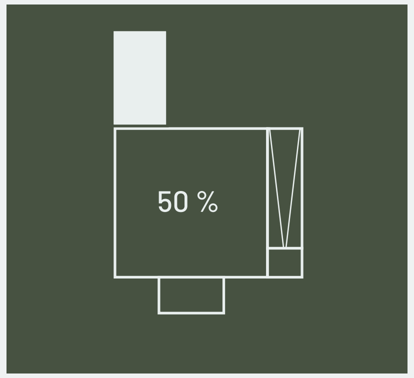
- Timber flooring
- Insulation membrane
- Fibre gypsum boards
- Two-layer plywood

# ENF02: Sunlighthouse



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

**Year (built):** 2010
**Floor area:** 275 $m^2$
**Reference area:** 292 $m^2$
**Use:** Residential
**Occupants:** 4
**Year (calculated):** 2022
**Heating:** Heat pump
**Solar cells:** Yes




## DESCRIPTION

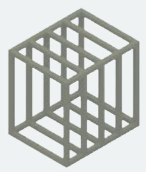
Sunlighthouse is an international case study from 2010 and thus the oldest study in the best practice case collection. The project is Austria's first carbon-neutral single-family dwelling whose sloped roof and other architectural features fully exploit the sunlight for maximum daylight and solar power. 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 $m^2$. With four occupants, this gives approx. 69 $m^2$/person, which is on the high side in the case collection.



Timber frame

3 storeys



# ENF02: Sunlighthouse

6,24 kg $CO_2$eq./$m^2$/year


**Figure ENF02.1: Emissions of kg $CO_2$eq./$m^2$/year**
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg $CO_2$eq./$m^2$ /year in single-family housing in the case collection.

75.183 kg $CO_2$eq.

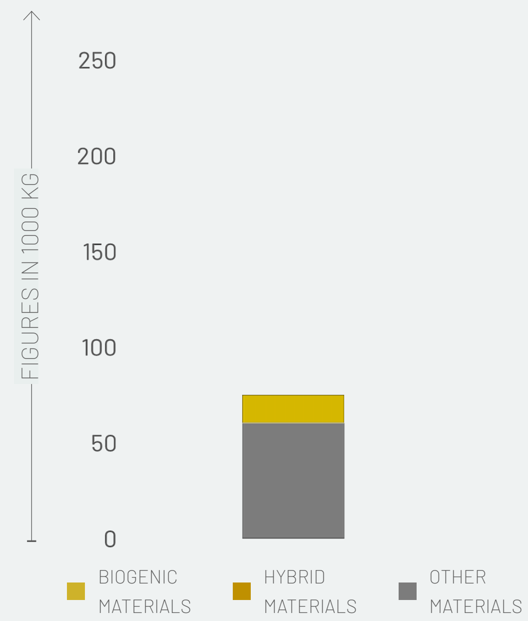



**Figure ENF02.2: Total emission of kg $CO_2$eq.**
The stacked bar chart shows the overall emission of kg $CO_2$eq. in the case study grouped into the three material categories: other, hybrids, and biogenic.

456 kg $CO_2$eq./person/year

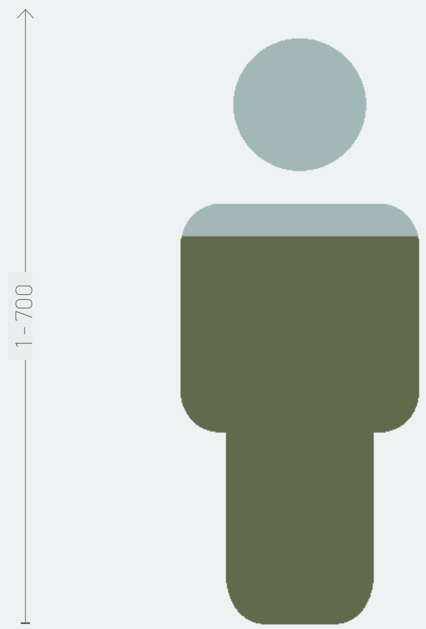



**Figure ENF02.3: Emissions of kg $CO_2$eq./person/year**
The span of the vertical axis is 1 to 700 kg $CO_2$eq./person/year

69 $m^2$/person

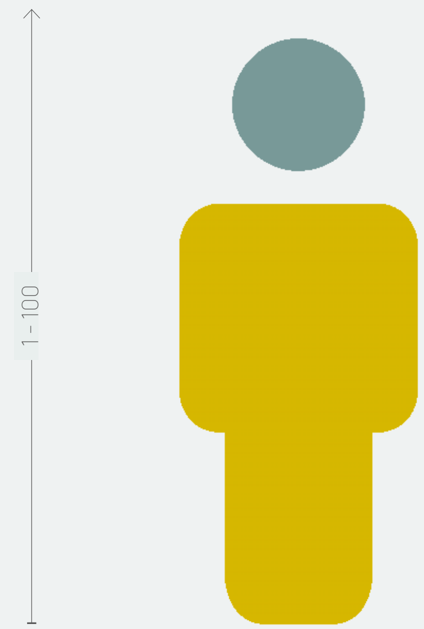



**Figure ENF02.4: $m^2$/person**
The span of the vertical axis is 1 to 100 $m^2$/person.

# 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 $CO_2$eq./m²/year.

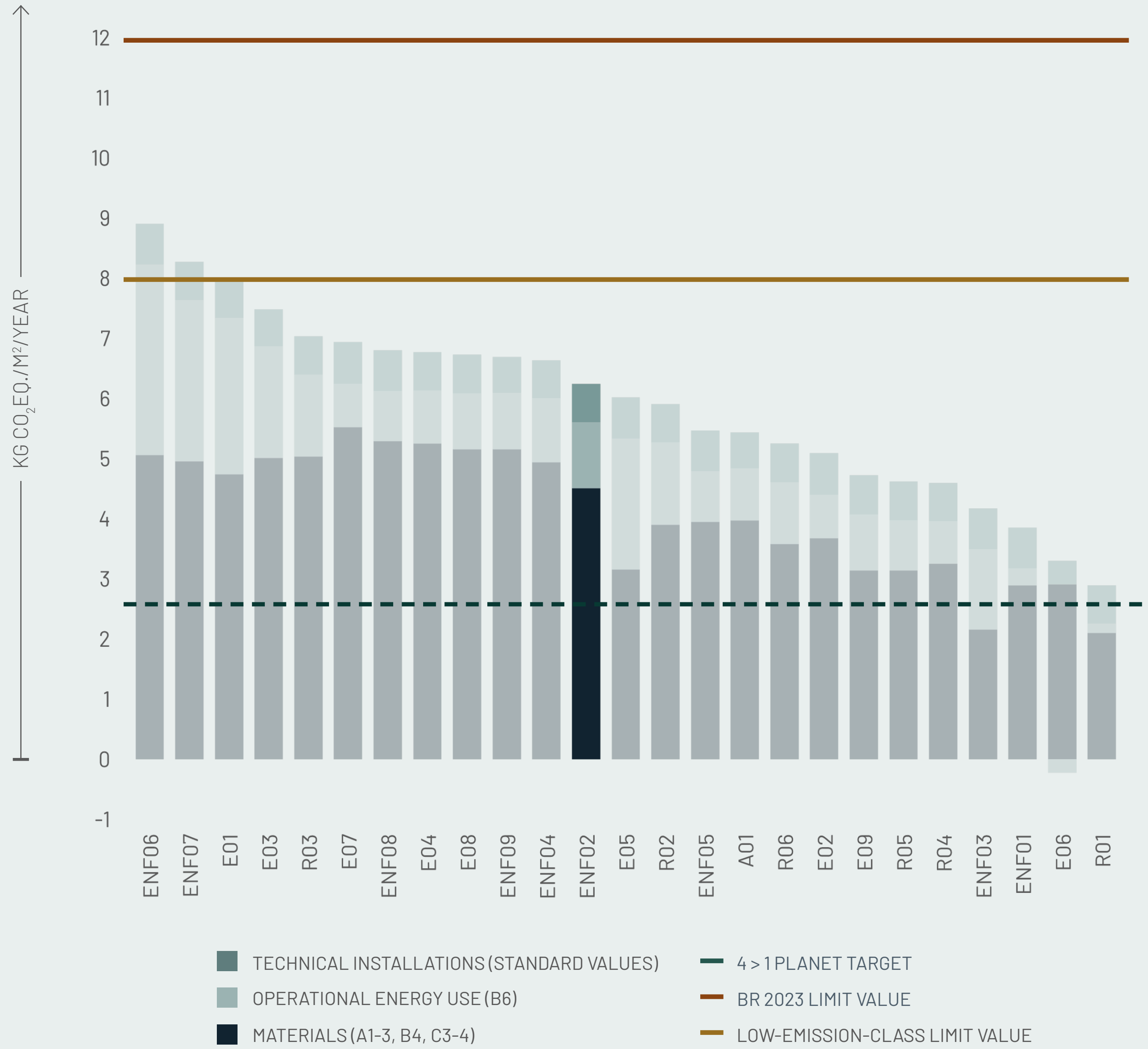



**Figure ENF02.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.



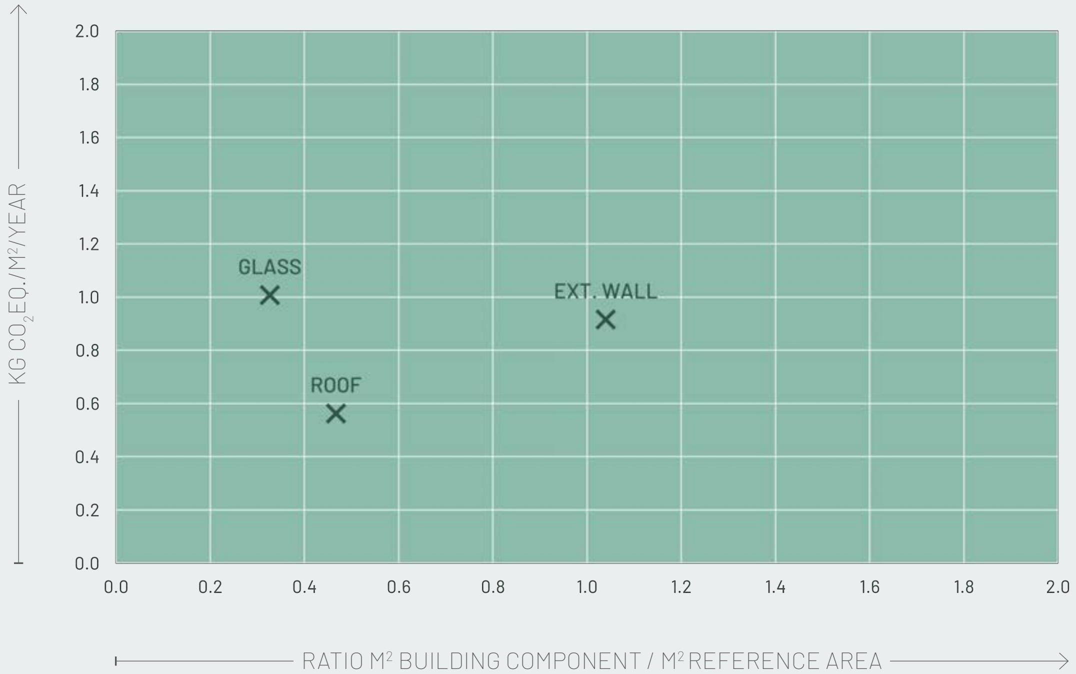
# ENF02: Sunlighthouse

## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in $CO_2$eq./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 $CO_2$eq./m²/year, and the 'safe operating space'.

## RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS




## ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

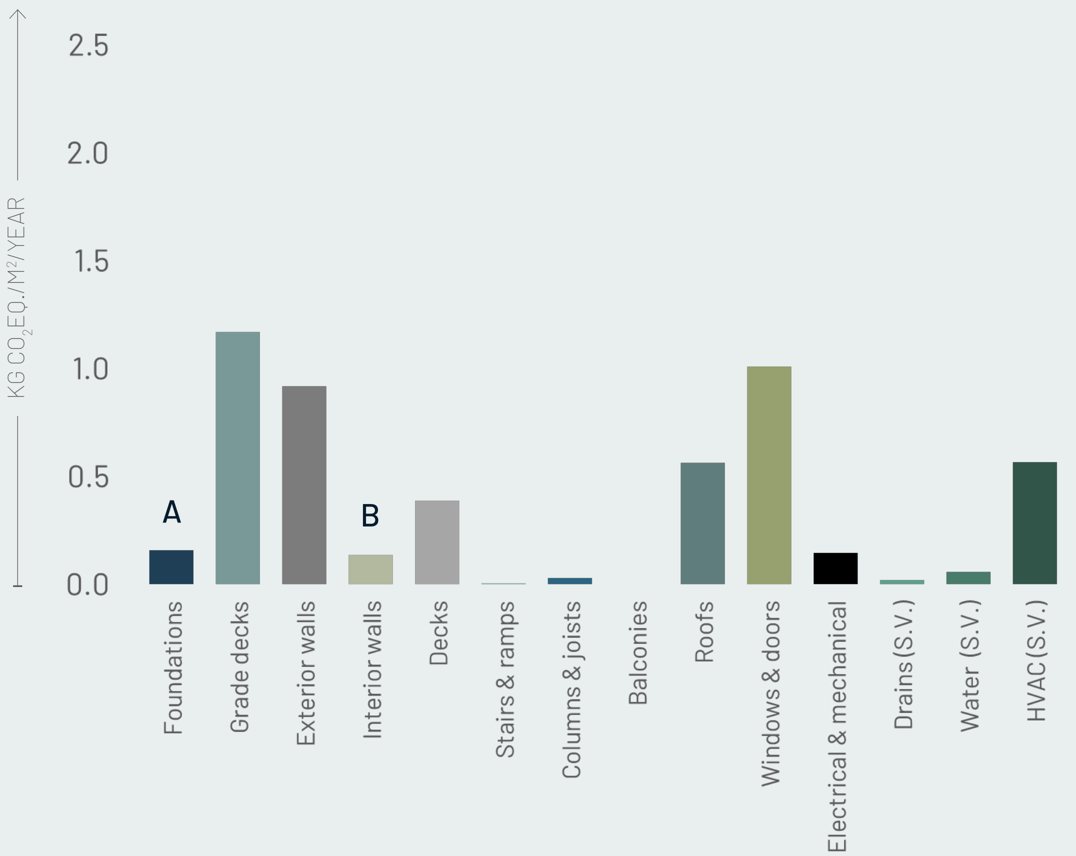



**Figure ENF02.7: $CO_2$ accounting for building components**
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades,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





## SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

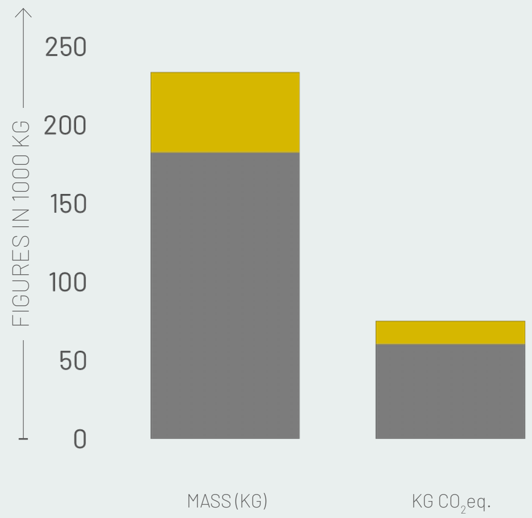
**Figure ENF02.8:**
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

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

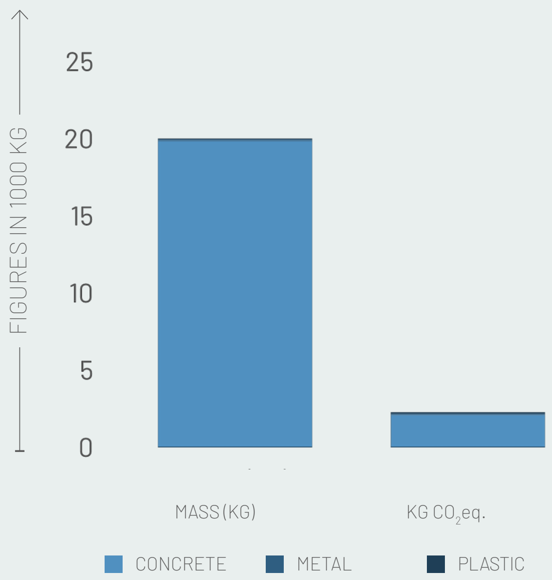
The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total $CO_2$eq grouped similarly.

BIOGENIC MATERIALS | HYBRID MATERIALS | OTHER MATERIALS

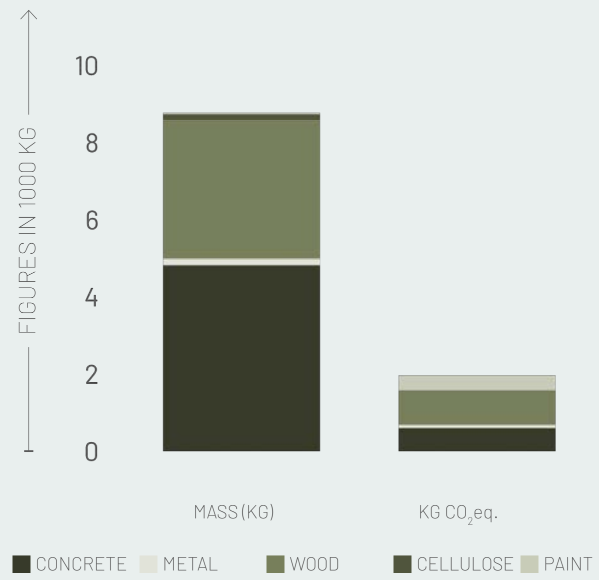



## MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG $CO_2$EQ.




### A. FOUNDATION

Reinforced concrete
EPS insulation



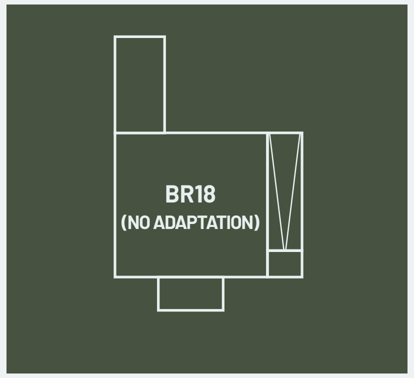

### B. INTERIOR WALL

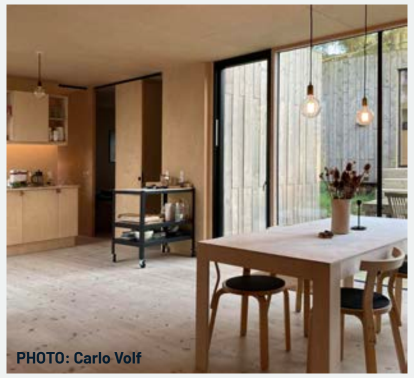
Timber frame
Cellulose insulation Plywood
Timber cladding

# 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

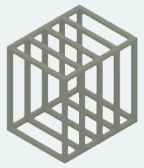
EcoHousing is an experimental project where construction principles and material choice are governed by their $CO_2$-storage properties. Consequently, the house is constructed in bio-based materials, except for foundations, bituminous felt, windows, and plumbing and heating components.

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 $CO_2$eq./m²/year

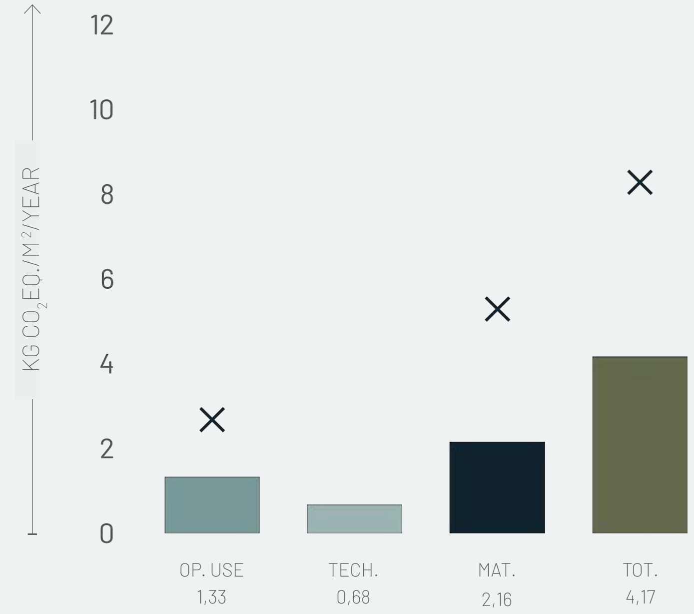



**Figure ENF03.1: Emissions of kg $CO_2$eq./m²/year**
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg $CO_2$eq./m²/year in single-family housing in the case collection.

12.209 kg $CO_2$eq.

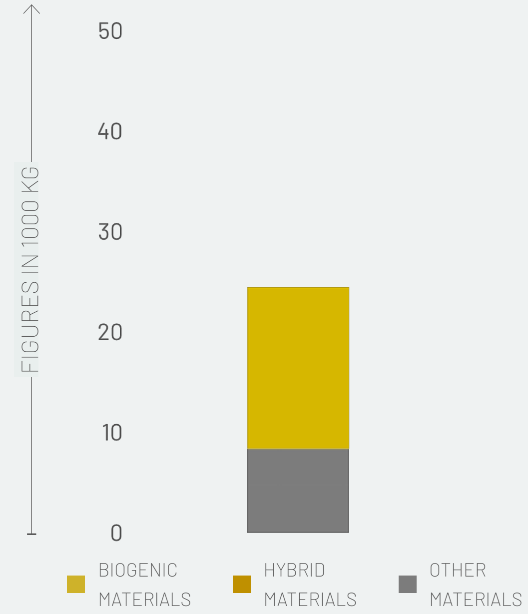



**Figure ENF03.2: Total emission of kg $CO_2$eq.**
The stacked bar chart shows the overall emission of kg $CO_2$eq. in the case study grouped into the three material categories: other, hybrids, and biogenic.

90 kg $CO_2$ eq./person/year

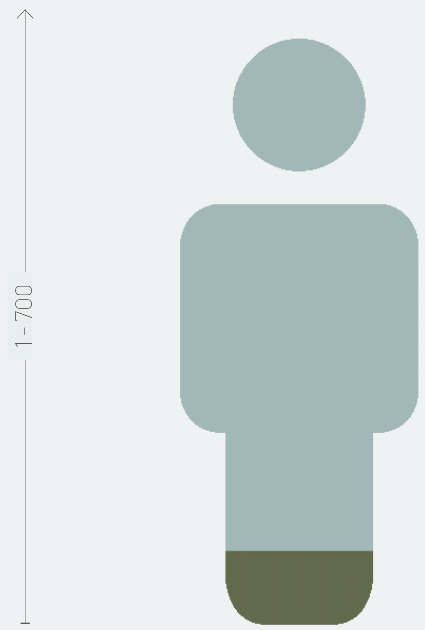



**Figure ENF03.3: Emissions of kg $CO_2$eq./person/year**
The span of the vertical axis is 1 to 700 kg $CO_2$eq./person/year

22 m²/person

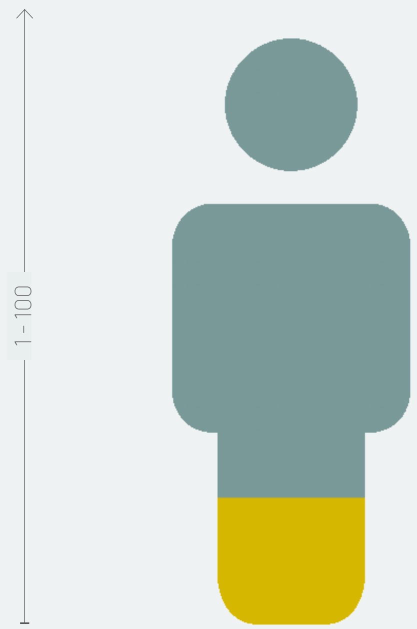



**Figure ENF03.4: m²/person**
The span of the vertical axis is 1 to 100 m²/person.

# 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 $CO_2$eq./m²/year.

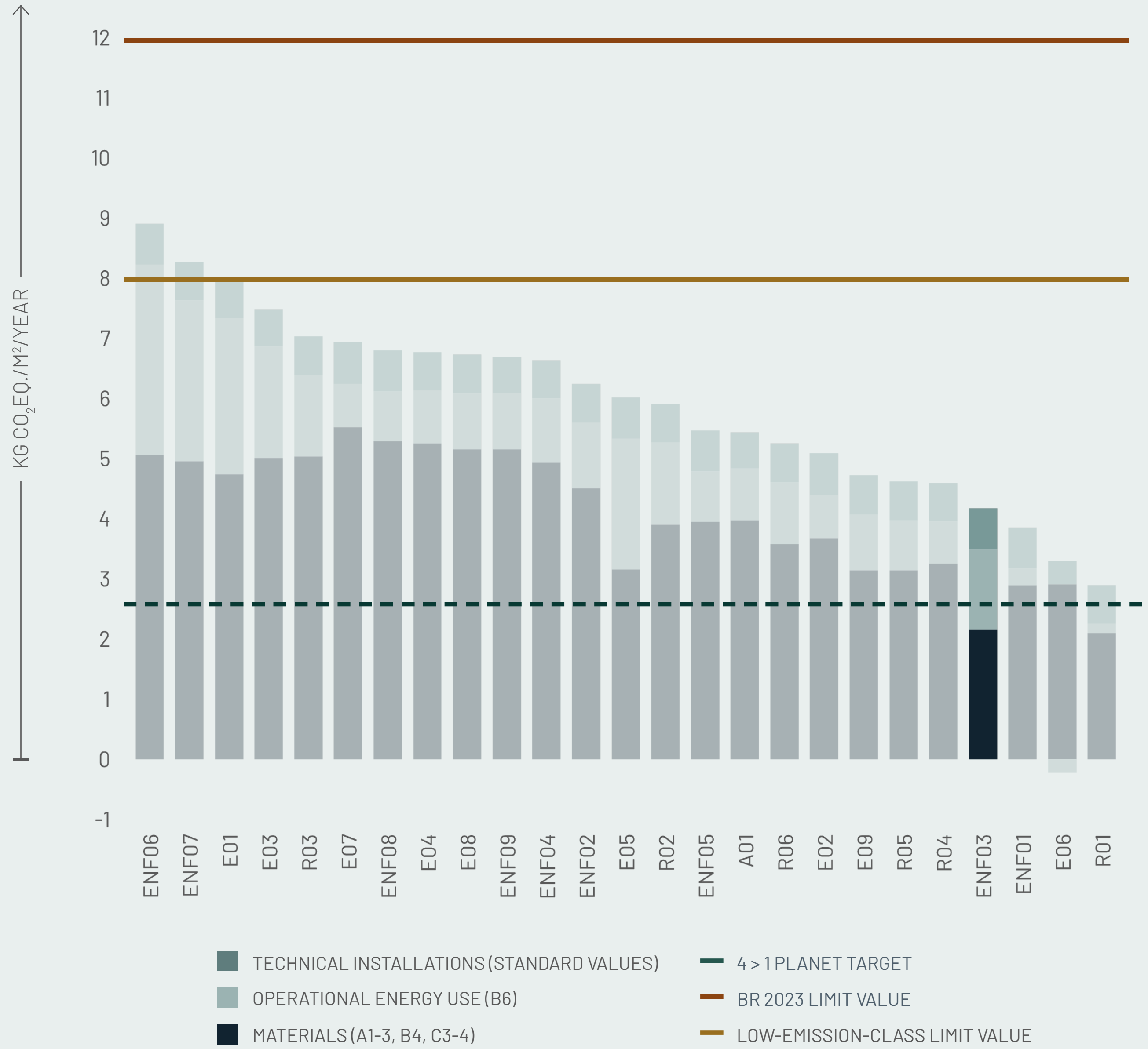



**Figure ENF03.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.



# ENF03: Ecohousing

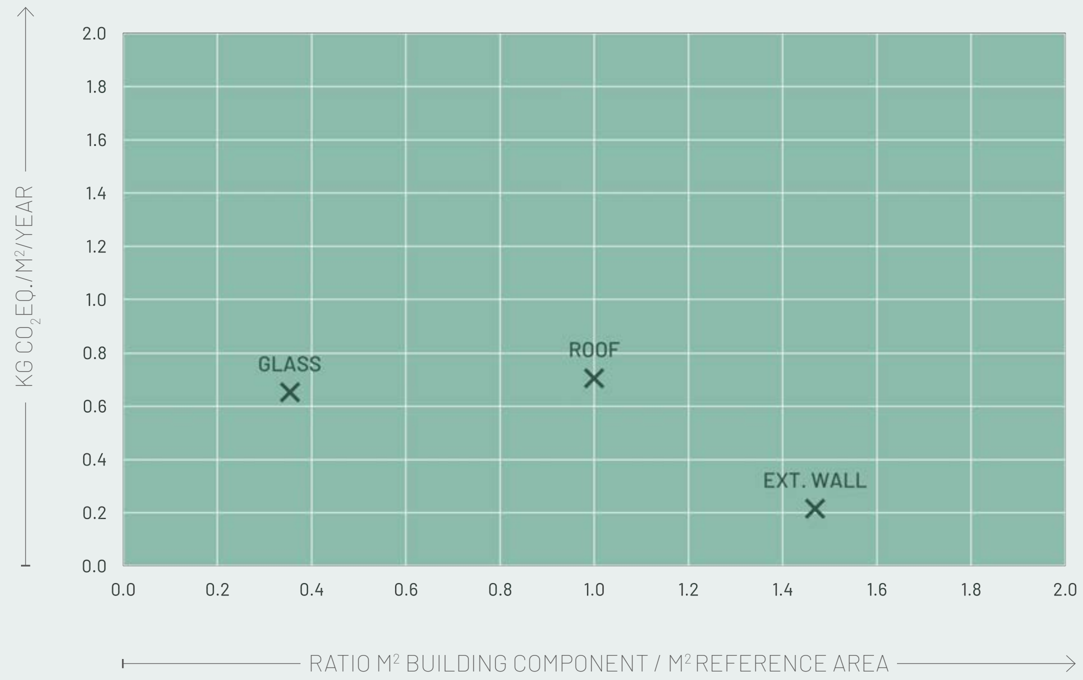
## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in $CO_2$eq./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 $CO_2$eq./m²/year, and the 'safe operating space'.

# ENF03: Ecohousing

## RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS




## ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

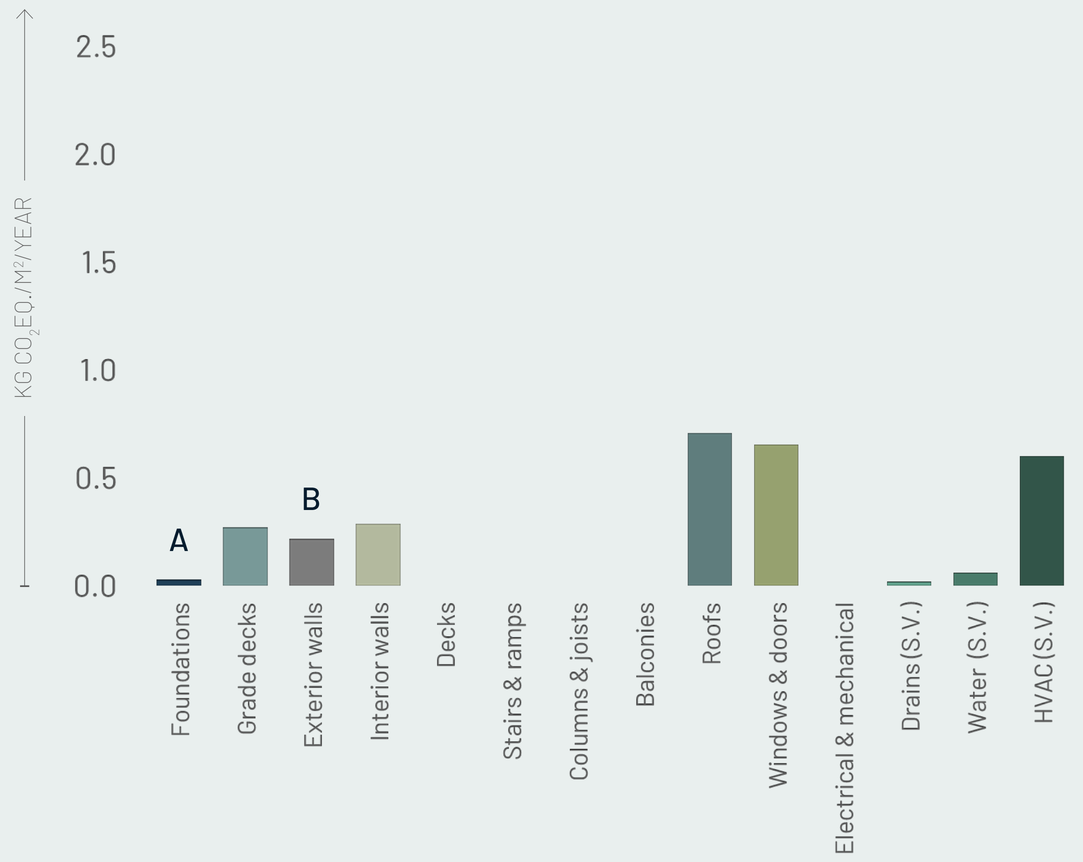



**Figure ENF03.7: $CO_2$ accounting for building components**
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades,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



# ENF03: Ecohousing

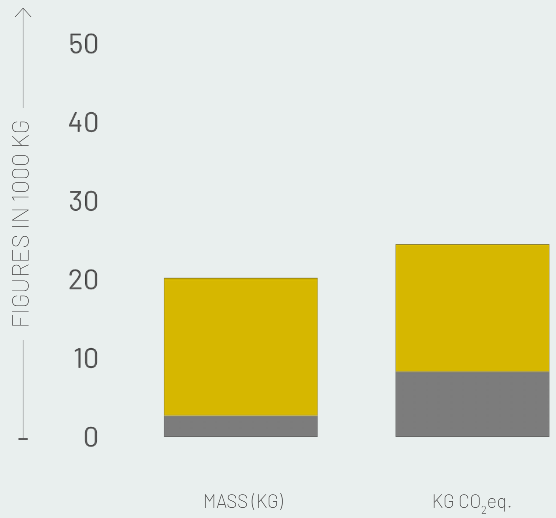
## SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

**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.

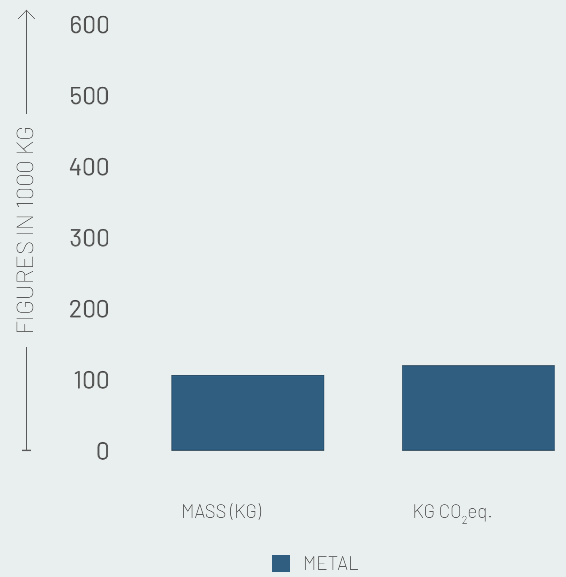
The bar on the left shows the building mass in kg grouped into material categories.

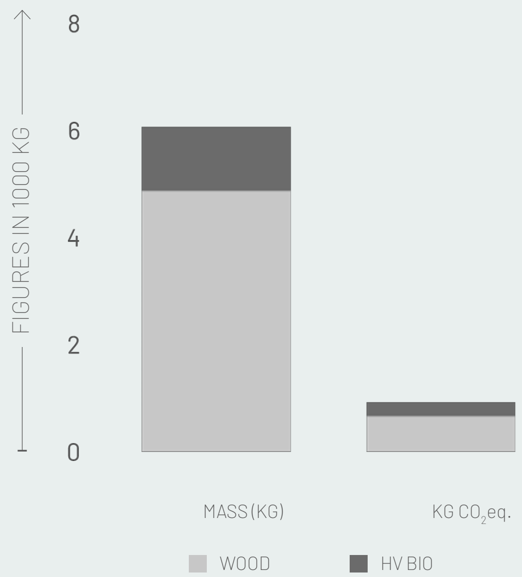
The bar on the right shows the building's total $CO_2$eq grouped similarly.




BIOGENIC MATERIALS   HYBRID MATERIALS   OTHER MATERIALS

## MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG $CO_2$EQ.




### A. FOUNDATION

Galvanised steel screws

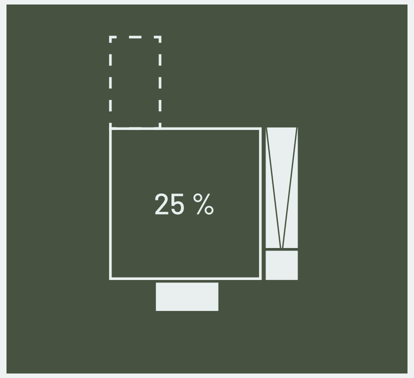
### B. EXTERIOR WALL

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 $CO_2$eq./m²/year

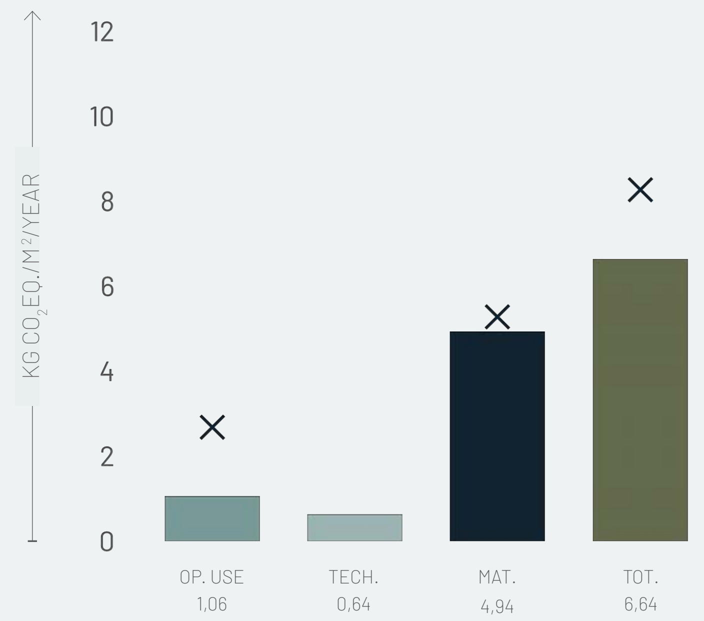



**Figure ENF04.1: Emissions of kg $CO_2$eq./m²/year**
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg $CO_2$eq./m²/year in single-family housing in the case collection.

### 19.908 kg $CO_2$eq.

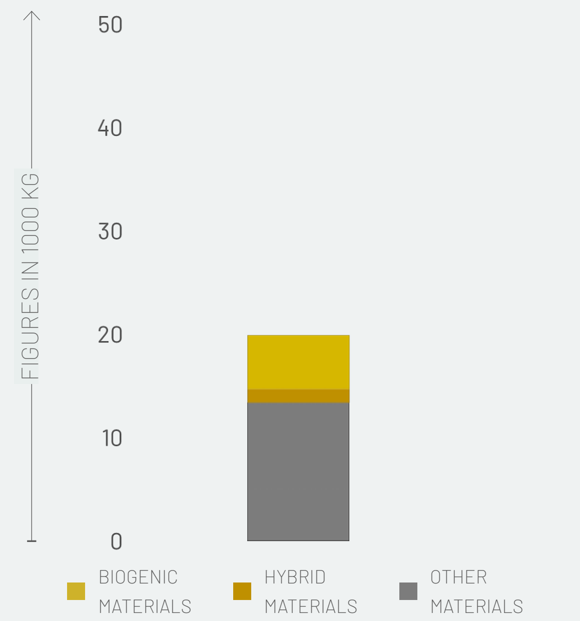



**Figure ENF04.2: Total emission of kg $CO_2$eq.**
The stacked bar chart shows the overall emission of kg $CO_2$eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

### 237 kg $CO_2$eq./person/year

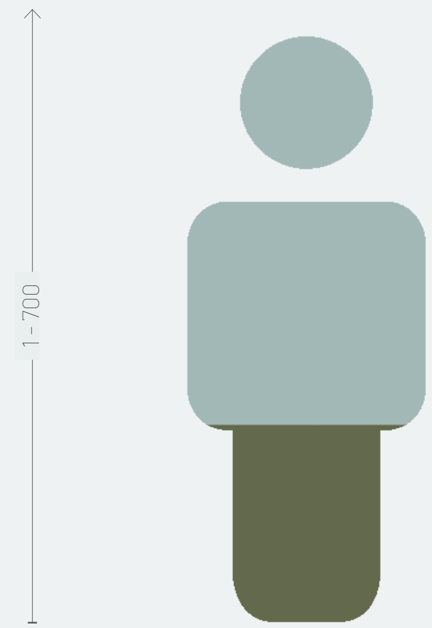



**Figure ENF04.3: Emissions of kg $CO_2$eq./person/year**
The span of the vertical axis is 1 to 700 kg $CO_2$eq./person /year

### 36 m²/person

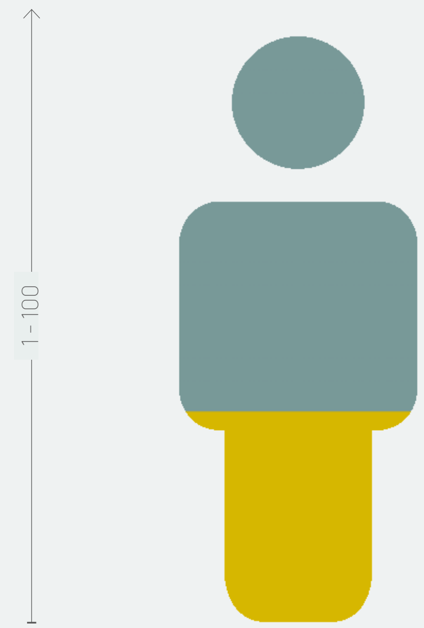



**Figure ENF04.4: m²/person**
The span of the vertical axis is 1 to 100 m²/person.

## 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 $CO_2$eq./m²/year.

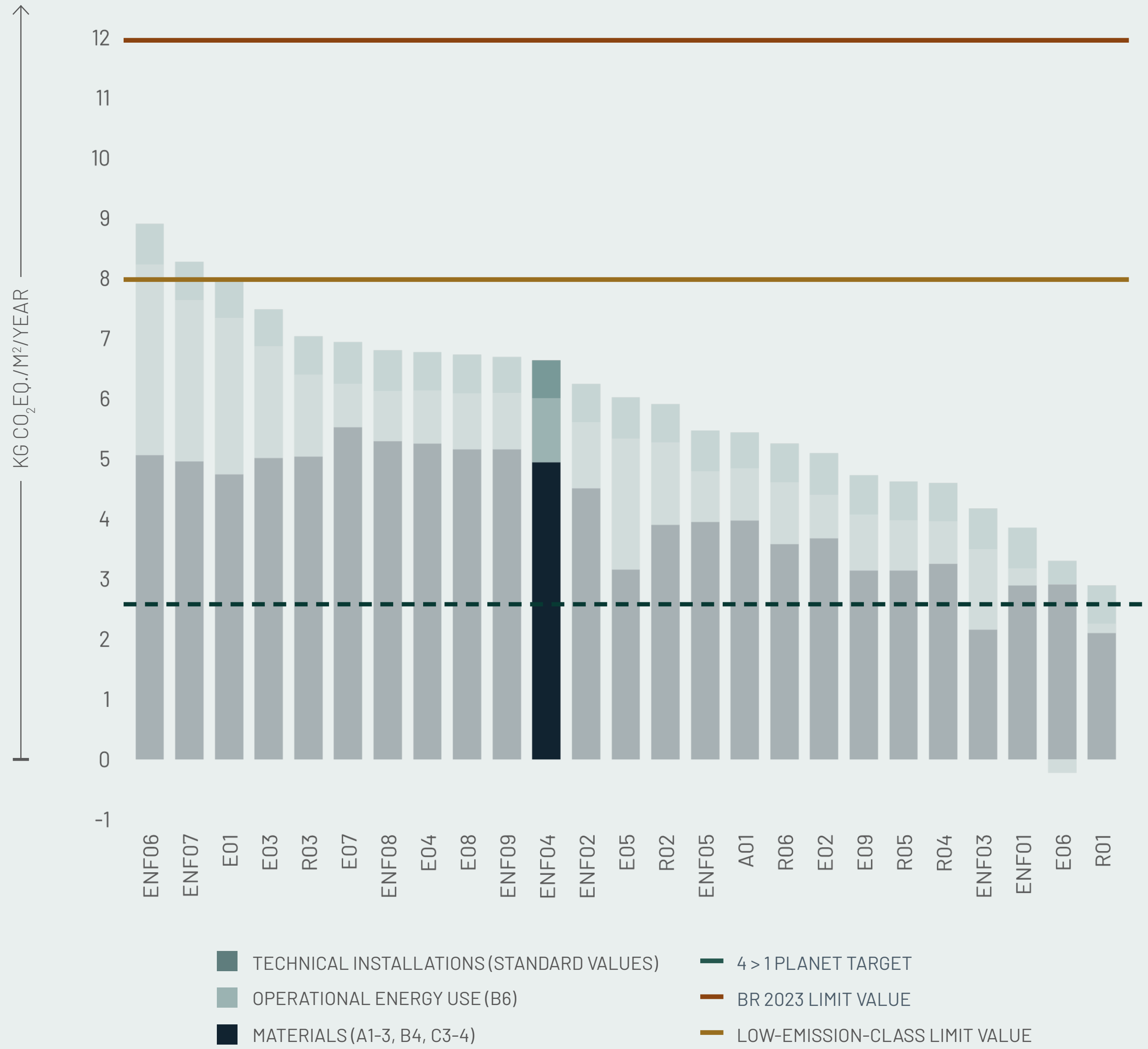



**Figure ENF04.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.



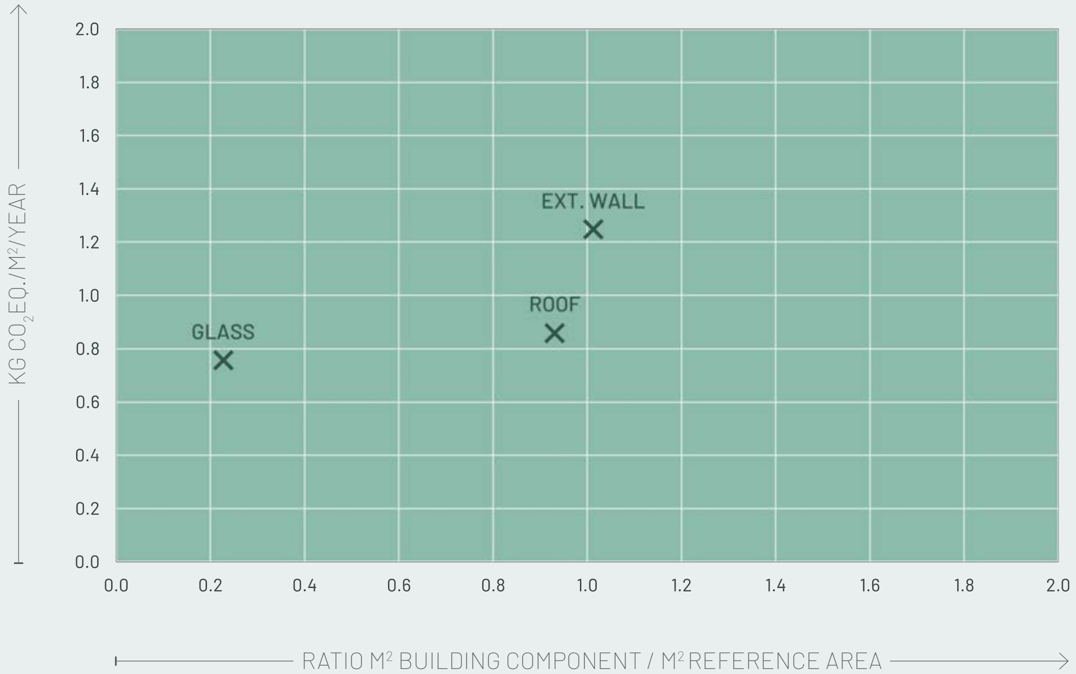
ENF04: Klimakassen

## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in $CO_2$eq./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 $CO_2$eq./m²/year, and the 'safe operating space'.

### RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS




### ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

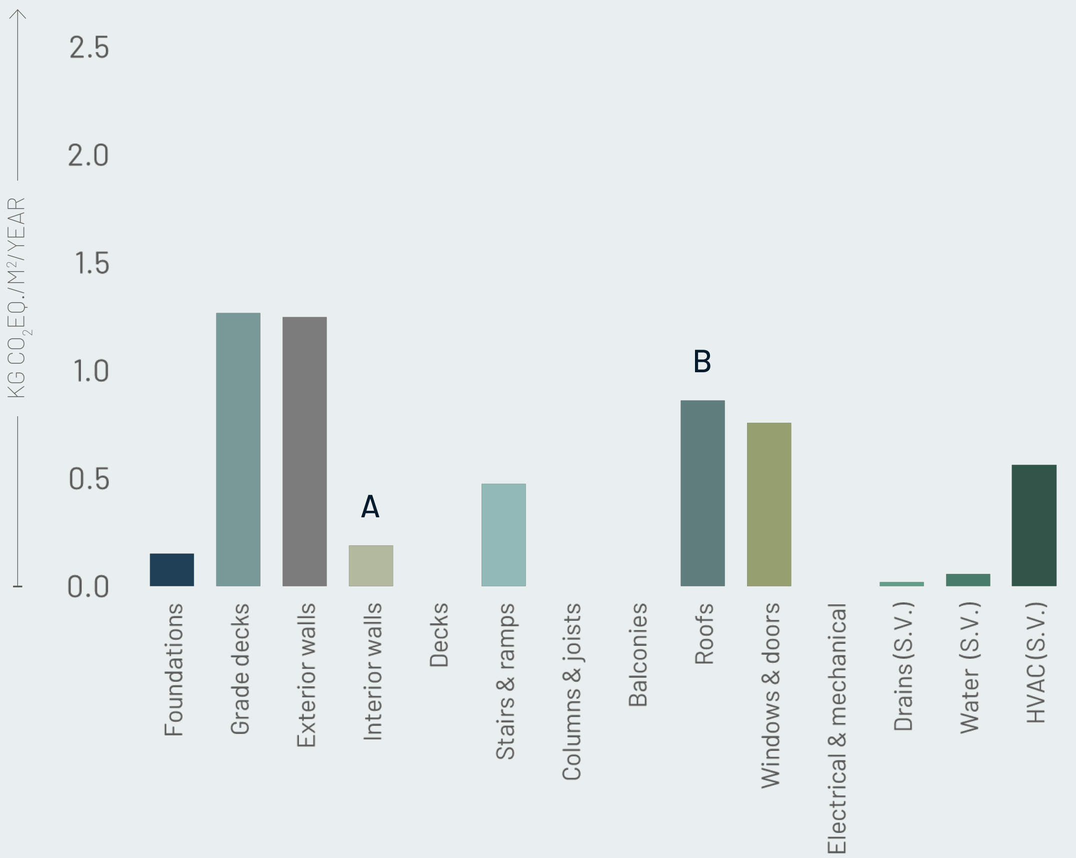



**Figure ENF04.7: $CO_2$ accounting for building components**
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades,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





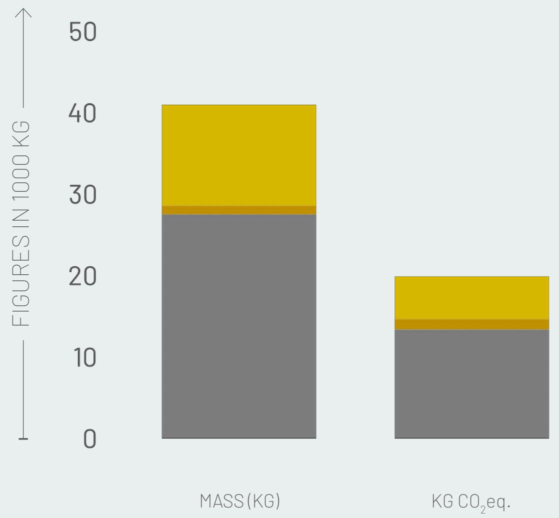
### SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

**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.

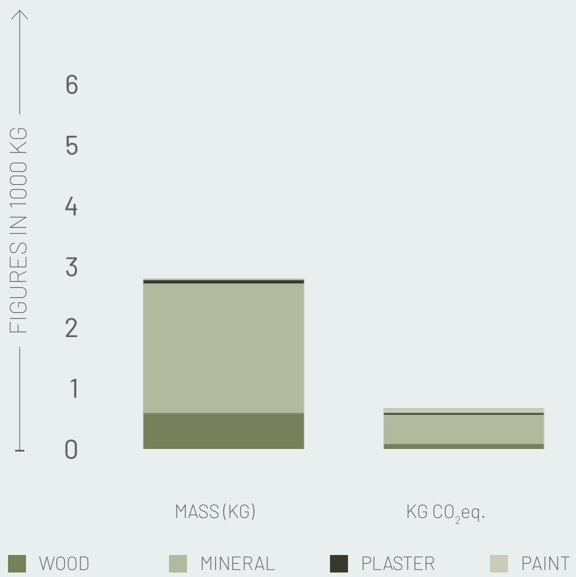
The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total $CO_2$eq grouped similarly.



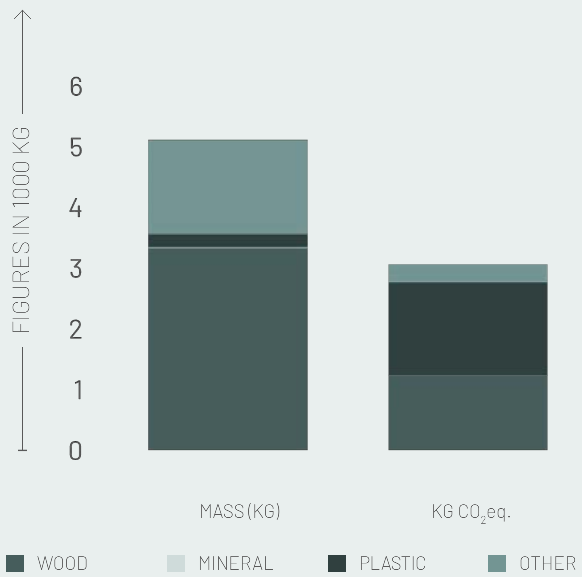

BIOGENIC MATERIALS  HYBRID MATERIALS  OTHER MATERIALS

### MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG $CO_2$EQ.




### A. INTERIOR WALL

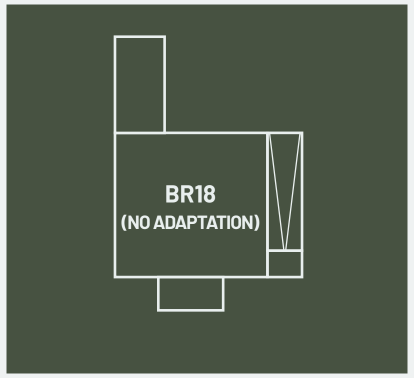
Timber cassettes
Loose-fill wood-fibre insulation
Fibre gypsum boards
Filler and paint




### 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


| | |
|---|---|
| **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

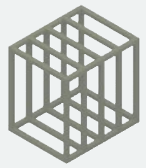
Snoezelhuset is a house appealing to the senses, built in bio-based renewable products by Helsingør Municipality. The house is designed as a single-family home but is used in a public context by one or two users plus their carers a couple of hours every day. In view of the use made of the building, extra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





### 5,47 kg $CO_2$eq./m²/year

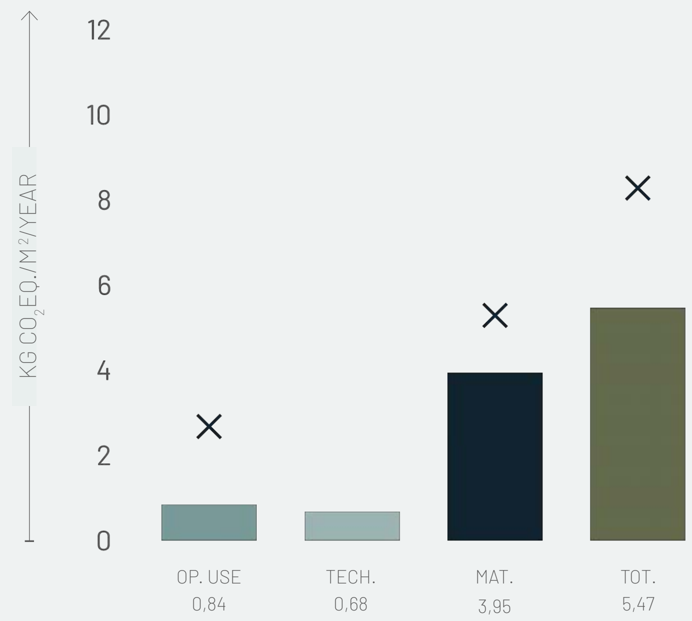



**Figure ENF05.1: Emissions of kg $CO_2$eq./m²/year**
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg $CO_2$eq./m²/year in single-family housing in the case collection.

### 45.107 kg $CO_2$eq.

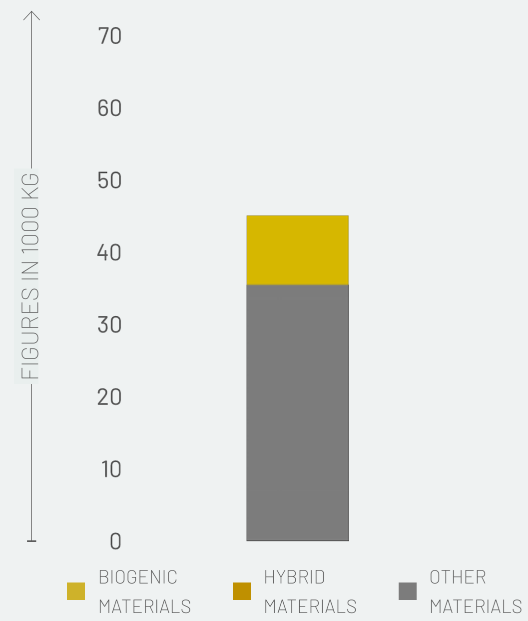



**Figure ENF05.2: Total emission of kg $CO_2$eq.**
The stacked bar chart shows the overall emission of kg $CO_2$-eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

### 329 kg $CO_2$eq./person/year

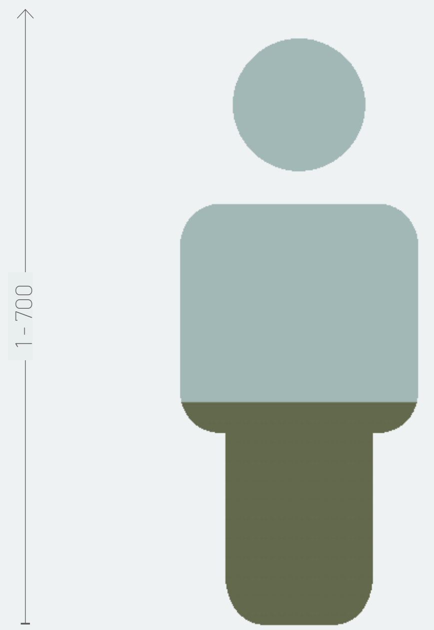



**Figure ENF05.3: Emissions of kg COeq./person/year**
The span of the vertical axis is 1 to 700 kg $CO_2$eq./person/year

### 49 m²/person

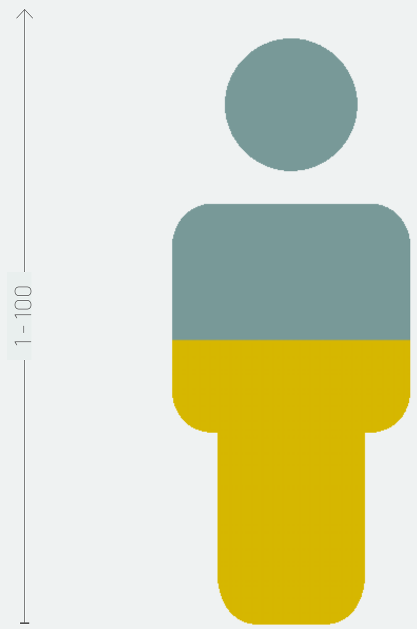



**Figure ENF05.4: m²/person**
The span of the vertical axis is 1 to 100 m²/person.

# 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 $CO_2$eq./m²/year.

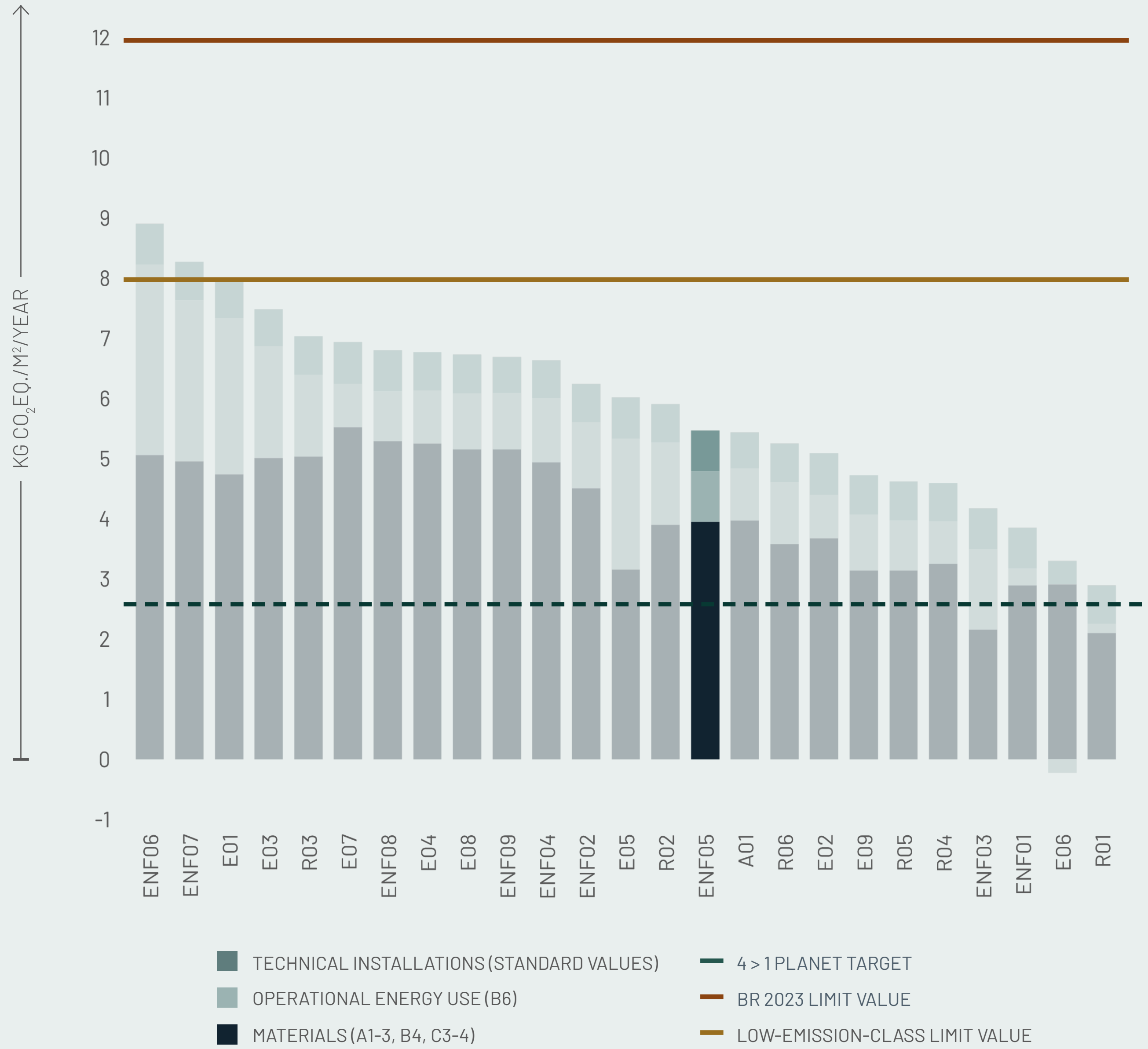



**Figure ENF05.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.



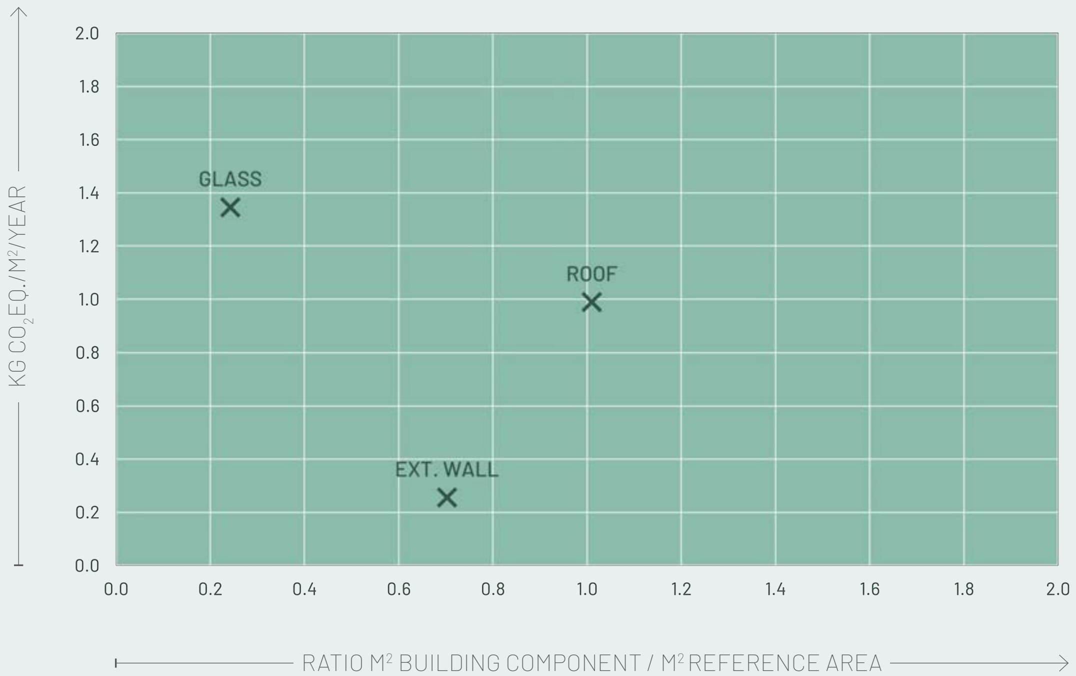
# ENF05: Snoezelhuset

## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in $CO_2$eq./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 $CO_2$eq./m²/year, and the 'safe operating space'.

## RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS




## ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

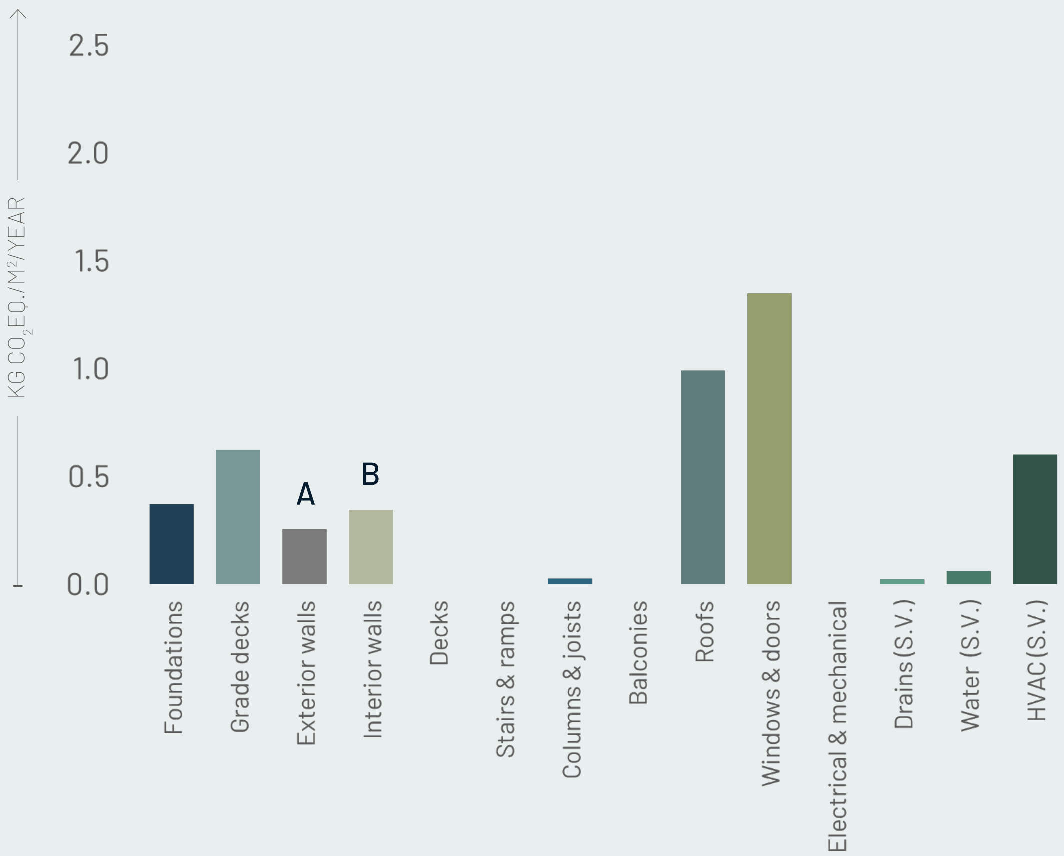



**Figure ENF05.7: $CO_2$ accounting for building components**

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

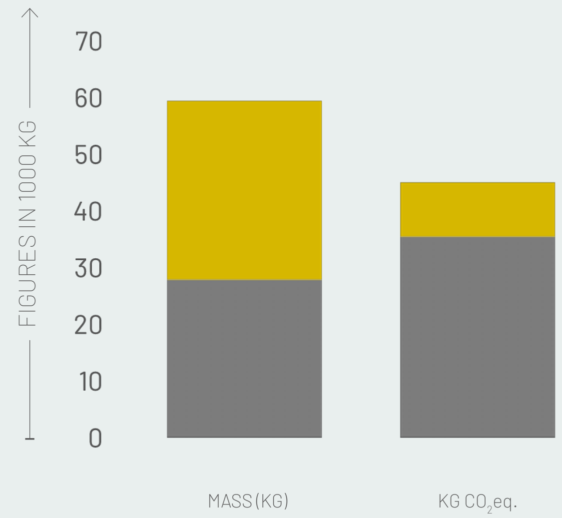
## SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

**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.

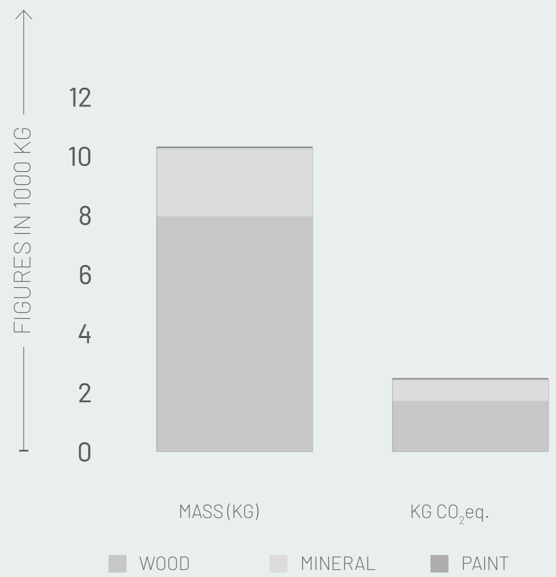
The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total $CO_2$eq grouped similarly.



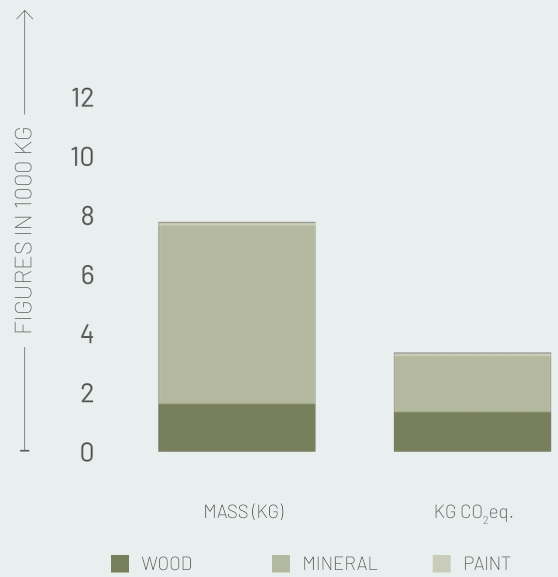

BIOGENIC MATERIALS — HYBRID MATERIALS — OTHER MATERIALS

## MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG $CO_2$EQ.




### 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



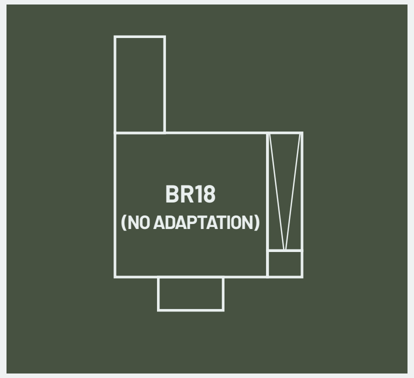

### B. INTERIOR WALL

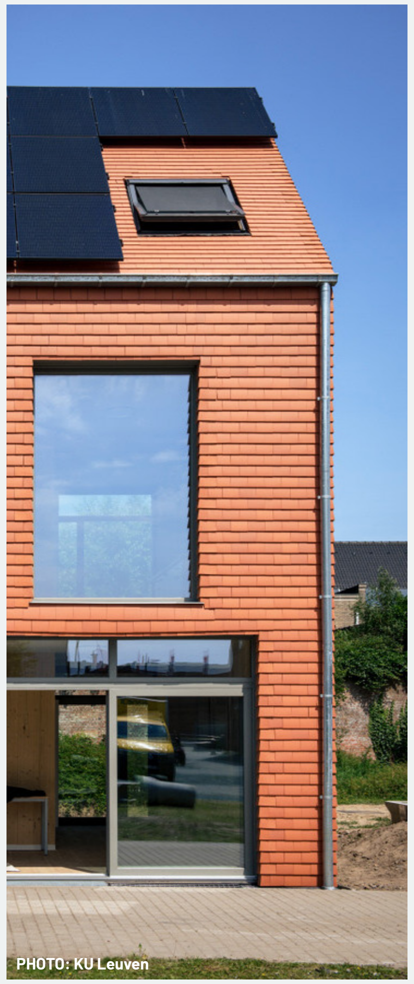
Timber frame
Wood-fibre insulation batts
Fibre gypsum boards
Filler and paint

# 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

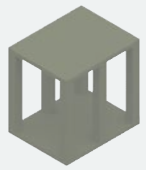
CBCI Living Lab Ghent is an international demo project with special emphasis on a design facilitating dismantling and use of bio-based materials.

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 $CO_2$eq./m²/year

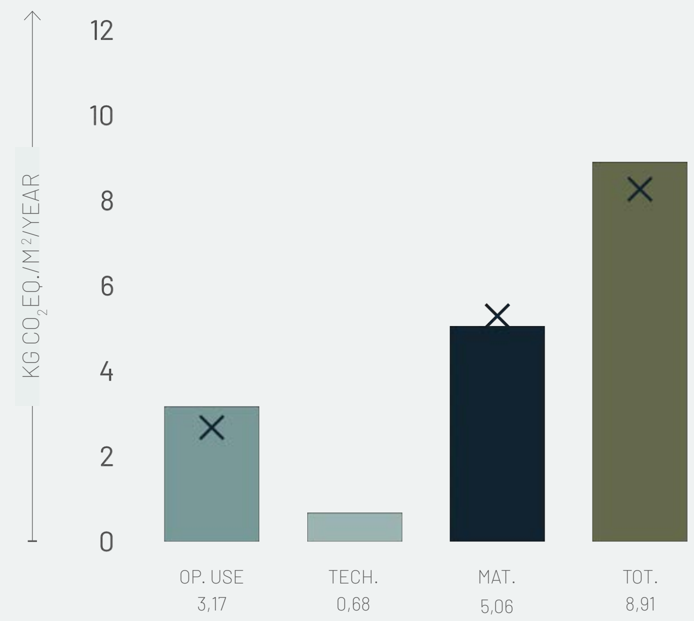



**Figure ENF06.1: Emissions of kg $CO_2$eq./m²/year**
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg $CO_2$eq/m² /year in single-family housing in the case collection. This case study has the highest $CO_2$eq/m²/year emissions from operational energy use, but since it is an international study, it is not used as reference (X).

24.107 kg $CO_2$eq.

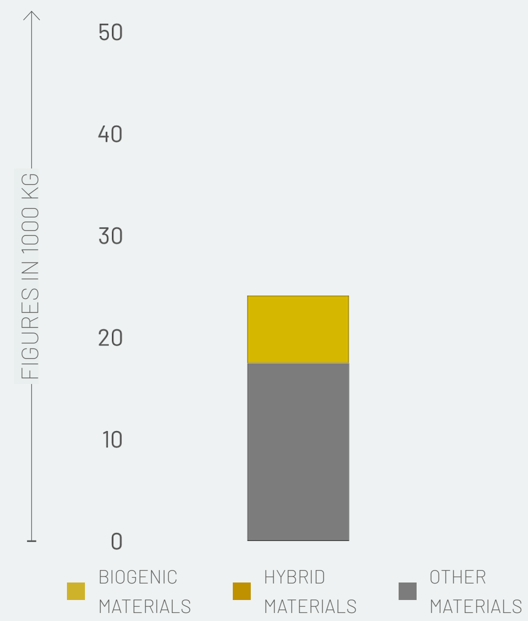



**Figure ENF06.2: Total emission of kg $CO_2$eq.**
The stacked bar chart shows the overall emission of kg $CO_2$eq. in the case study grouped into the three material categories: other, hybrids, and biogenic.

362 kg $CO_2$eq./person/year

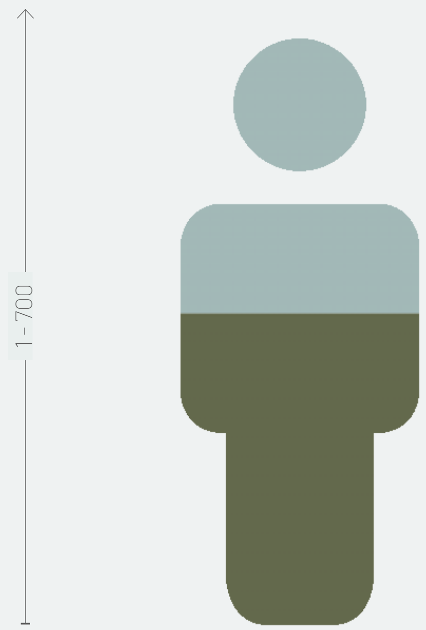



**Figure ENF06.3: Emissions of kg $CO_2$eq./person/year**
The span of the vertical axis is 1 to 700 kg $CO_2$eq./person/year

42 m²/person

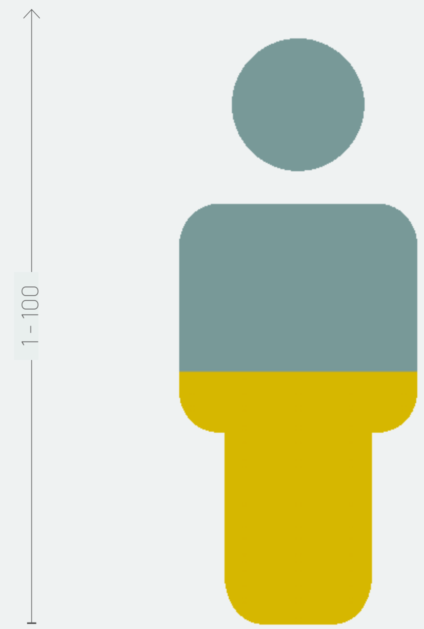



**Figure ENF6.4: m²/person**
The span of the vertical axis is 1 to 100 m²/person.

# 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 $CO_2$eq./m²/year.

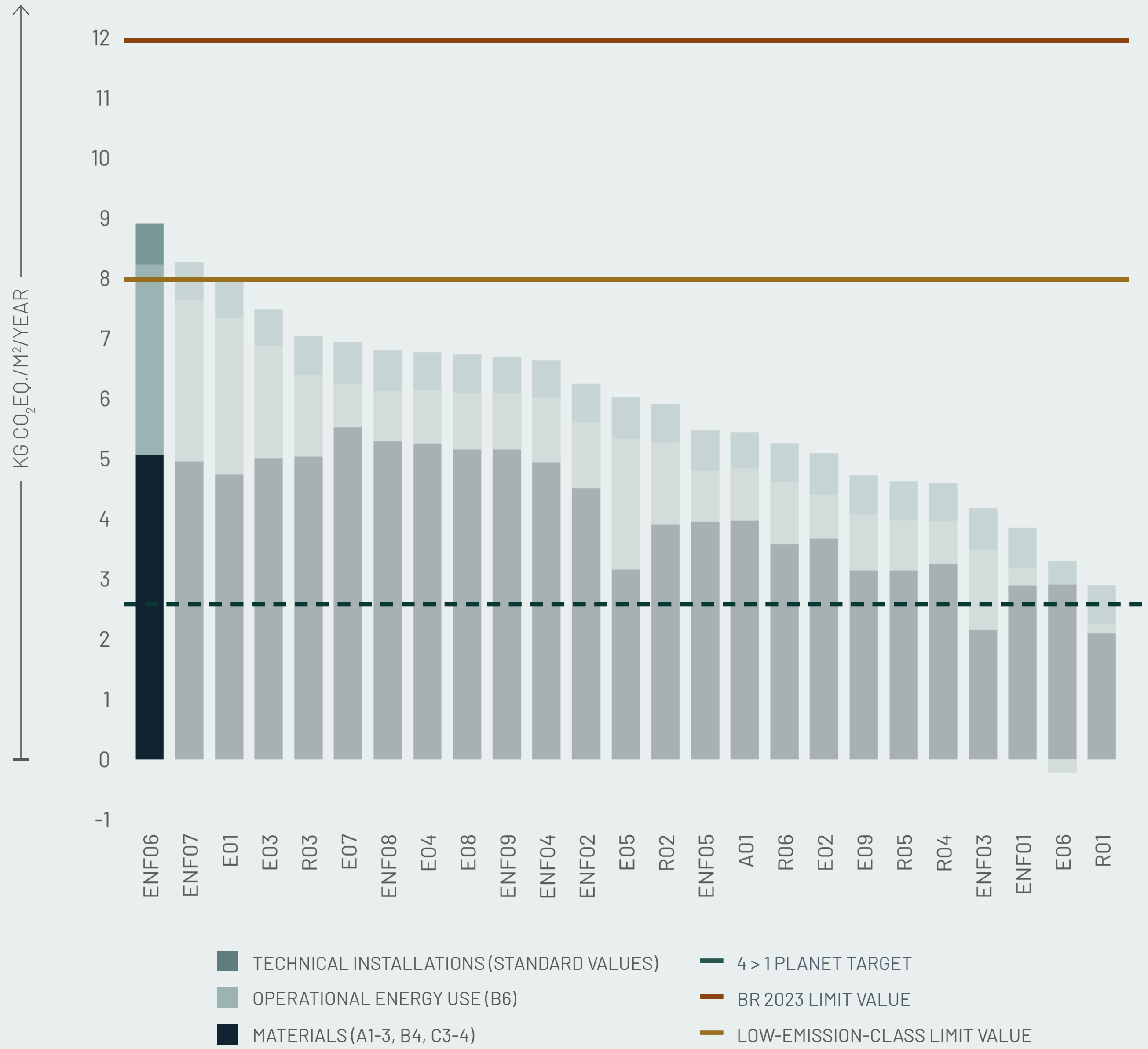



**Figure ENF06.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.



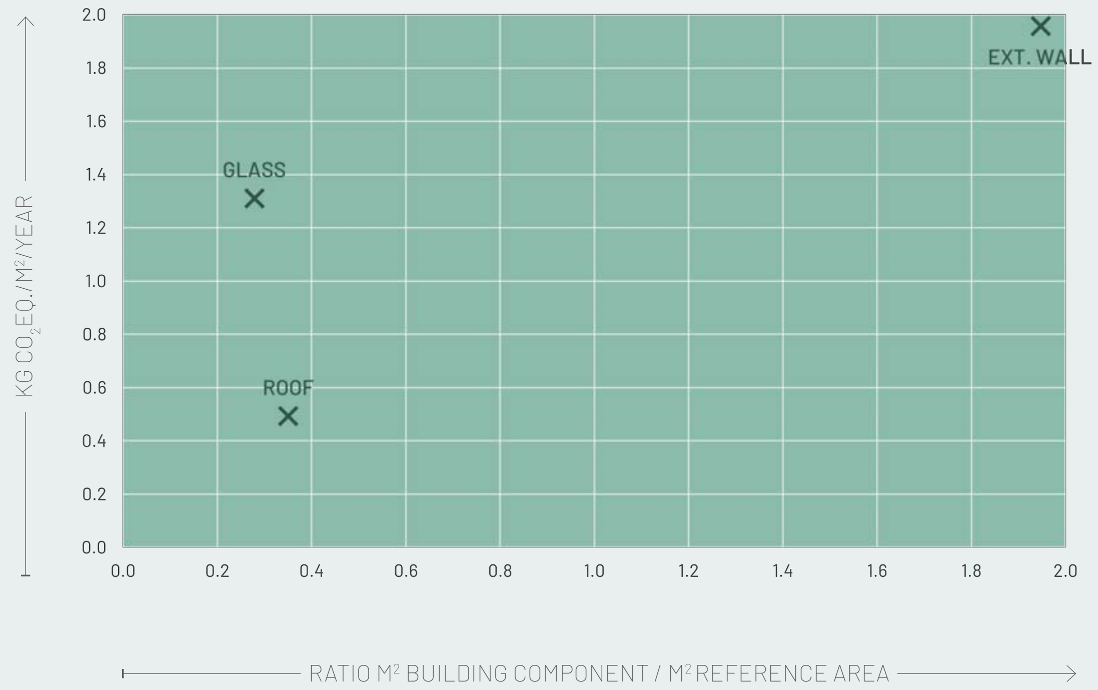
# ENF06: CBCI Living Lab

## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in $CO_2$eq./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 $CO_2$eq./m²/year, and the 'safe operating space'.

## RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS




## ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

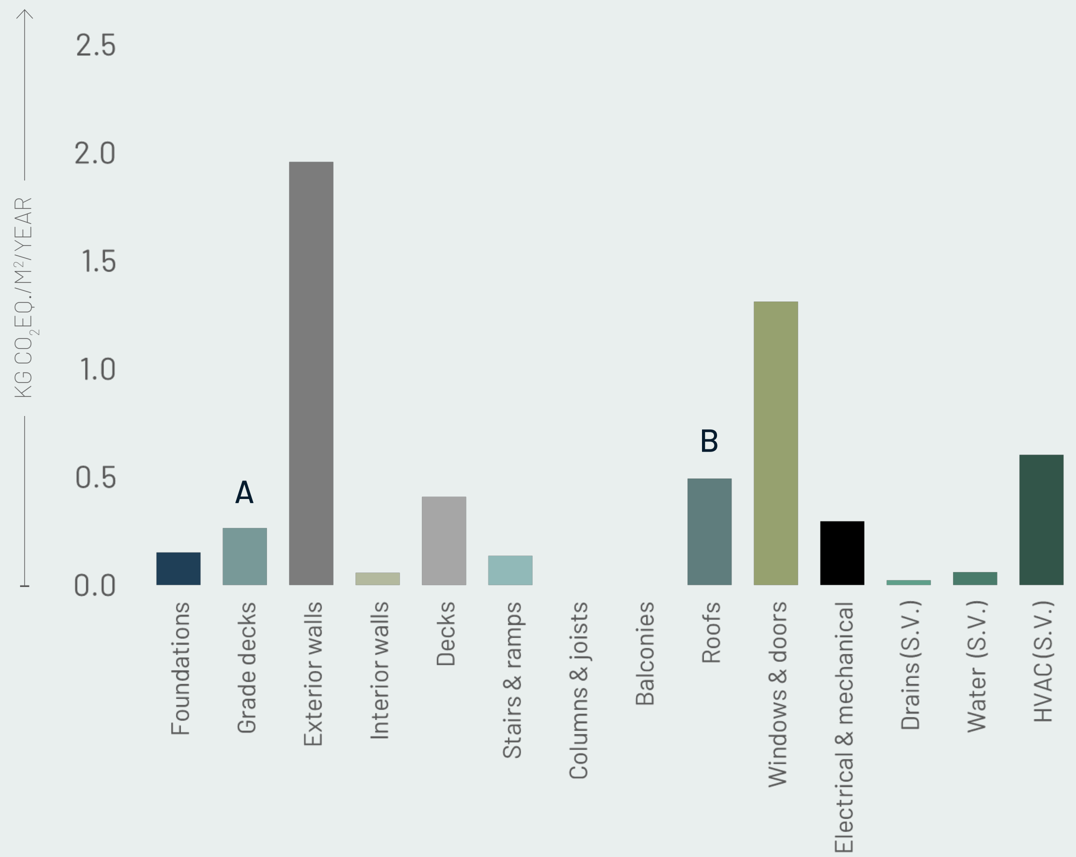



**Figure ENF06.7: $CO_2$ accounting for building components**
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades,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



ENF06: CBCI Living Lab

## SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

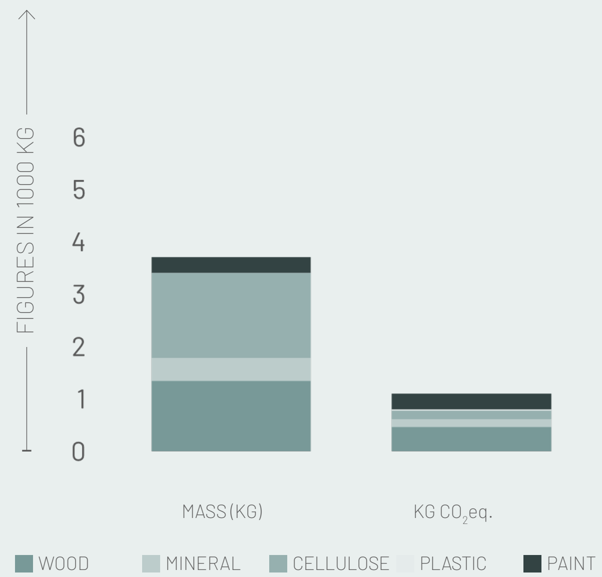
**Figure ENF06.8:**
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

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.

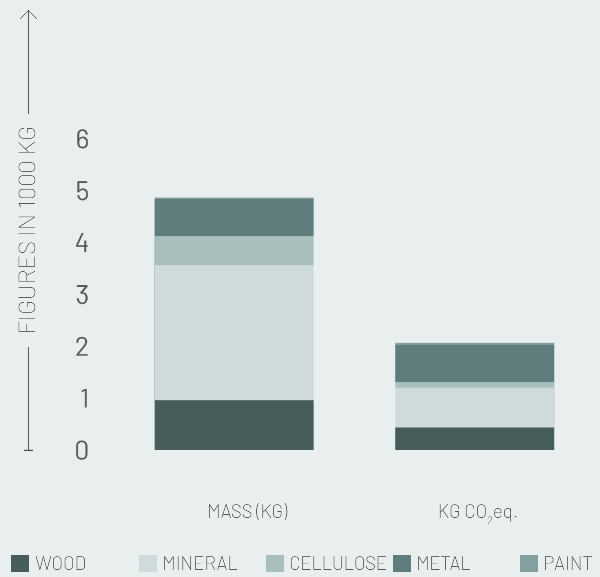
The bar on the right shows the building's total $CO_2$eq grouped similarly.


## MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG $CO_2$EQ.




### A. GRADE DECK

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



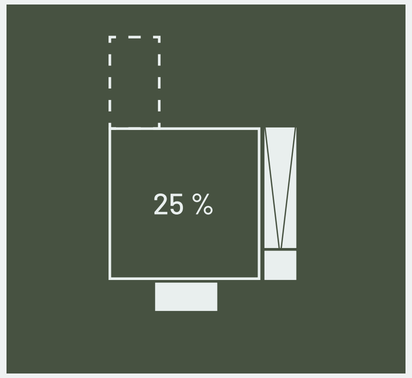

### B. ROOF

- 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

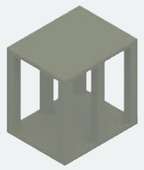
Upcycle House is one of five single-family dwellings collectively known as the MiniCO$_2$ Houses. In this single-family housing project backed by Realdania By & Byg, the common denominator is affordable housing and where emphasis has been on reducing CO$_2$ emissions in various ways. Upcycle House is 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

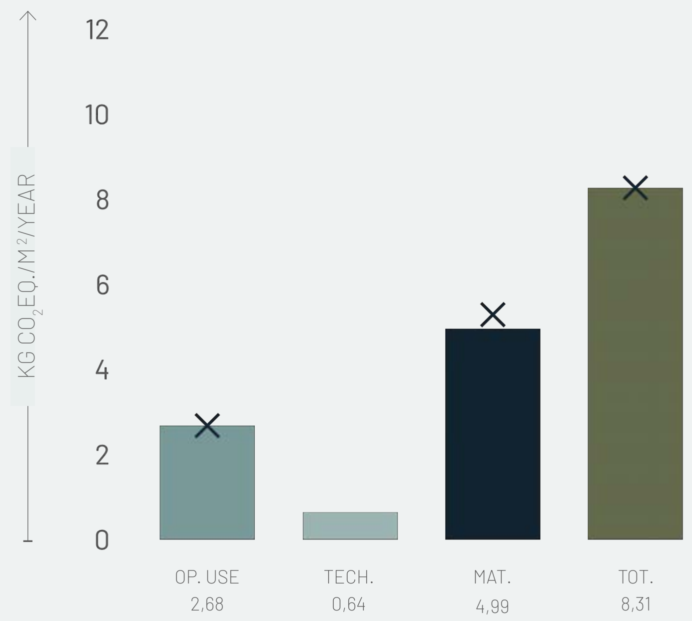



**Figure ENF07.1: Emissions of kg CO$_2$eq./m²/year**
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg CO$_2$eq./m²/year in single-family housing in the case collection.

39.951 kg CO$_2$eq.

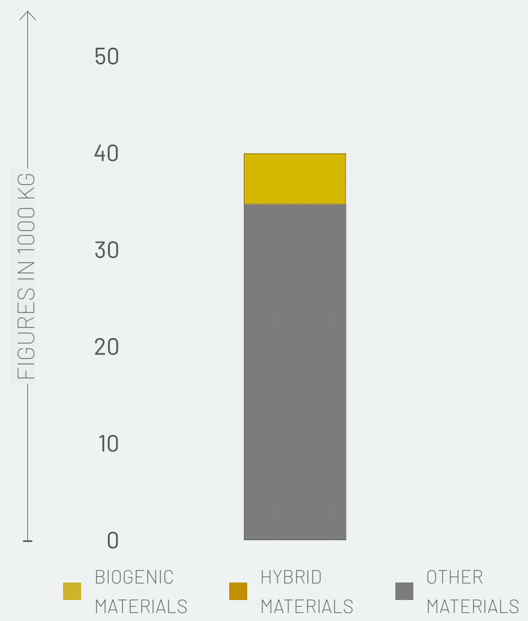



**Figure ENF07.2: Total emission of kg CO$_2$eq.**
The stacked bar chart shows the overall emission of kg CO$_2$eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

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

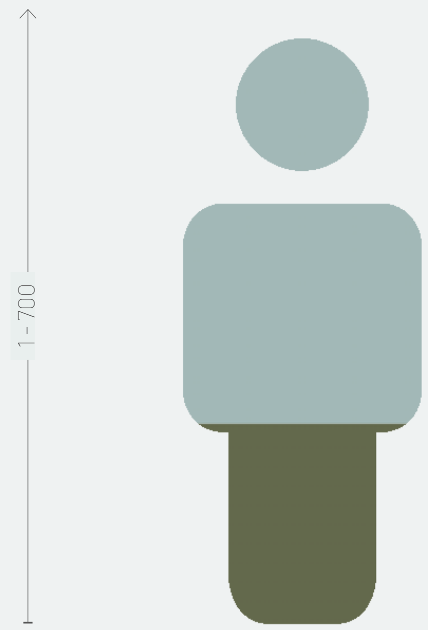



**Figure ENF07.3: Emissions of kg CO$_2$eq./person/year**
The span of the vertical axis is 1 to 700 kg CO$_2$eq./person/year

29 m²/person

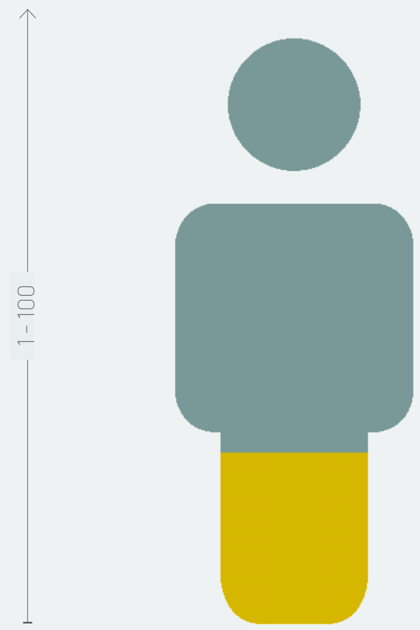



**Figure ENF07.4: m²/person**
The span of the vertical axis is 1 to 100 m²/person.

# 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 $CO_2$eq./m²/year.

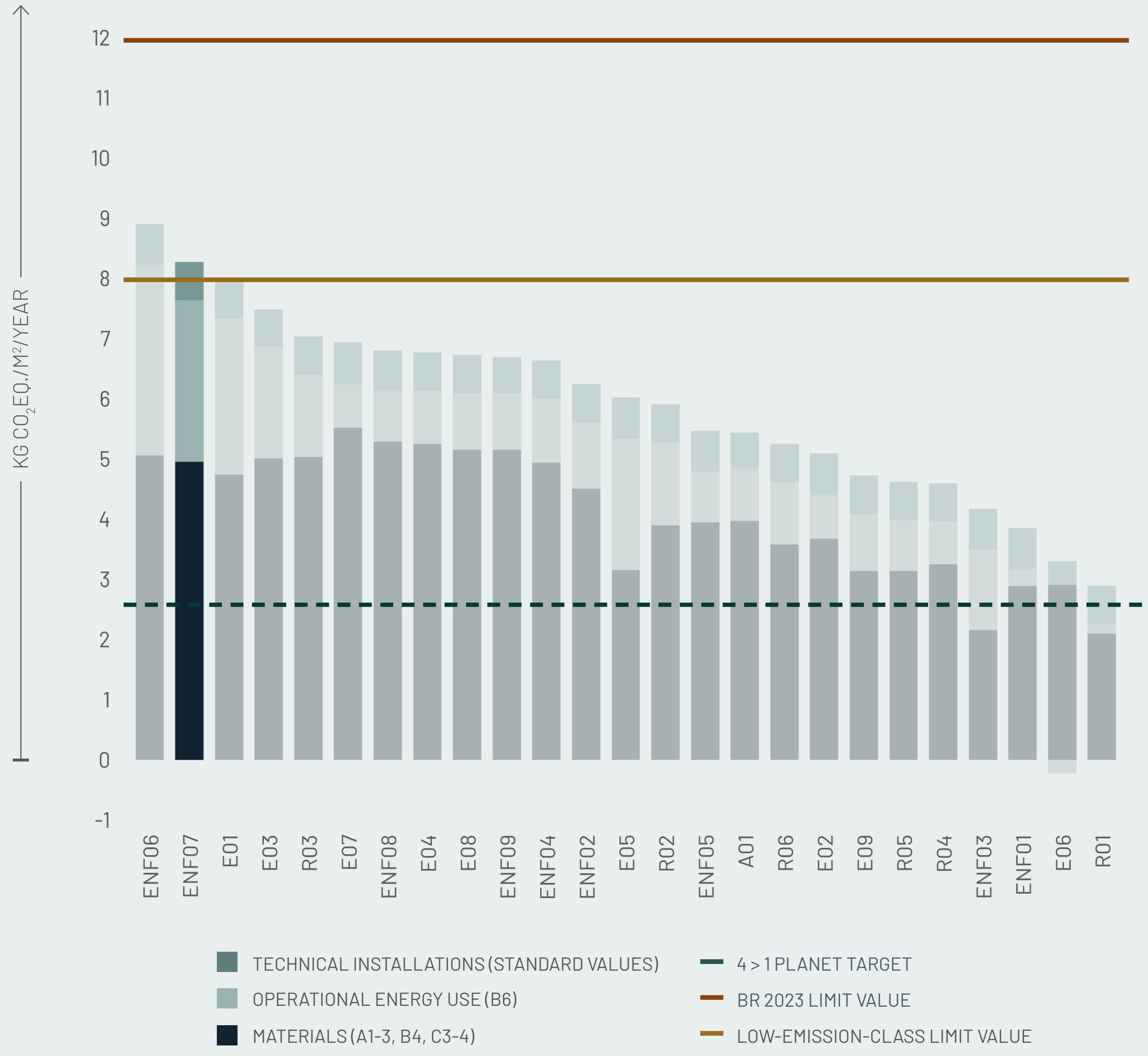



**Figure ENF07.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.



# ENF07: Upcycle House

## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in $CO_2$eq./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.

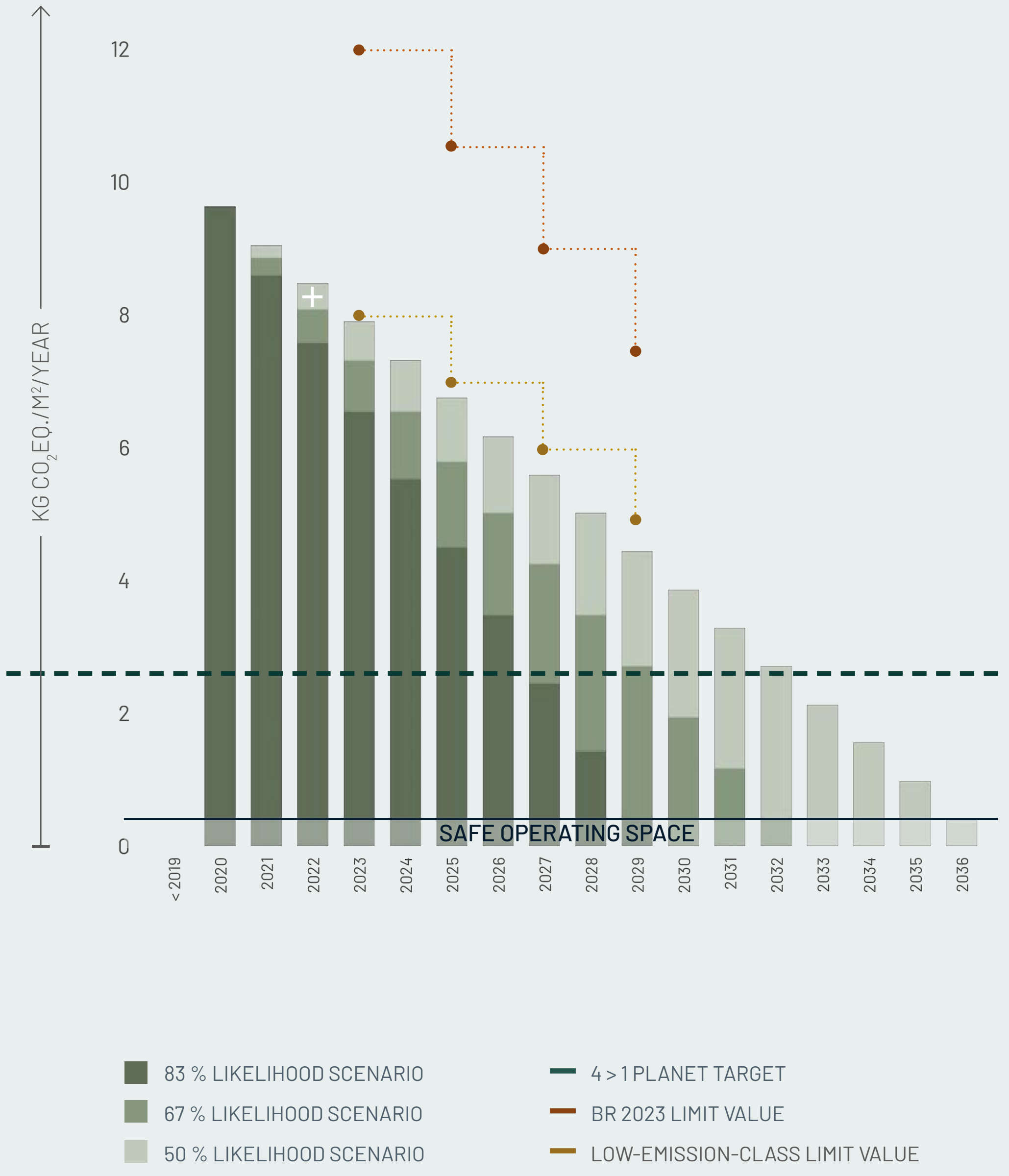
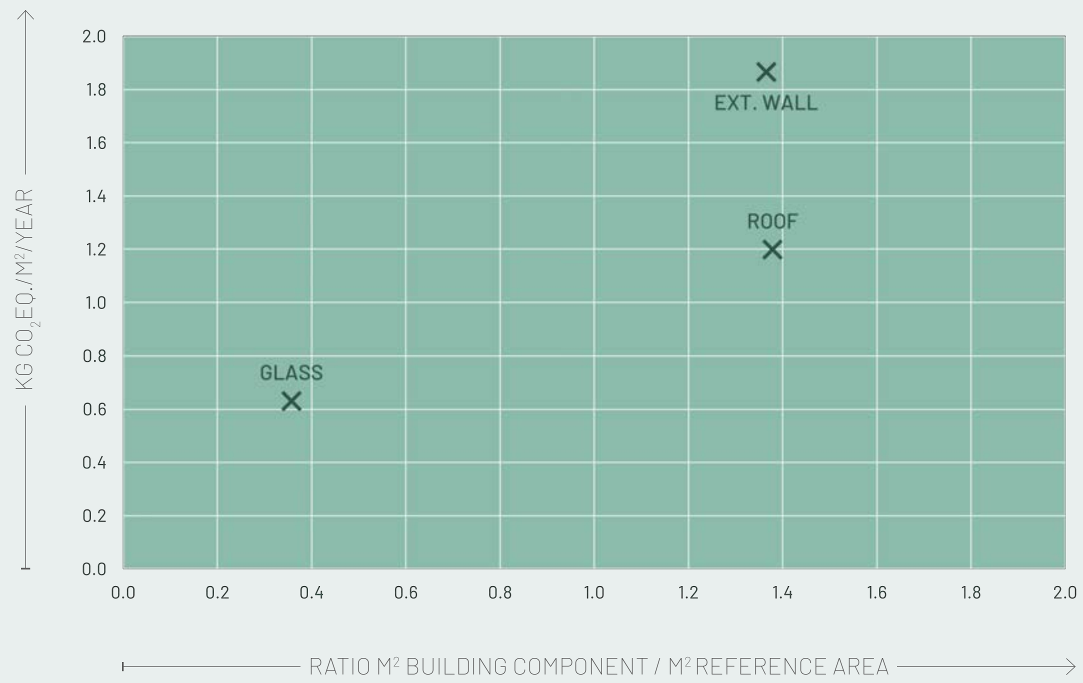



**Figure ENF07.6: Reduction Roadmap**
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg $CO_2$eq./m²/year, and the 'safe operating space'.

# ENF07: Upcycle House

## RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS




## ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

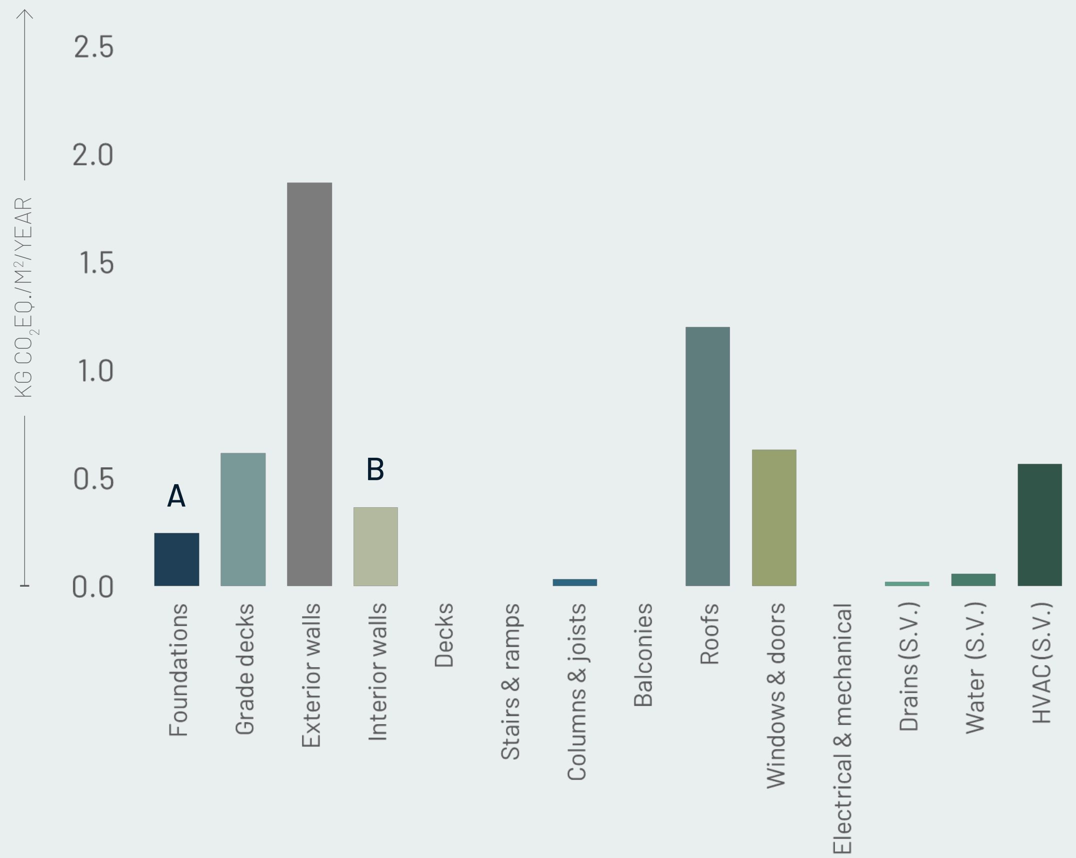



**Figure ENF07.7: $CO_2$ accounting for building components**
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades,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



# ENF07: Upcycle House

## SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

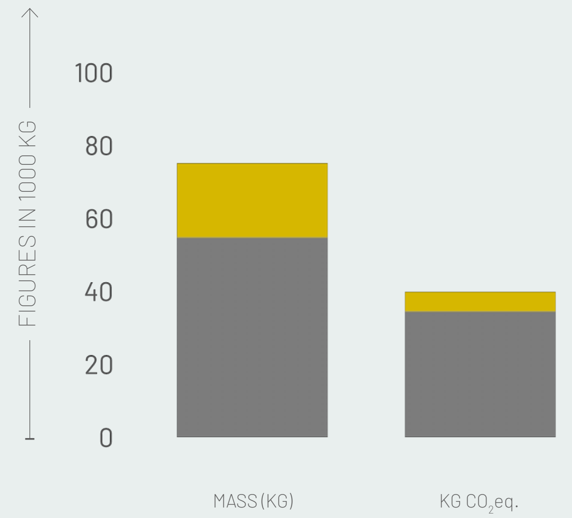
**Figure ENF07.8:**
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

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

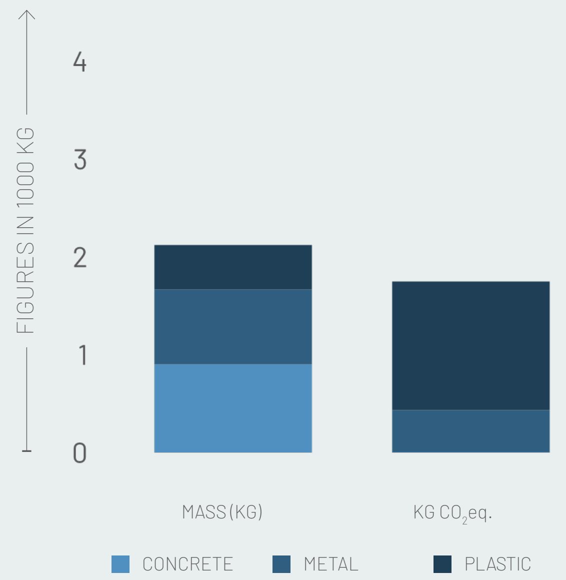
The bar on the left shows the building mass in kg grouped into material categories.

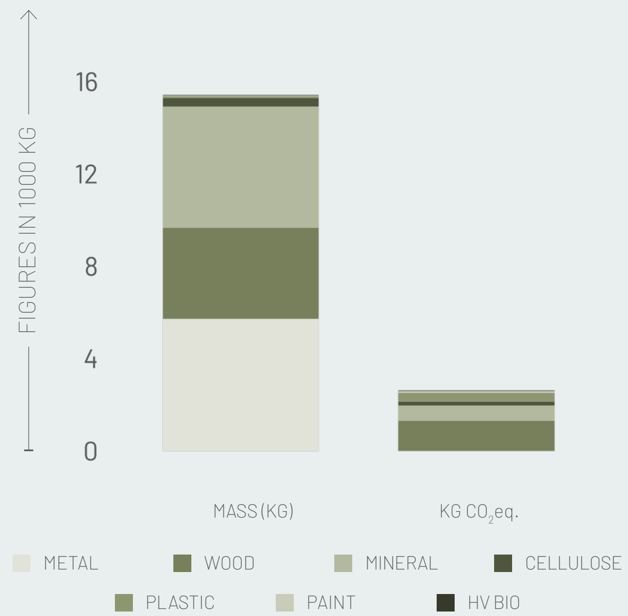
The bar on the right shows the building's total $CO_2$eq grouped similarly.

BIOGENIC MATERIALS
HYBRID MATERIALS
OTHER MATERIALS




## MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG $CO_2$EQ.




### A. FOUNDATION

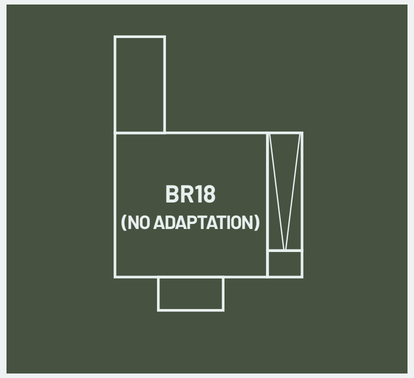
Point foundations, concrete (reuse)
Screw-pile footings, steel (part reuse)

### 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





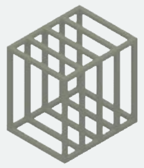
## DESCRIPTION

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 $CO_2$eq./m²/year

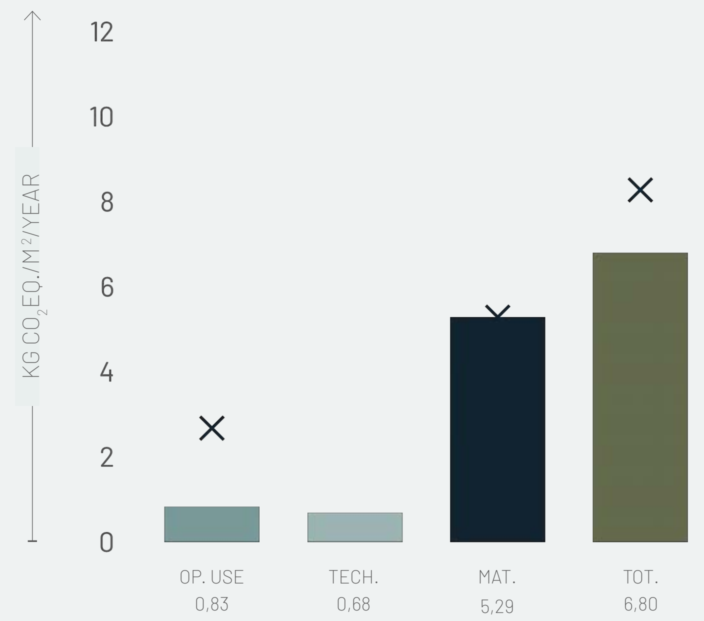



**Figure ENF08.1: Emissions of kg $CO_2$eq./m²/year**
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg $CO_2$eq./m²/year in single-family housing in the case collection.

17.545 kg $CO_2$eq.

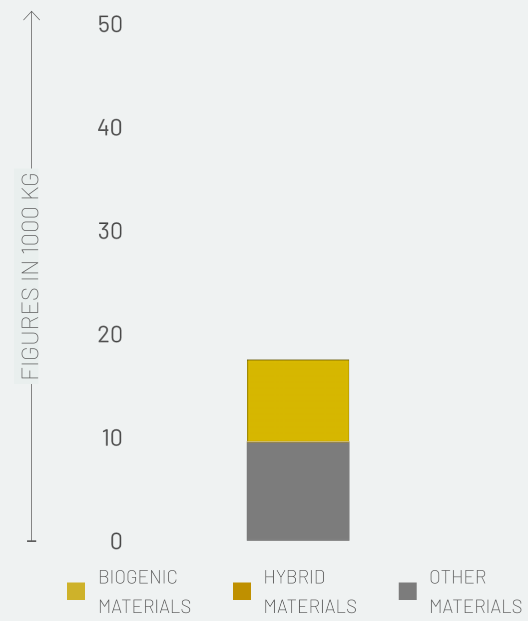



**Figure ENF08.2: Total emission of kg $CO_2$eq.**
The stacked bar chart shows the overall emission of kg $CO_2$eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

200 kg $CO_2$-eq / person / year

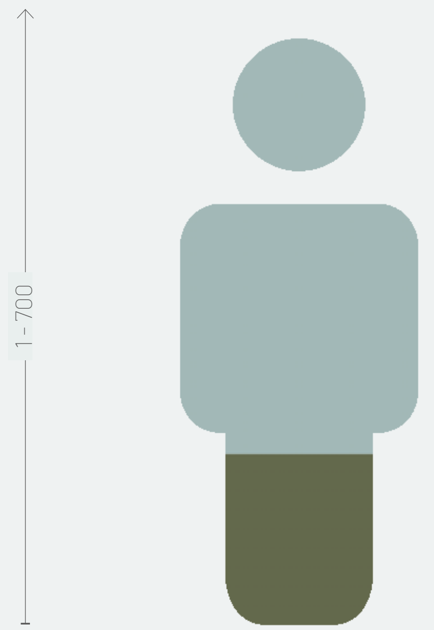



**Figure ENF08.3: Emissions of kg $CO_2$eq./person/year**
The span of the vertical axis is 1 to 700 kg $CO_2$eq./person/year

29 m² / person

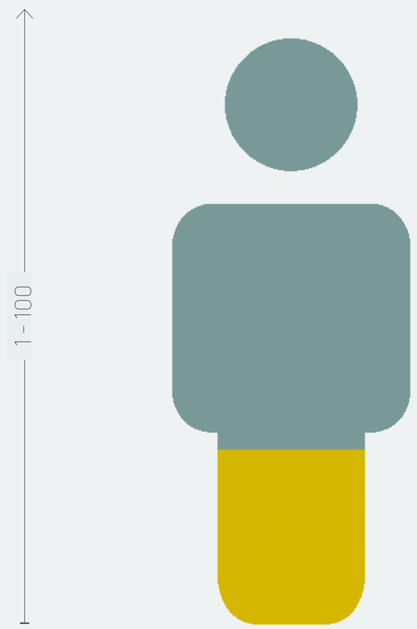



**Figure ENF08.4: m²/person**
The span of the vertical axis is 1 to 100 m²/person.

## 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 $CO_2$eq./m²/year.

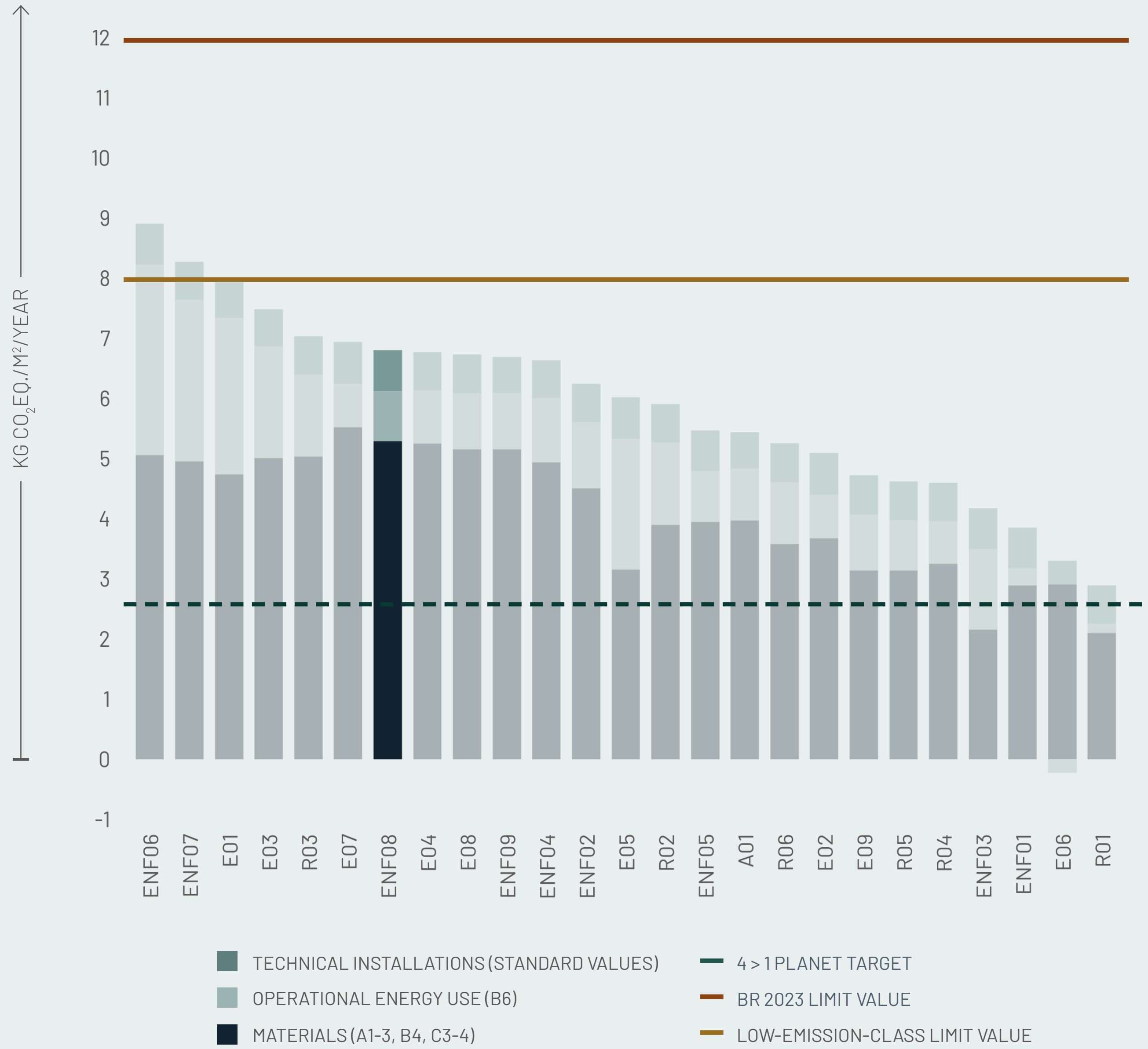



**Figure ENF08.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.





## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in $CO_2$eq./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.

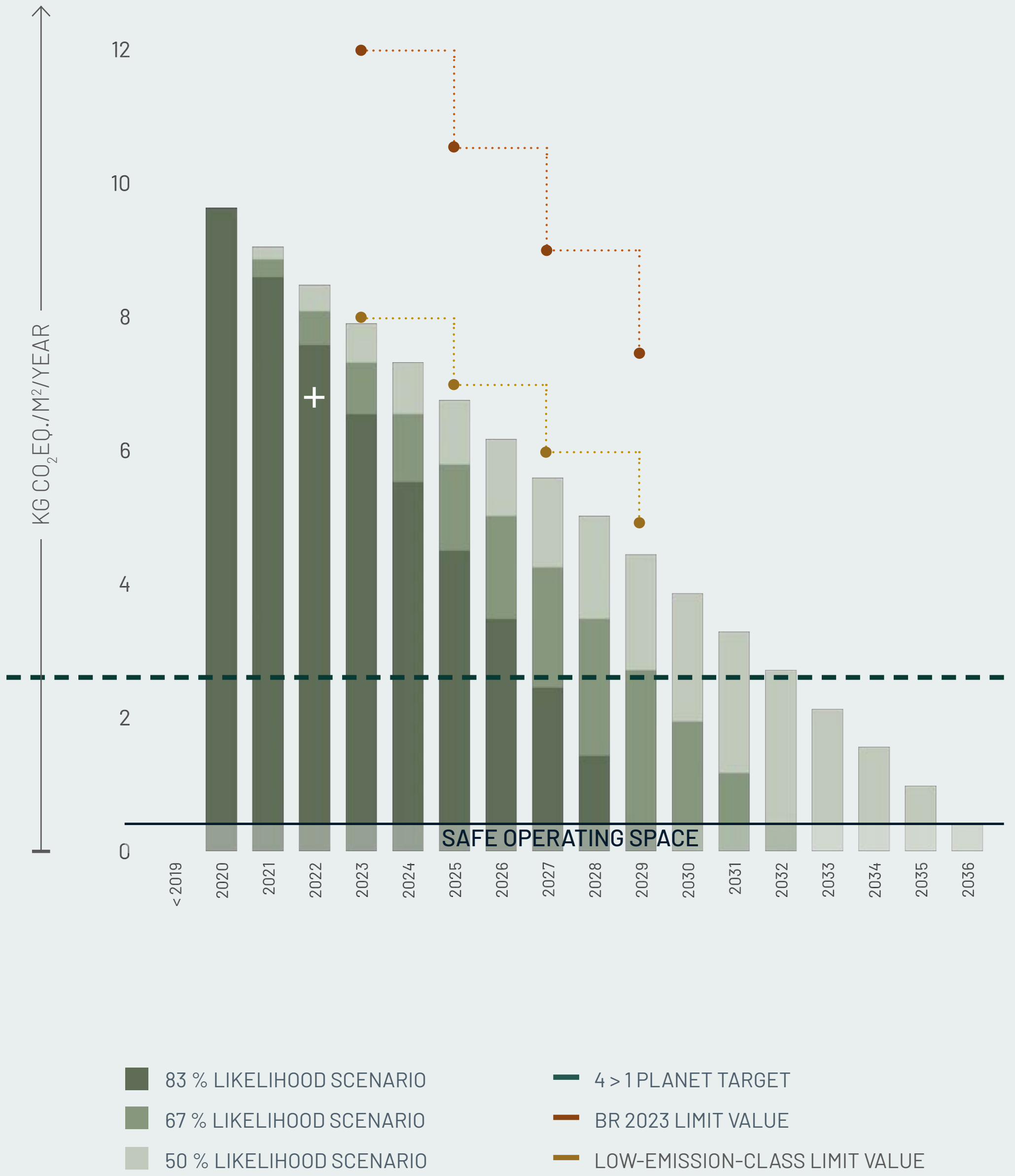
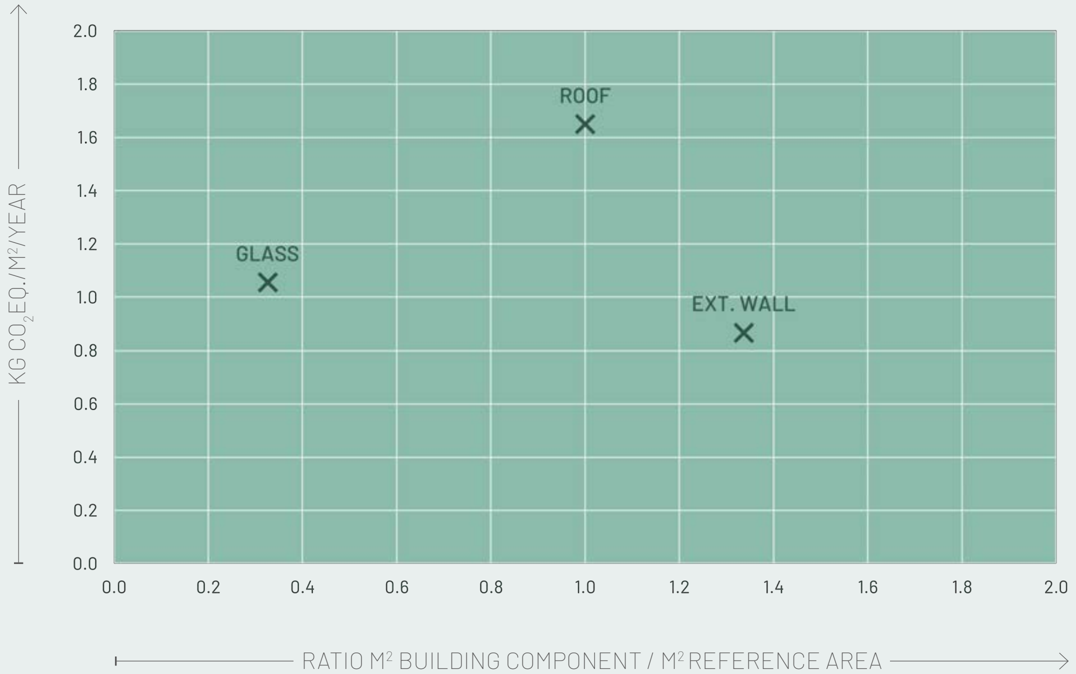



**Figure ENF08.6: Reduction Roadmap**
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg $CO_2$eq./m²/year, and the 'safe operating space'.

## RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS




## ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

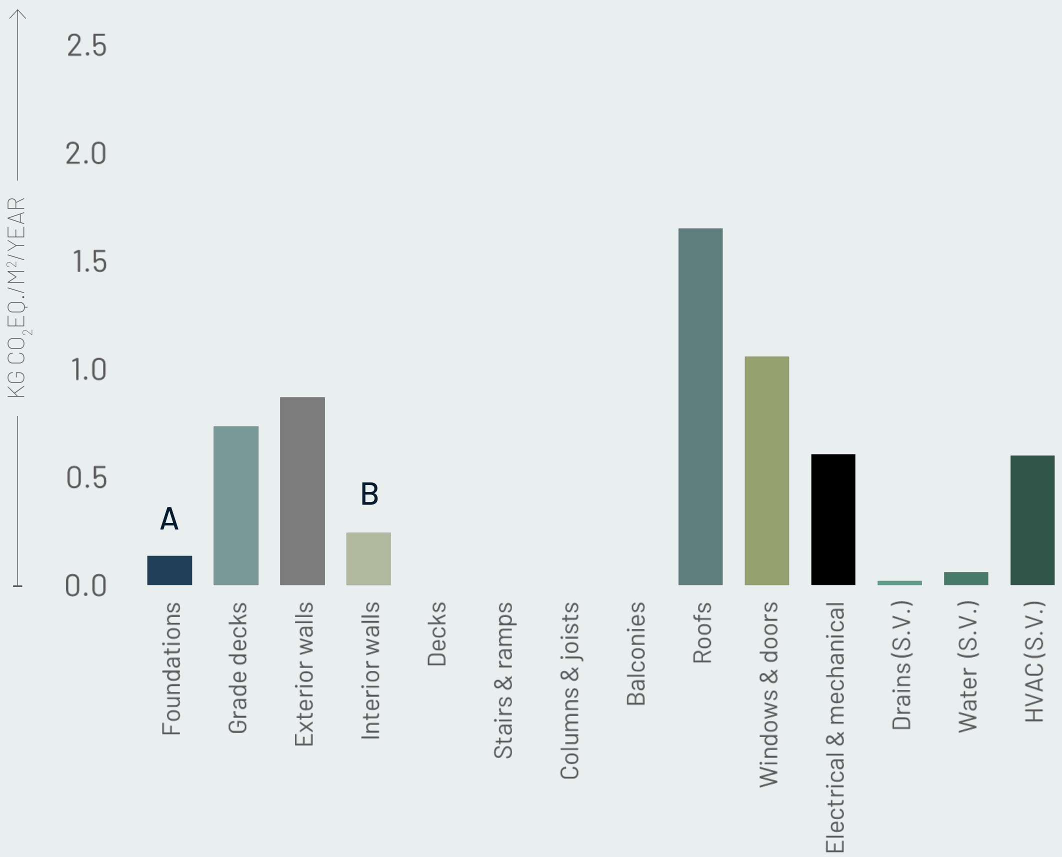



**Figure ENF08.7: $CO_2$ accounting for building components**
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades,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



ENF08: Ecomodul360 PIXIE CASE

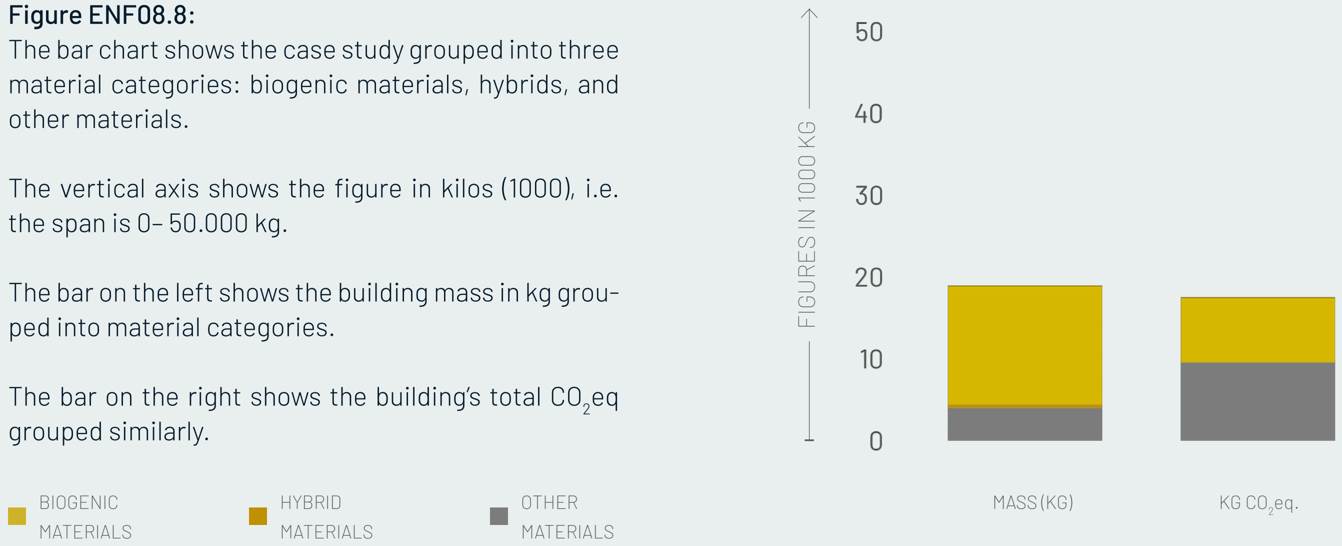
## SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

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

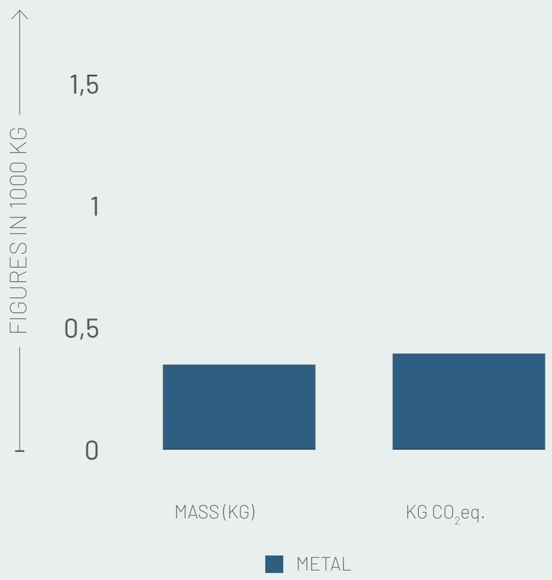
The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

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 $CO_2$eq grouped similarly.




## MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG $CO_2$EQ.




### A. FOUNDATION

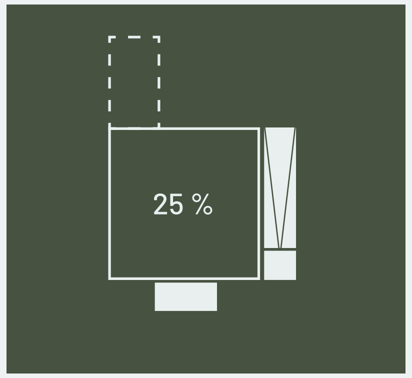
Screw-pile foundations, steel


### 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

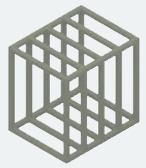
Pramvejen is a project designed and built for a private client, whose concept of a healthy house without materials of toxic or plastic content governed the construction principles and choice of material. The idea was to construct a sustainable house in bio-based materials that would meet the parameters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





6,69 kg $CO_2$eq./m²/year


**Figure ENF09.1: 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.

40.005 kg $CO_2$eq.

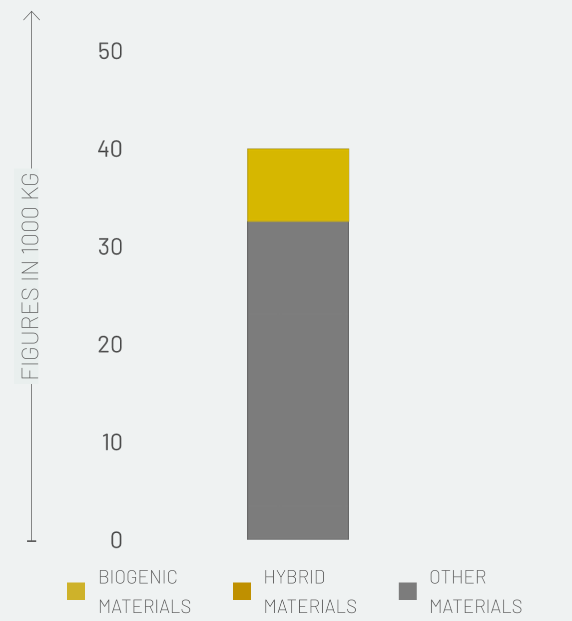



**Figure ENF09.2: Total emission of kg $CO_2$eq.**
The stacked bar chart shows the overall emission of kg $CO_2$eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

204 kg $CO_2$eq./person/year

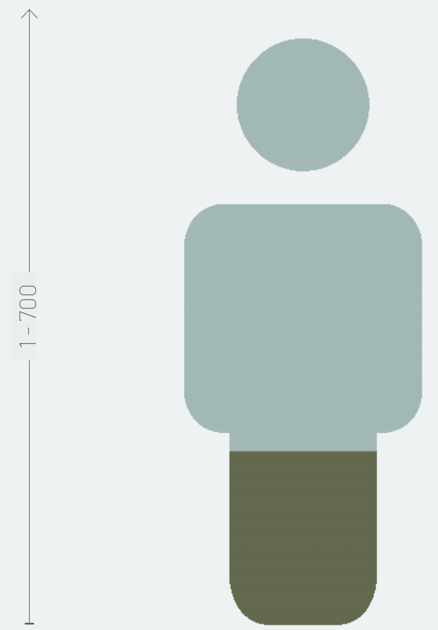



**Figure ENF09.3: Emissions of kg $CO_2$eq./person/year**
The span of the vertical axis is 1 to 700 kg $CO_2$eq./person/year

31 m²/person

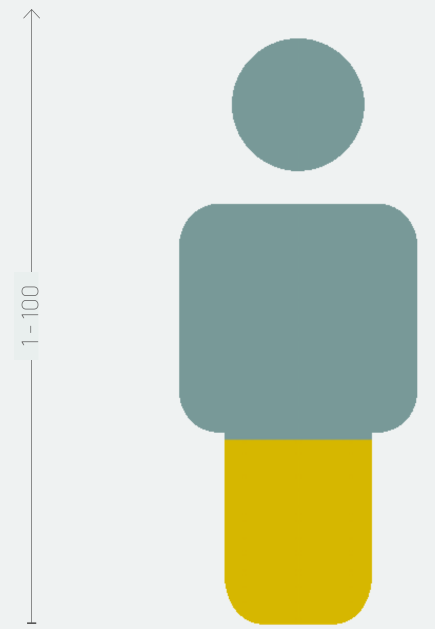



**Figure ENF09.4: m²/person**
The span of the vertical axis is 1 to 100 m²/person.

## 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 $CO_2$eq./m²/year.

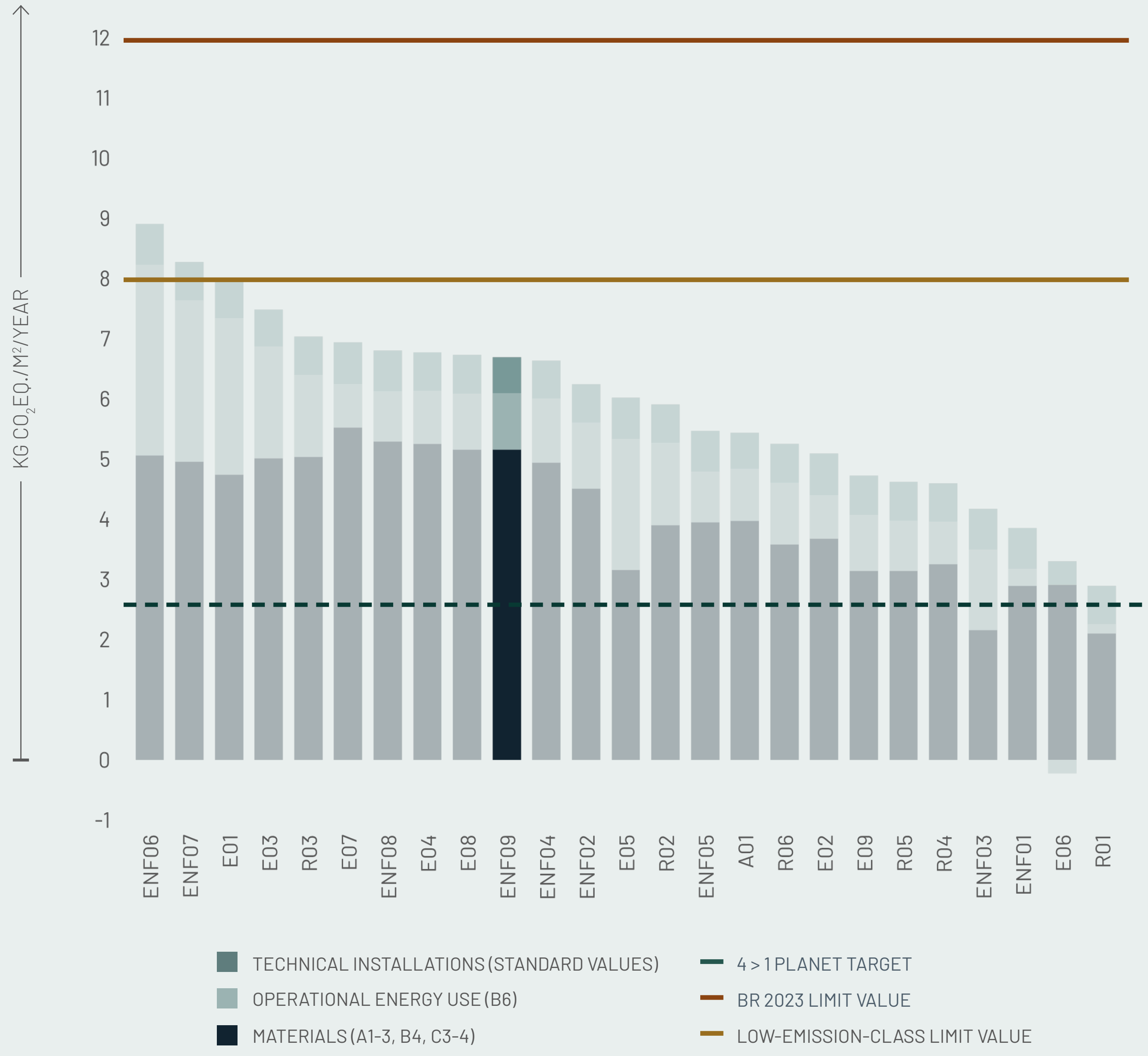



**Figure ENF09.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.



ENF09: Pramvejen PIXIE CASE

## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in $CO_2$eq./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.

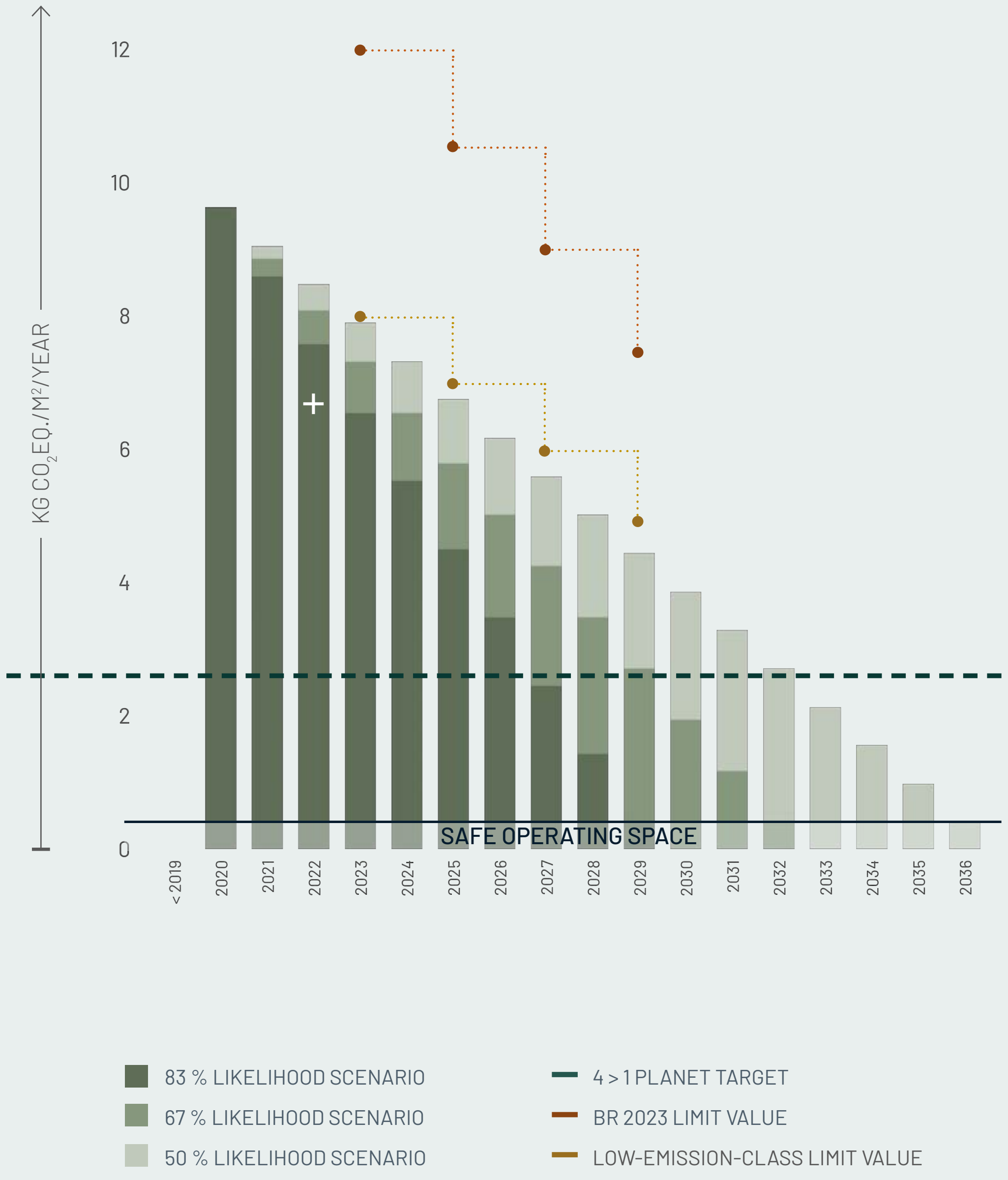
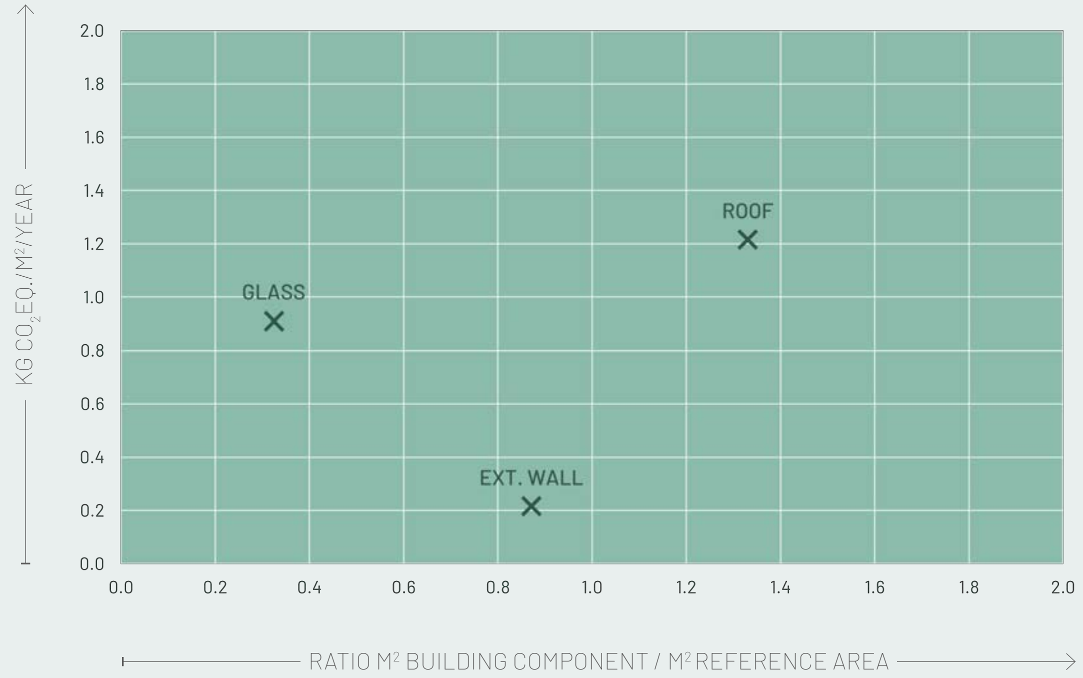



**Figure ENF09.6: Reduction Roadmap**
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg $CO_2$eq./m²/year, and the 'safe operating space'.

## RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS




## ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

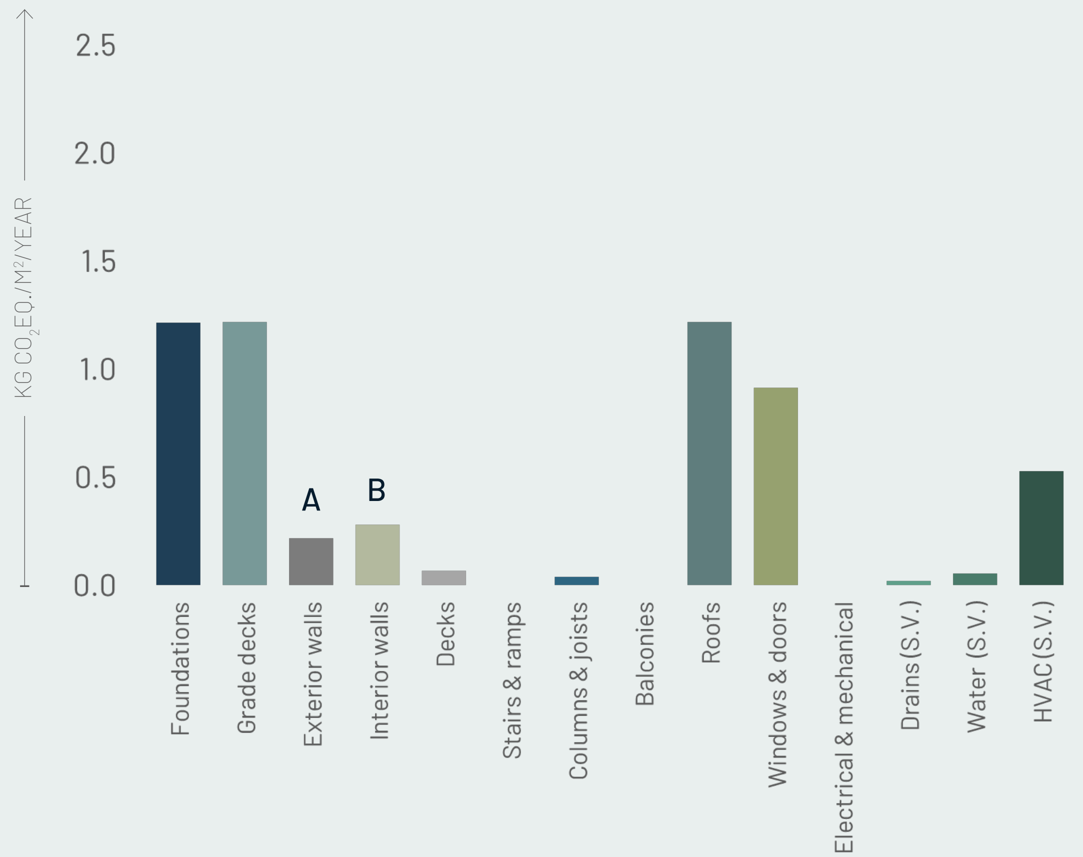



**Figure ENF01.9: $CO_2$ accounting for building components**
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades,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



ENF09: Pramvejen PIXIE CASE

## SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

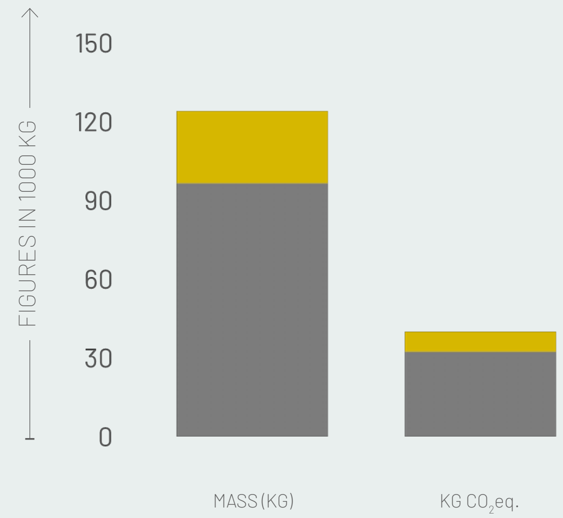
**Figure ENF09.8:**
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

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

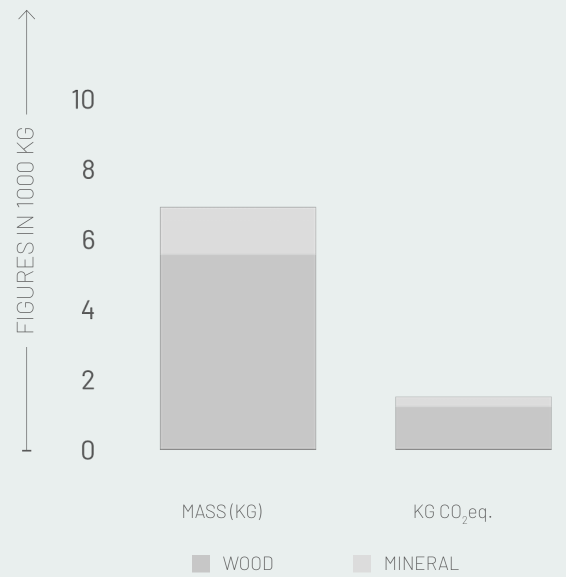
The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total $CO_2$eq grouped similarly.

BIOGENIC MATERIALS  HYBRID MATERIALS  OTHER MATERIALS

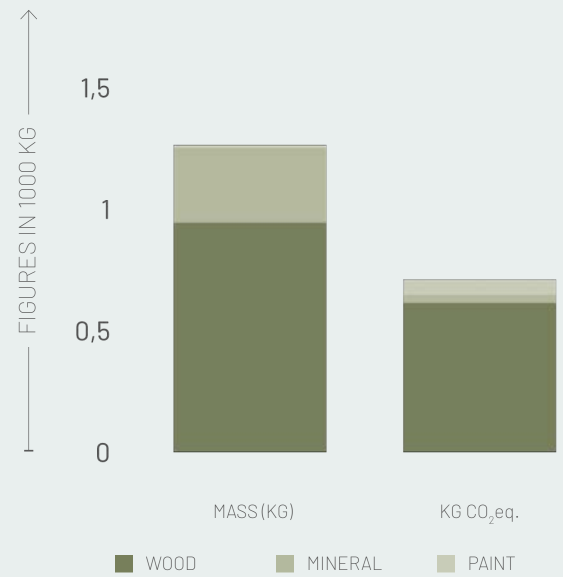



## MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG $CO_2$EQ.




### 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

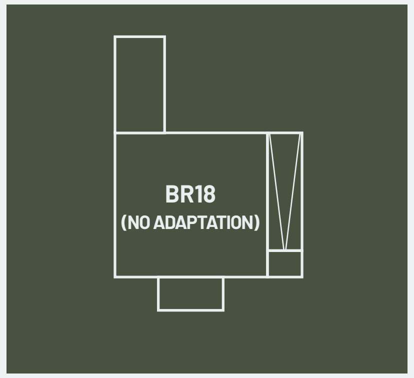



### B. INTERIOR WALL

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

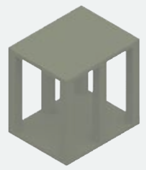
Living Places terraced housing is a $CO_2$-optimised version of the already registered project Living Places as a detached single-family dwelling. There are no specific plans as yet to construct the terraced version, and it is not, therefore, fully projected.

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



R01: Living Places II PIXIE CASE

### 2,89 kg $CO_2$eq./m²/year

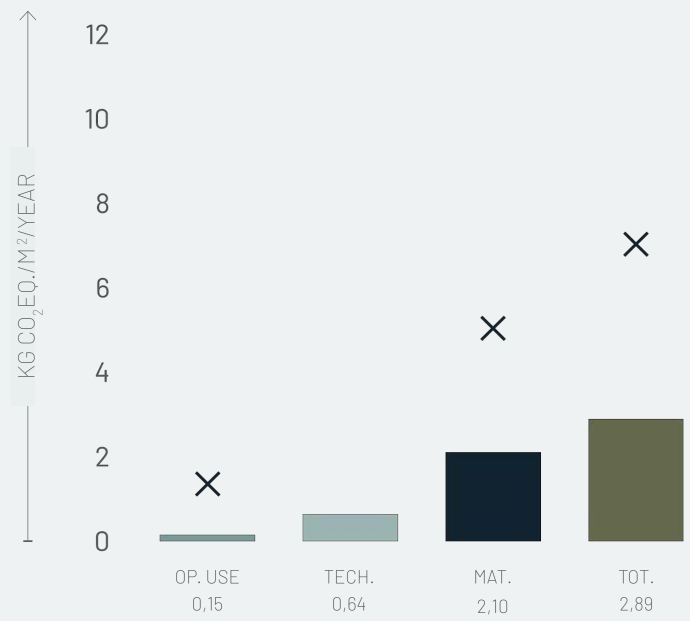



**Figure R01.1: Emissions of kg $CO_2$eq./m²/year**
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg $CO_2$eq./m²/year in terraced housing in the case collection.

### 141.157 kg $CO_2$eq.

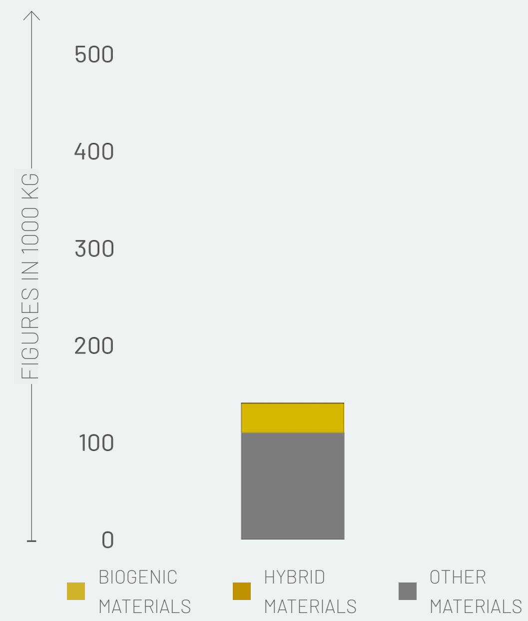



**Figure R01.2: Total emission of kg $CO_2$eq.**
The stacked bar chart shows the overall emission of kg $CO_2$eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

### 106 kg $CO_2$eq./person/year

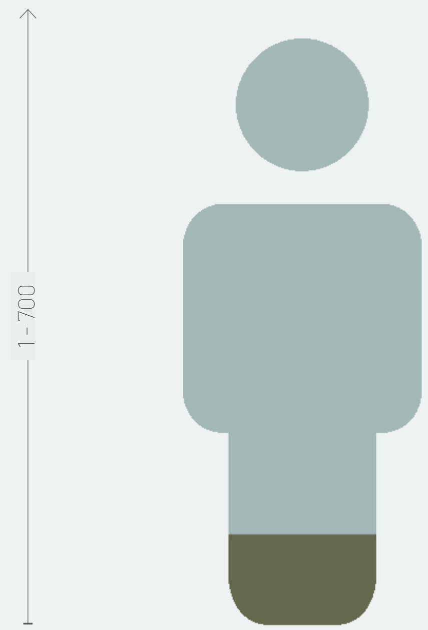



**Figure R01.3: Emissions of kg $CO_2$eq./person/year**
The span of the vertical axis is 1 to 700 kg $CO_2$eq./person/year

### 37 m²/person

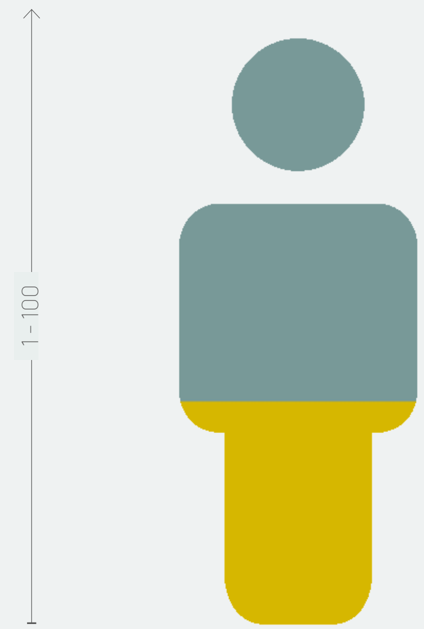
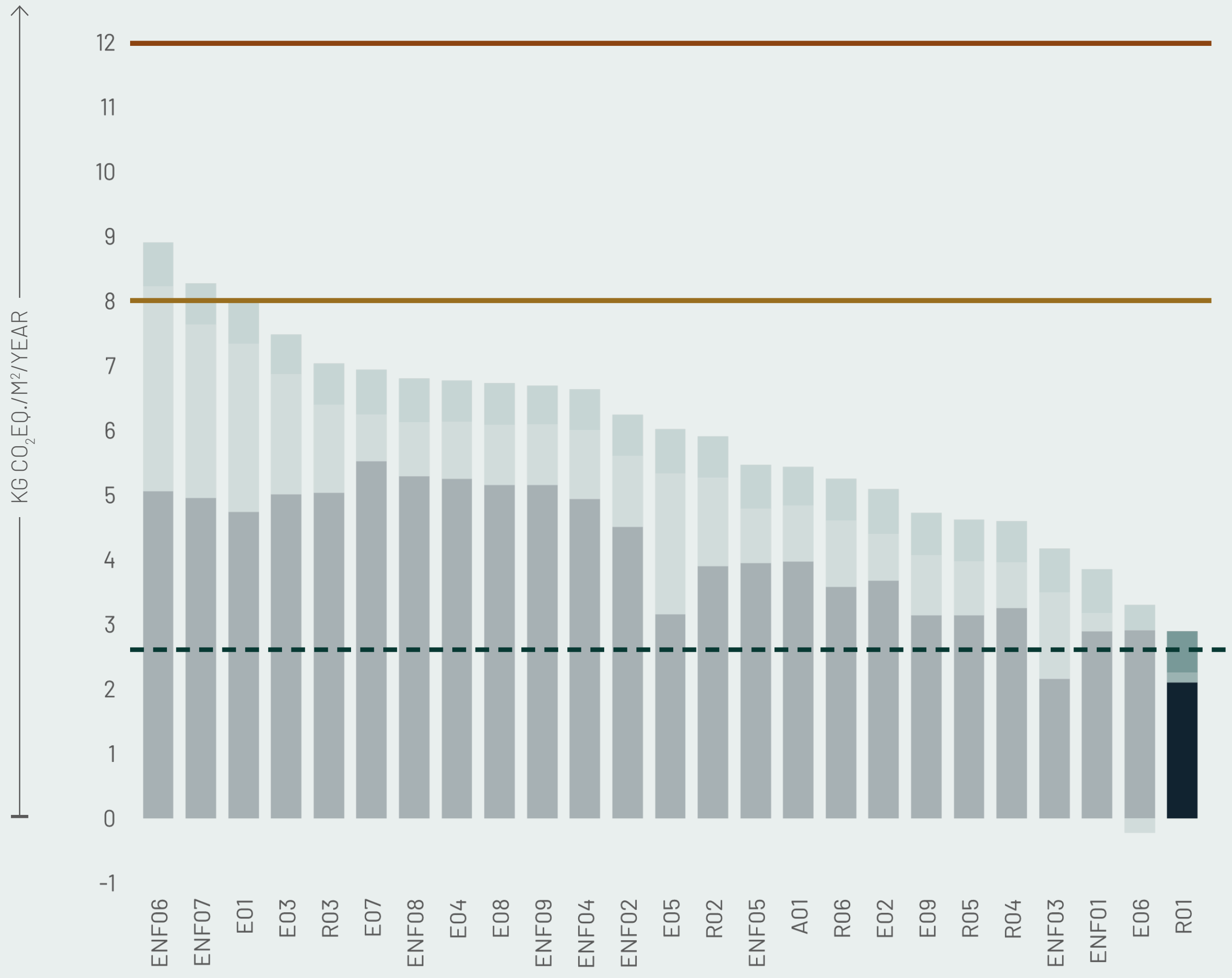



**Figure R01.4: m² / person**
The span of the vertical axis is 1 to 100 m²/person.

## 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 $CO_2$eq./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

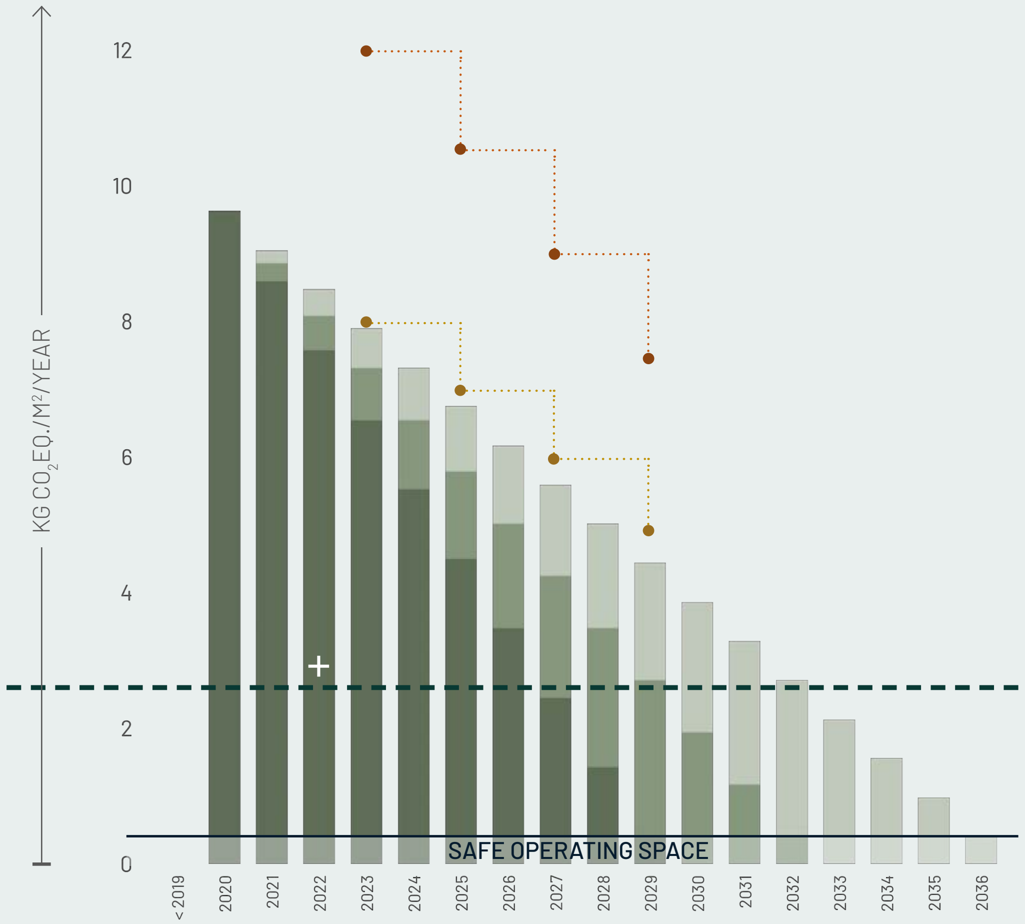
**Figure R01.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.



R01: Living Places II PIXIE CASE

## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

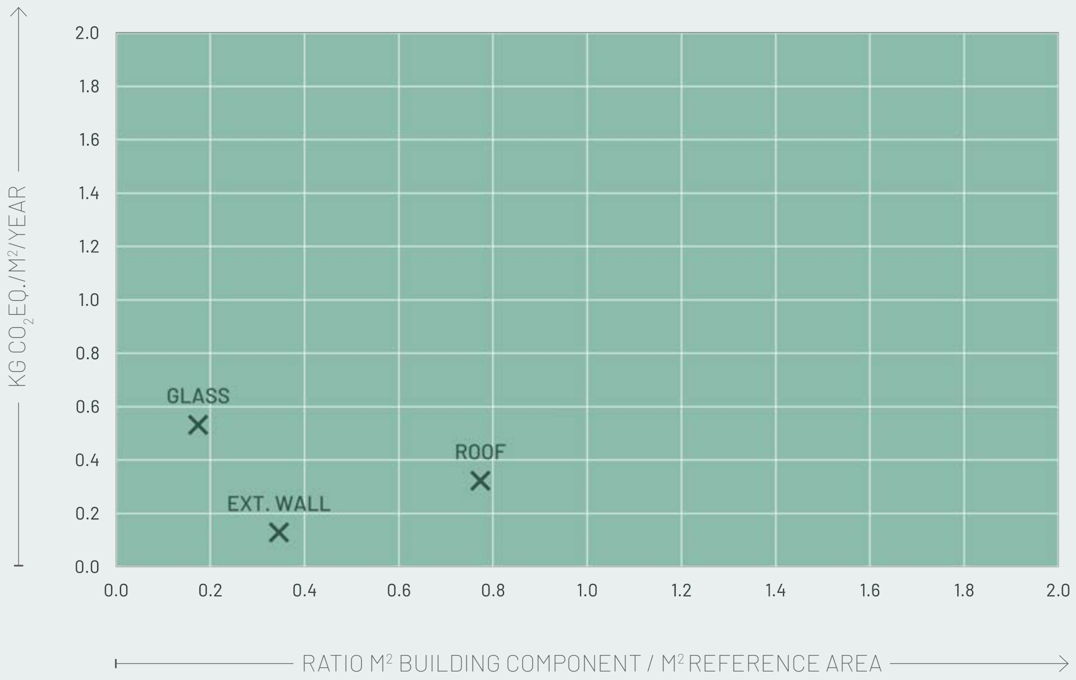
Environmental impact is shown in $CO_2$eq./m²/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is well within the fastest 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 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 $CO_2$eq./m²/year, and the 'safe operating space'.

## RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS




## ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

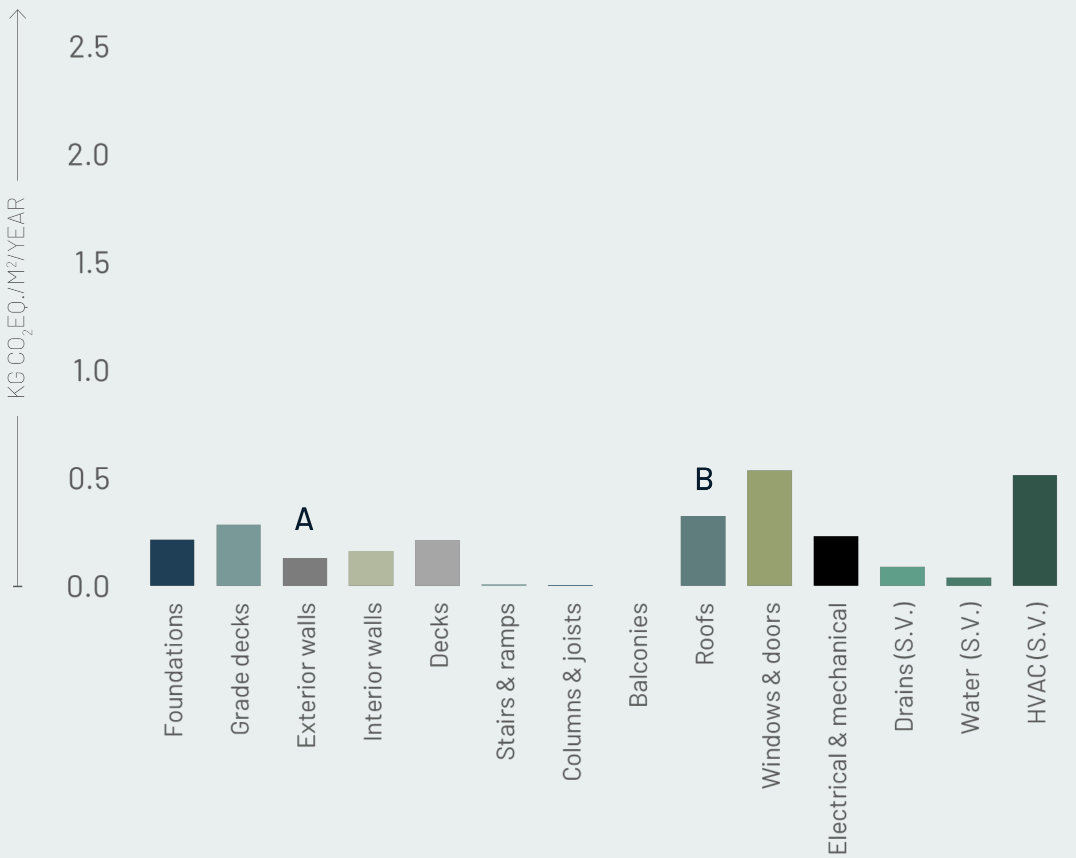



**Figure R01.7: $CO_2$ accounting for building components**
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades,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



R01: Living Places II PIXIE CASE

## SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

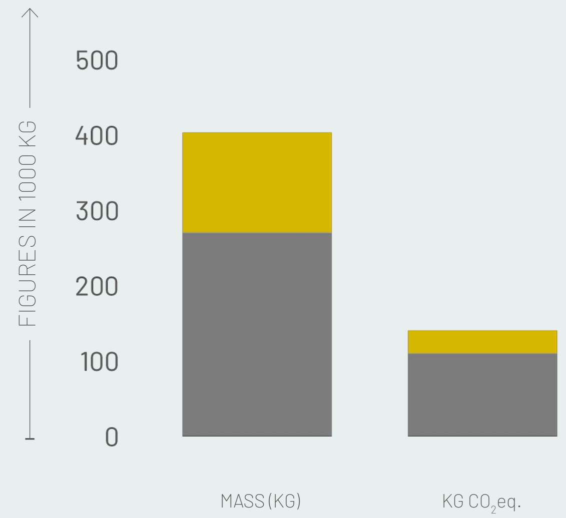
**Figure R01.8:**
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

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

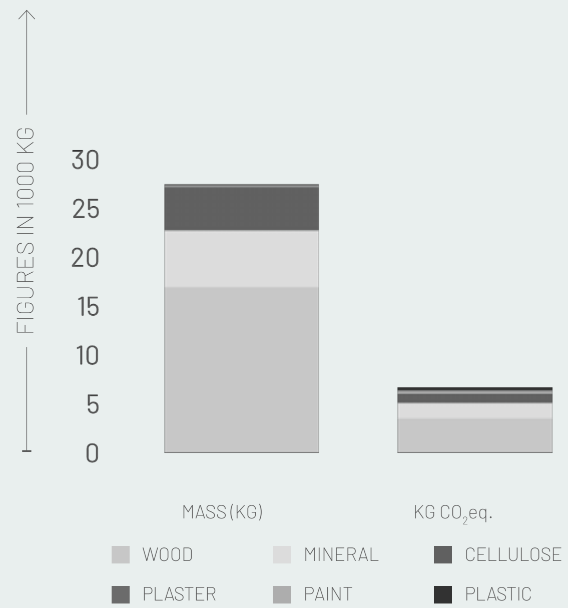
The bar on the left shows the building mass in kg grouped into material categories.

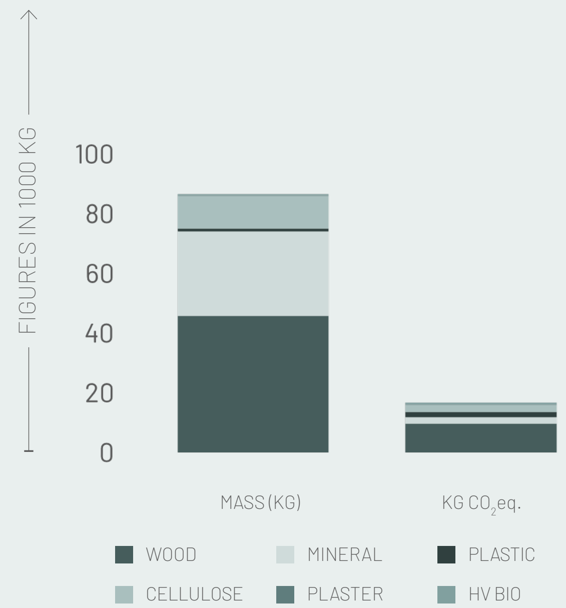
The bar on the right shows the building's total $CO_2$eq grouped similarly.

BIOGENIC MATERIALS | HYBRID MATERIALS | OTHER MATERIALS




## MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG $CO_2$EQ.



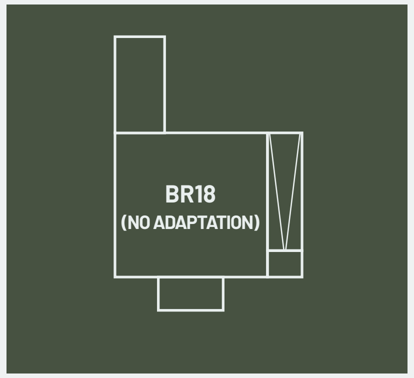

### A. EXTERIOR WALL

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


**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.

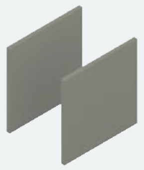
The two-storey blocks are built on combined pile and continuous foundations of lightweight aggregate blocks and reinforced concrete insulated with PIR foam. The grade deck is concrete and EPS.

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





5,91 kg $CO_2$eq./$m^2$/year


**Figure R02.1: Emissions of kg $CO_2$eq./$m^2$/year**
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg $CO_2$eq./$m^2$/year in terraced housing in the case collection.

942.098 kg $CO_2$eq.

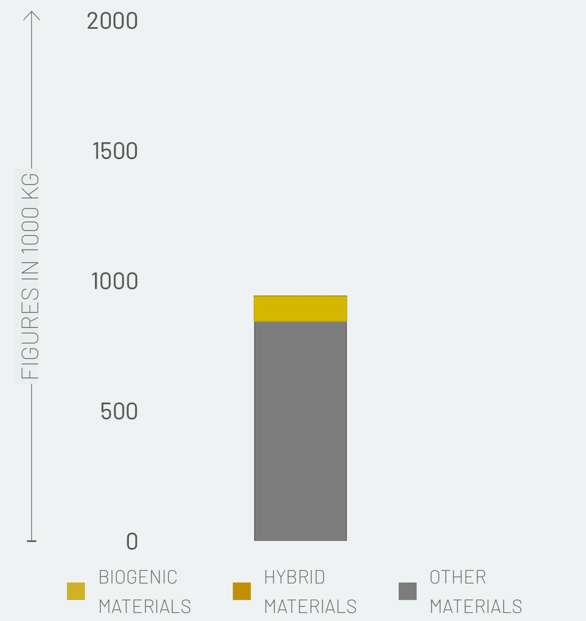



**Figure R02.2: Total emission of kg $CO_2$eq.**
The stacked bar chart shows the overall emission of kg $CO_2$eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

165 kg $CO_2$eq./person/year

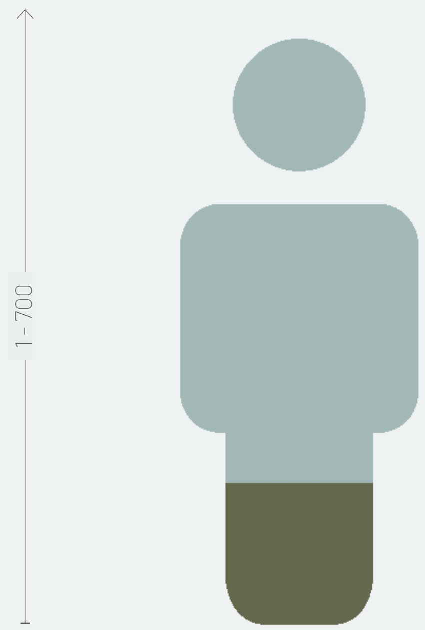



**Figure R02.3: Emissions of kg $CO_2$eq./person/year**
The span of the vertical axis is 1 to 700 kg $CO_2$eq./person/year

28 $m^2$/person

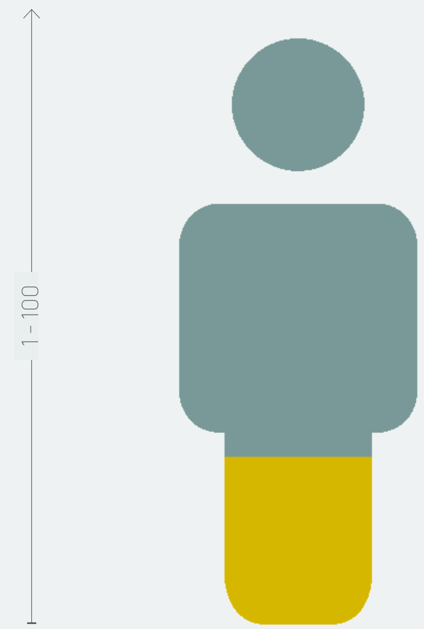
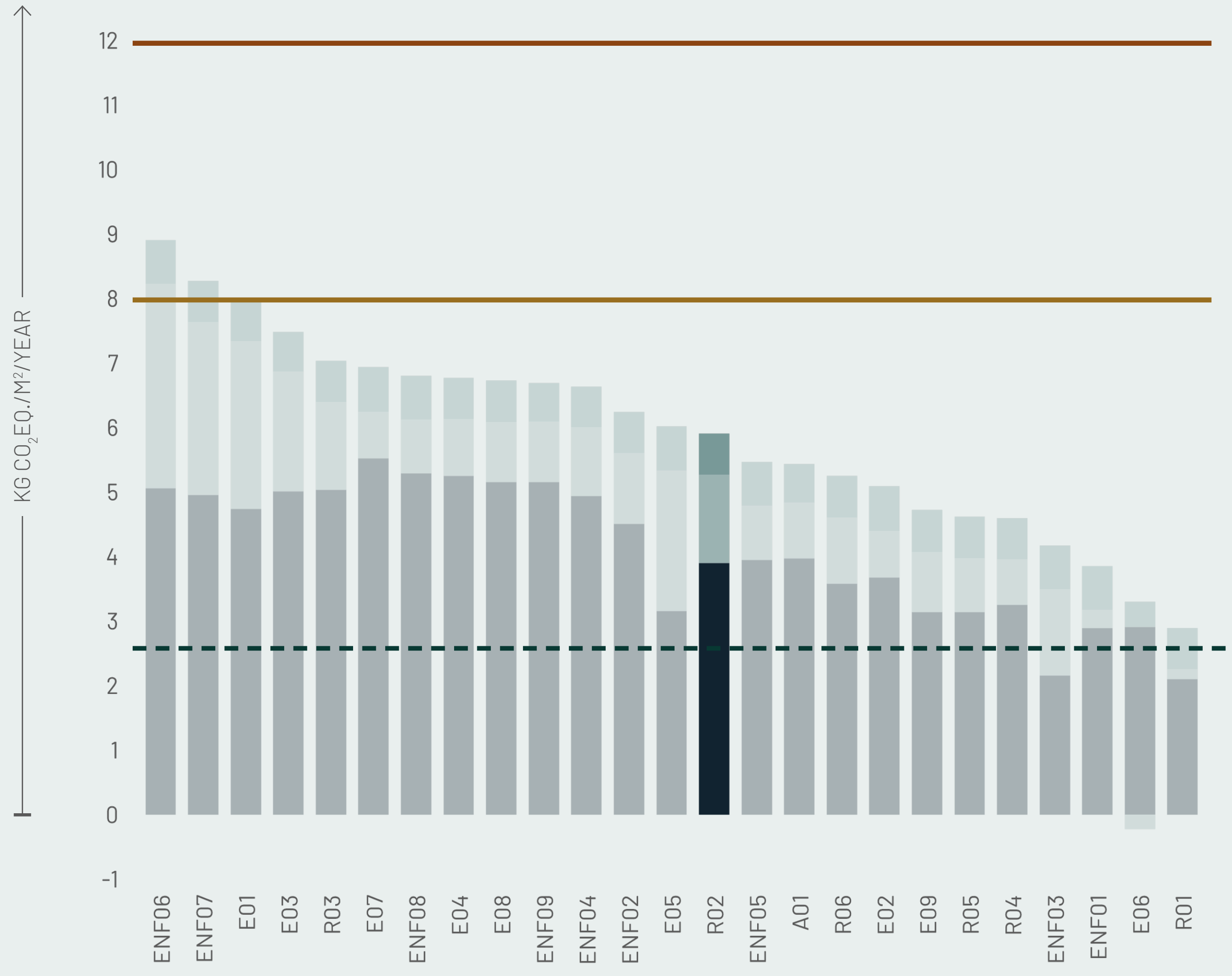



**Figure R02.4: $m^2$/person**
The span of the vertical axis is 1 to 100 $m^2$/person.

# 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 $CO_2$eq./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

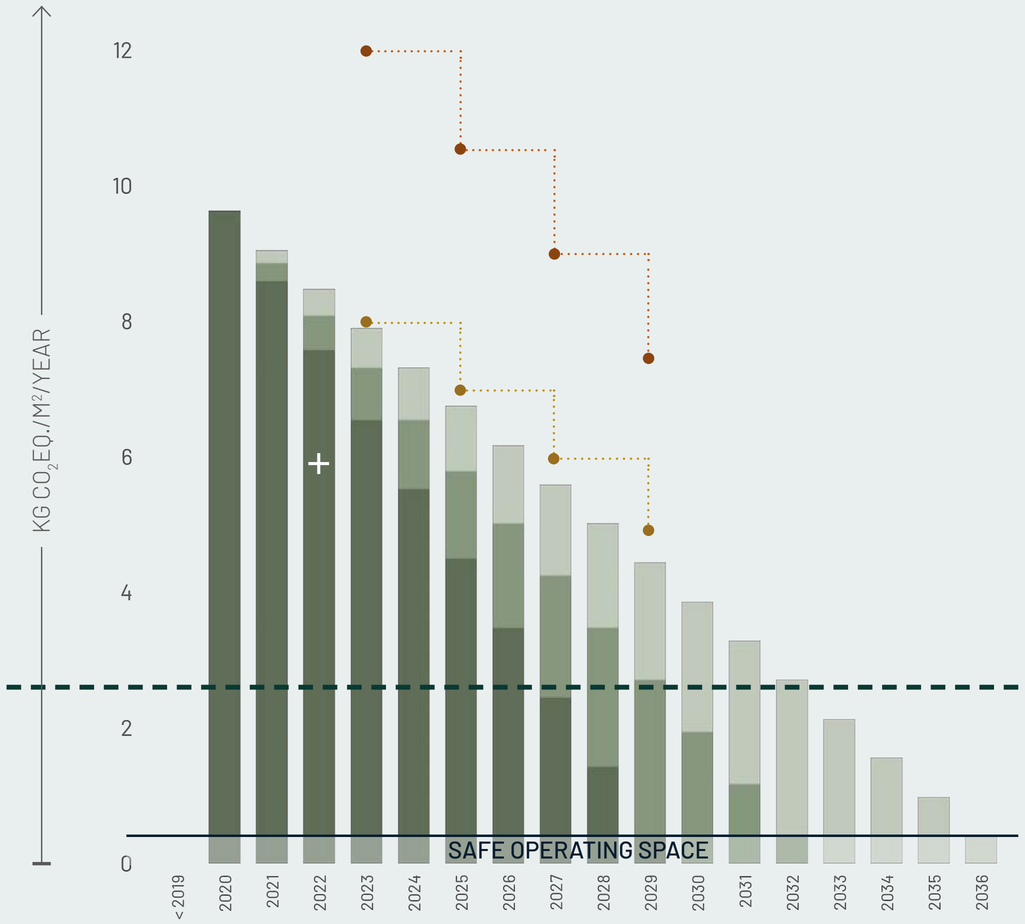
**Figure R02.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.



# R02: Skademosen

## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in $CO_2$eq./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.

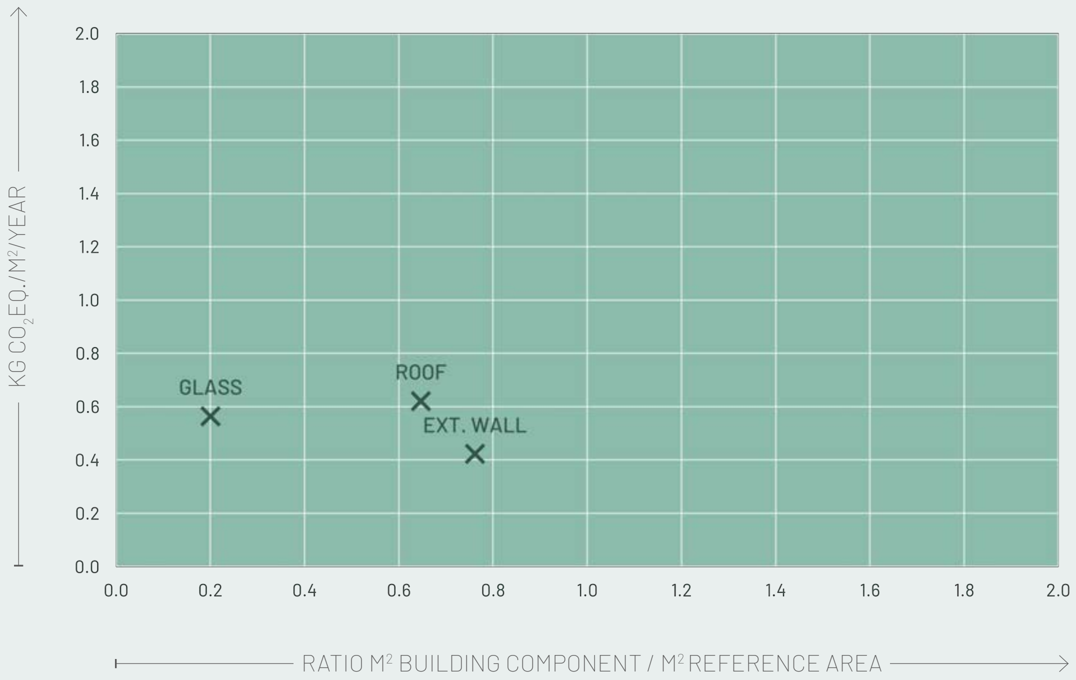



83 % LIKELIHOOD SCENARIO
67 % LIKELIHOOD SCENARIO
50 % LIKELIHOOD SCENARIO
4 > 1 PLANET TARGET
BR 2023 LIMIT VALUE
LOW-EMISSION-CLASS LIMIT VALUE

**Figure 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 $CO_2$eq./m²/year, and the 'safe operating space'.

# R02: Skademosen

## RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS




## ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

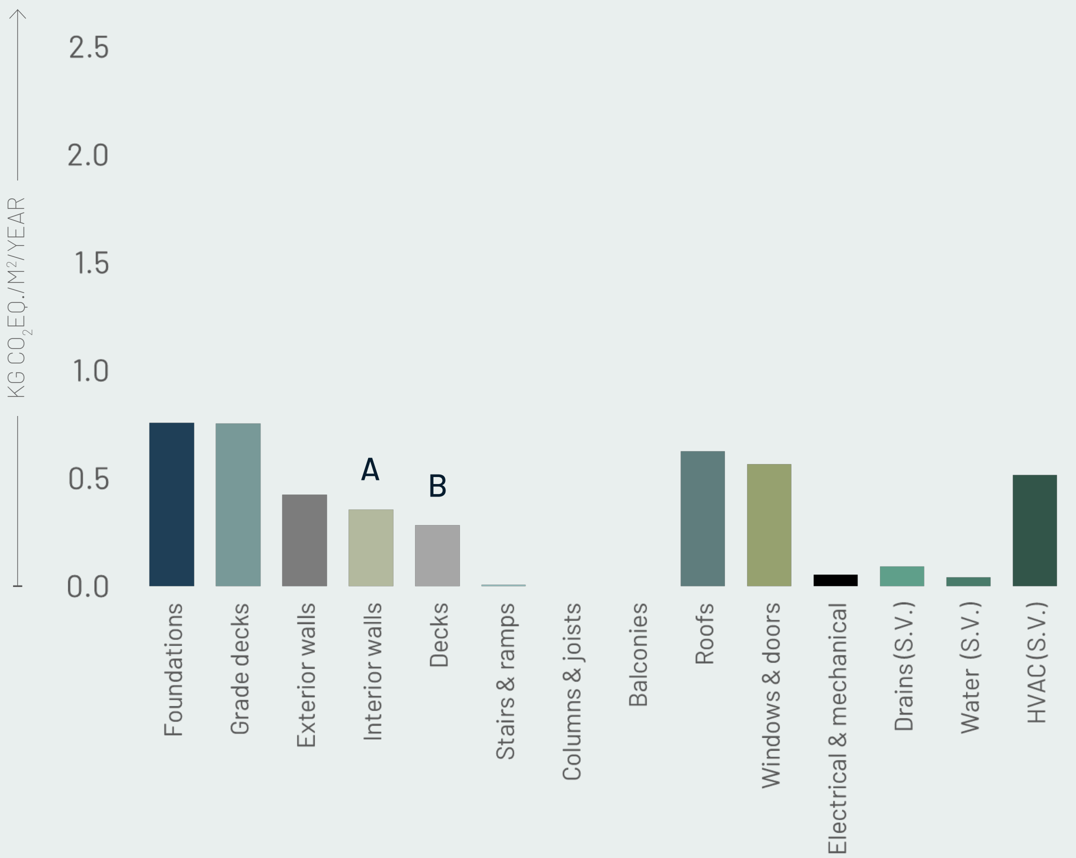



**Figure R02.7: $CO_2$ accounting for building components**
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades,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



# R02: Skademosen

## 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.

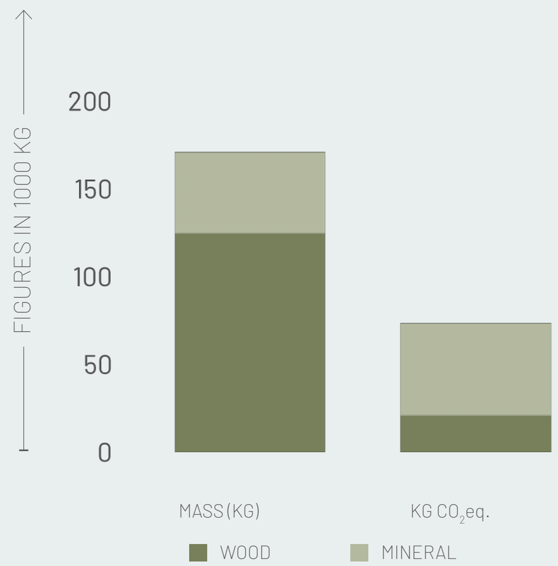
The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

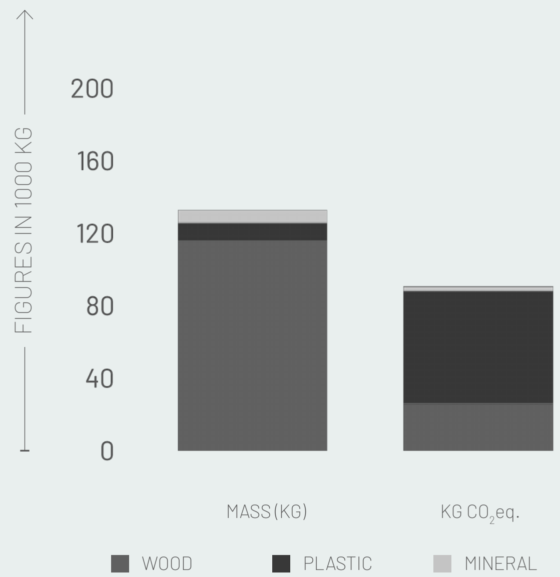
The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total $CO_2$eq grouped similarly.

BIOGENIC MATERIALS
HYBRID MATERIALS
OTHER MATERIALS


## MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG $CO_2$EQ.




### A. INTERIOR WALL

CLT cassette
Mineral wool insulation
Gypsum plasterboard

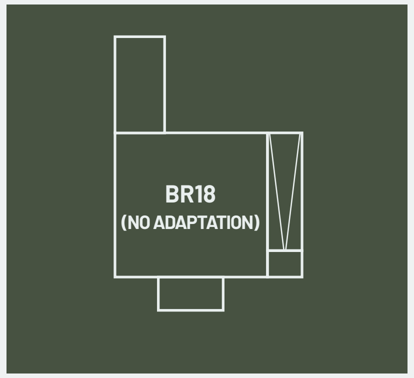
### B. DECK

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.

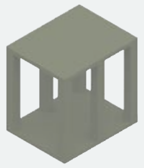
The one- or two-storey buildings are built on concrete point foundations of steel girders. Grids are mounted in the facade line to vent the cavity space beneath the building, and there is level access to the building. The grade deck is made of glulam modules with mineral wool and pressure-impregnated 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 $CO_2$eq./m²/year


**Figure R03.1: 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 terraced housing in the case collection.

150.725 kg $CO_2$eq.

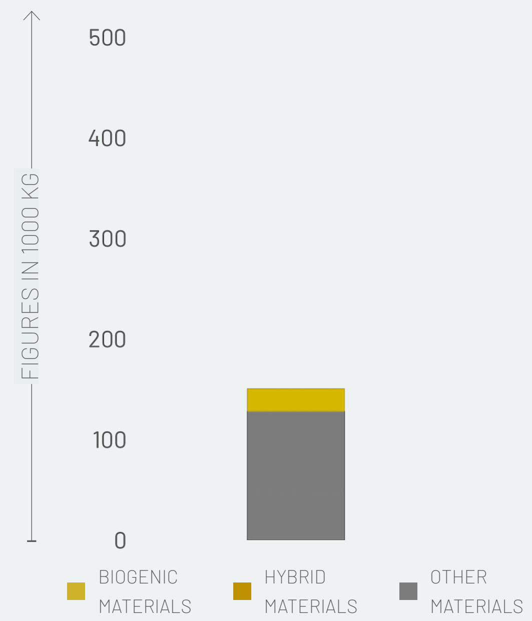



**Figure R03.2: Total emission of kg $CO_2$eq.**
The stacked bar chart shows the overall emission of kg $CO_2$eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

189 kg $CO_2$eq./person/year

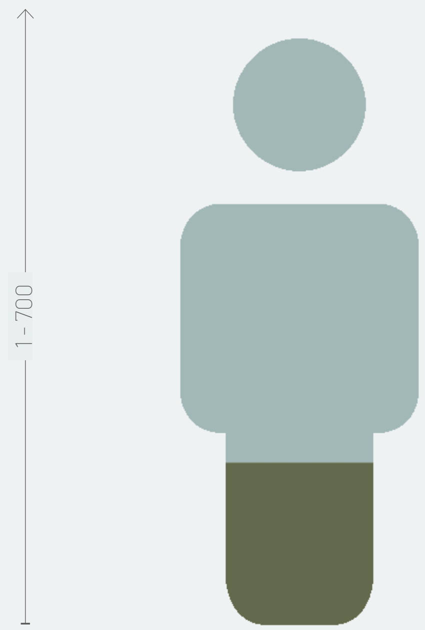



**Figure R03.3: Emissions of kg $CO_2$eq./person/year**
The span of the vertical axis is 1 to 700 kg $CO_2$eq./person/year

28 m²/person

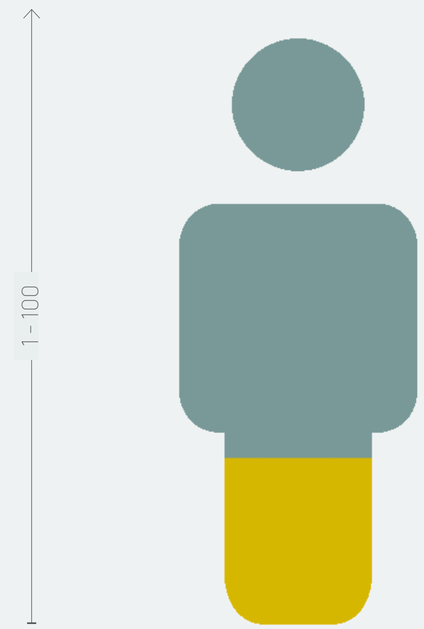



**Figure R03.4: m²/person**
The span of the vertical axis is 1 to 100 m²/person.

## 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 $CO_2$eq./m²/year.

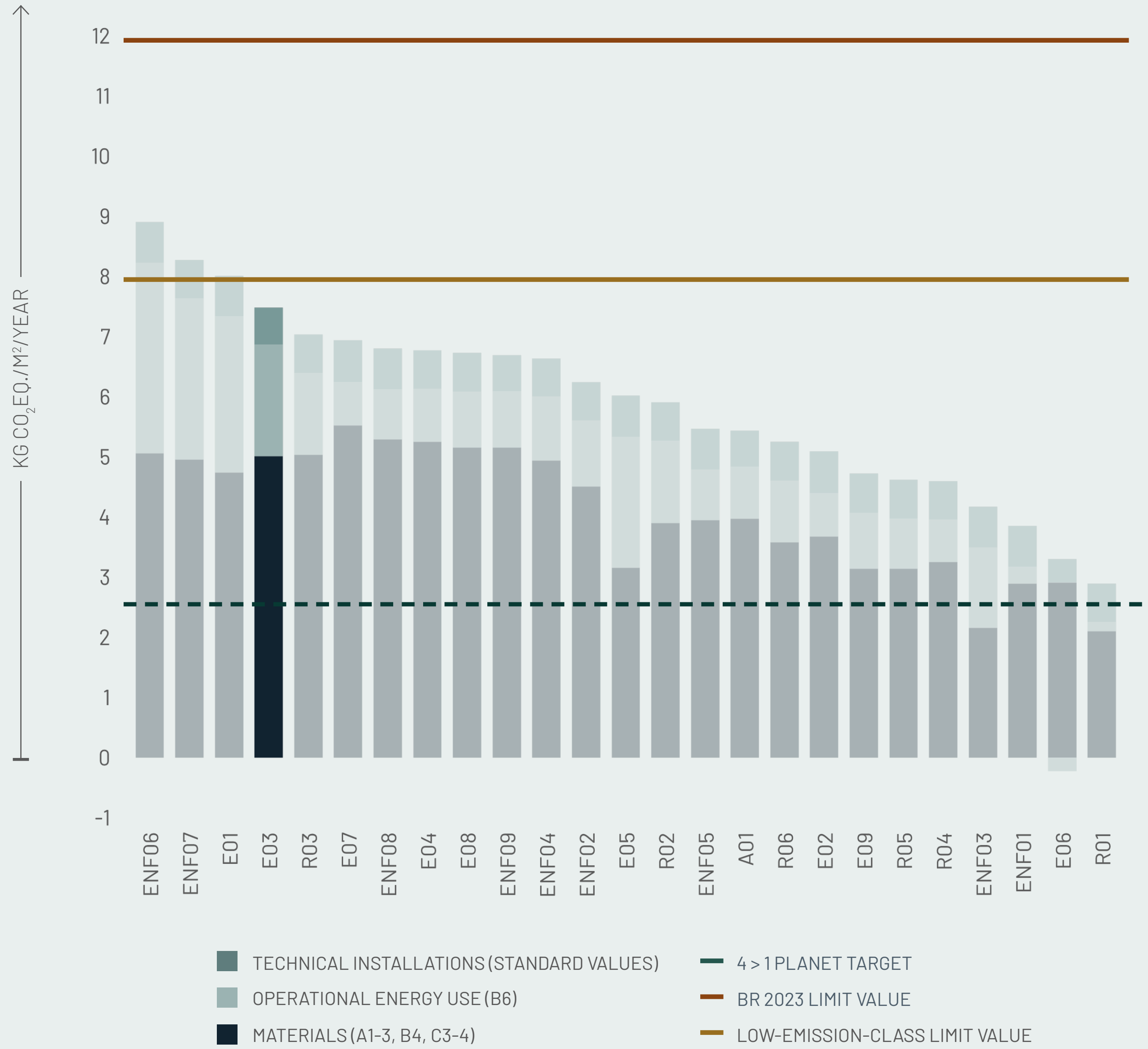



**Figure R03.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.



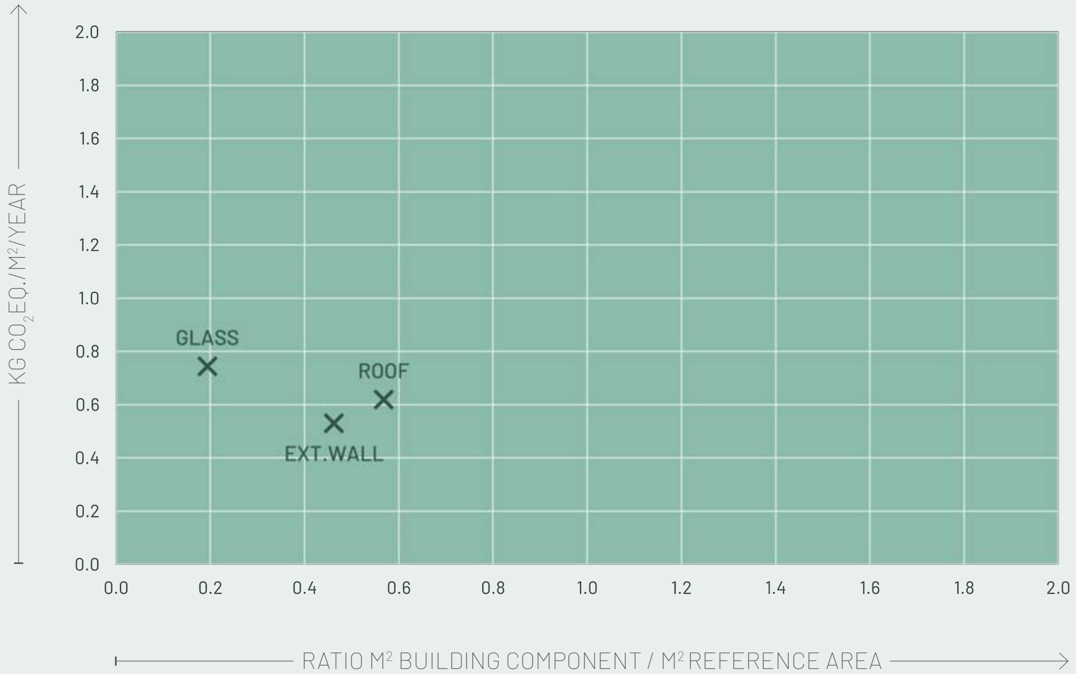
R03: Tømmergården

## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in $CO_2$eq./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 $CO_2$eq./m²/year, and the 'safe operating space'.

## RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS




## ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

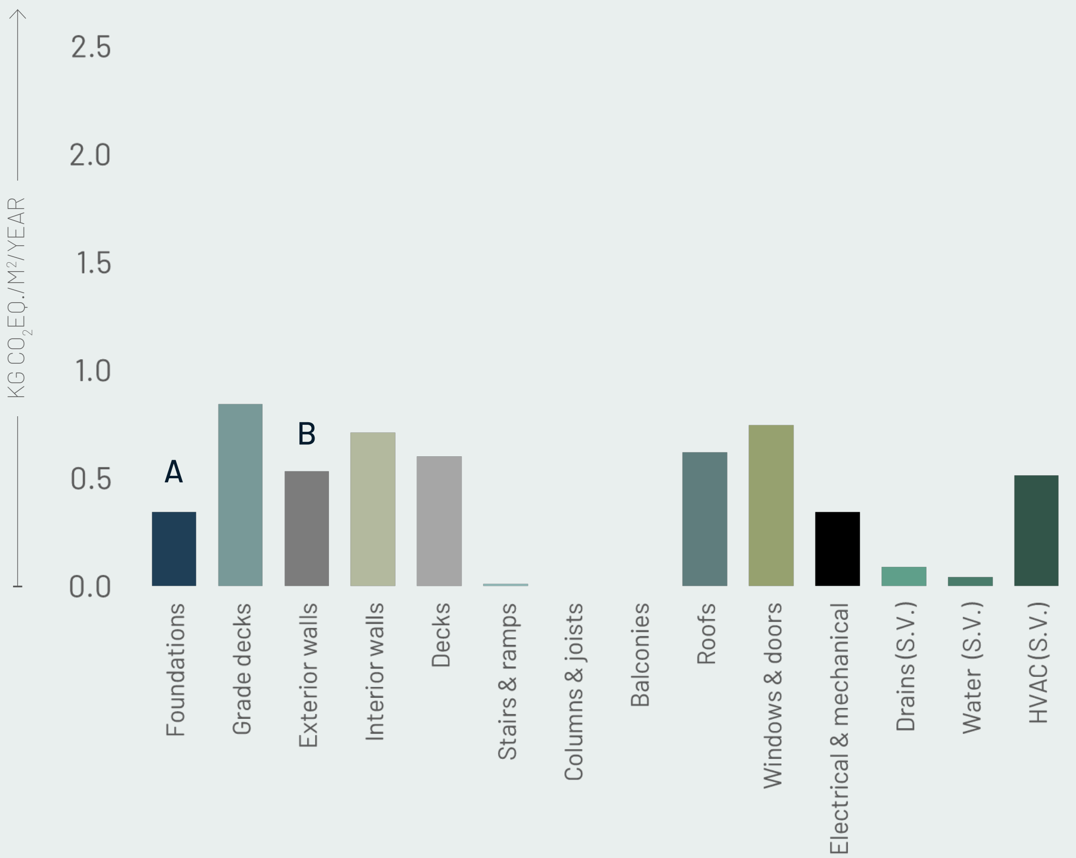



**Figure R03.7: $CO_2$ accounting for building components**
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades,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



R03: Tømmergården

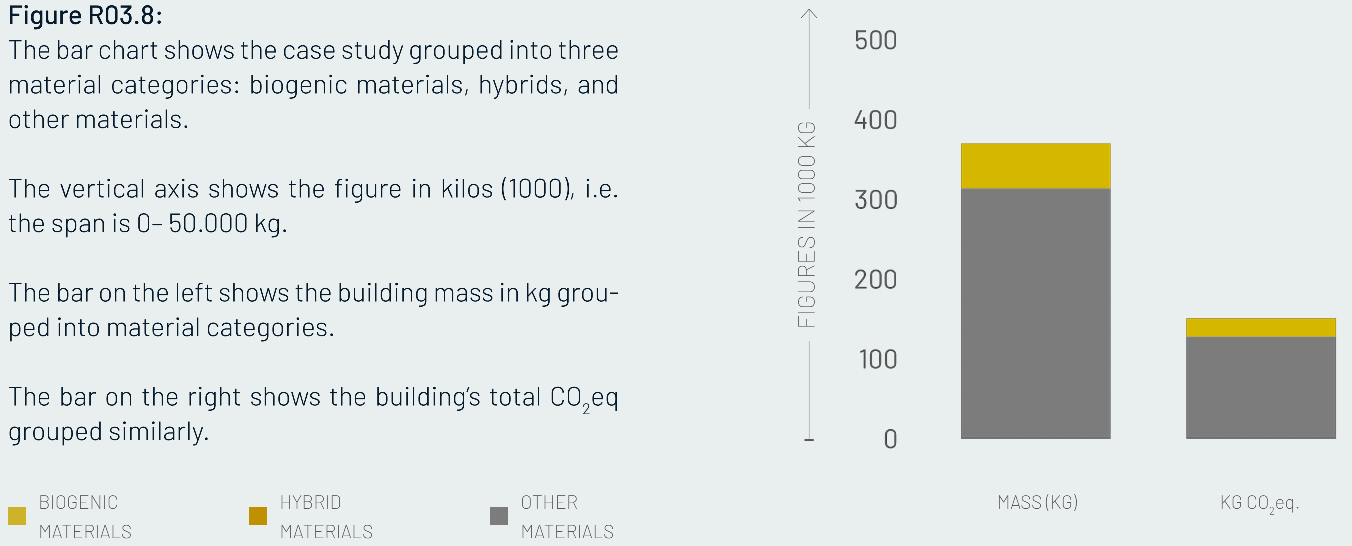
## SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

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

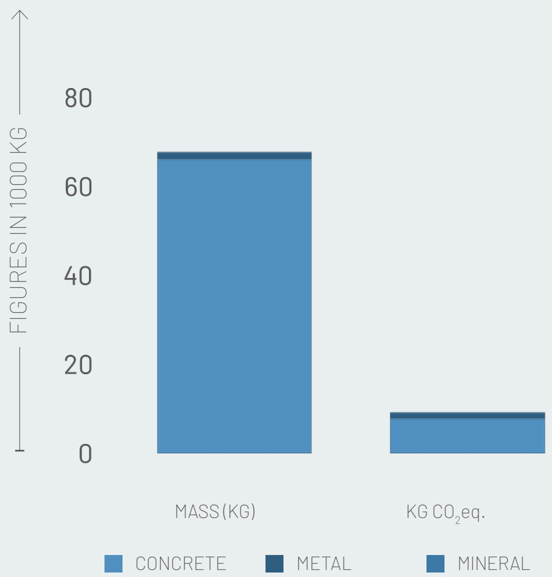
The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

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 $CO_2$eq grouped similarly.

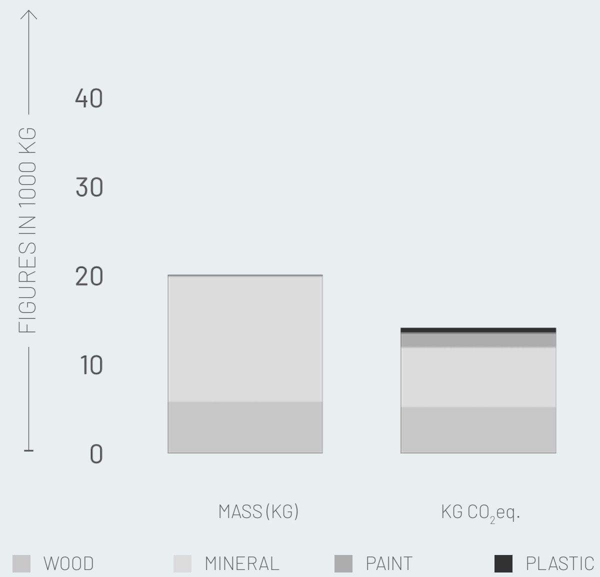



## MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG $CO_2$EQ.




### A. FOUNDATION

Concrete point foundations
Steel girders

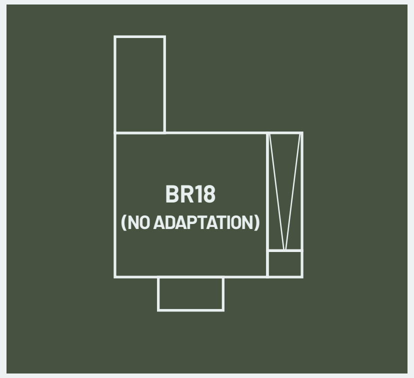



### B. EXTERIOR WALL

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

# R04: Danmarksgrunden


**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 $CO_2$eq./m²/year

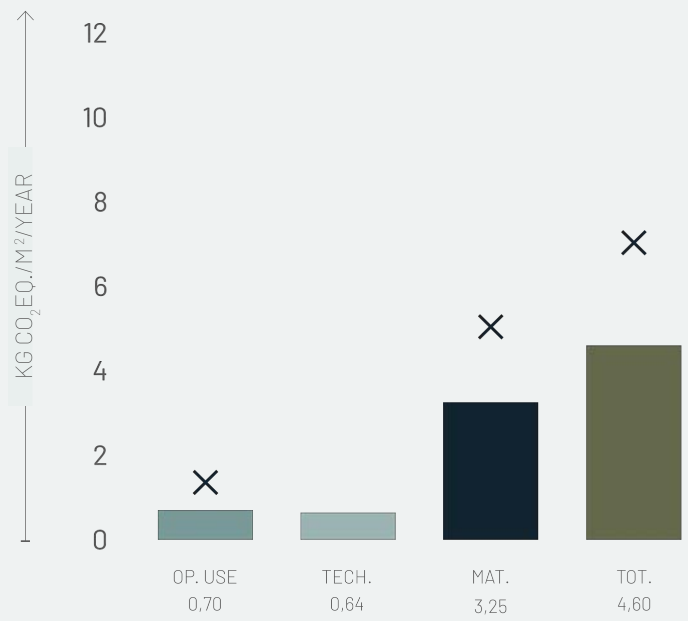



**Figure R04.1: Emissions of kg $CO_2$eq./m²/year**
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg $CO_2$eq./m²/year in terraced housing in the case collection.

1.632.490 kg $CO_2$eq.

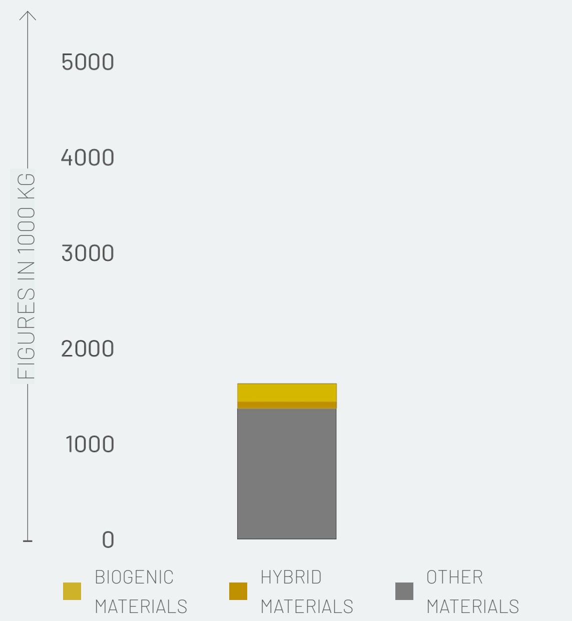



**Figure R04.2: Total emission of kg $CO_2$eq.**
The stacked bar chart shows the overall emission of kg $CO_2$eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

186 kg $CO_2$eq./person/year

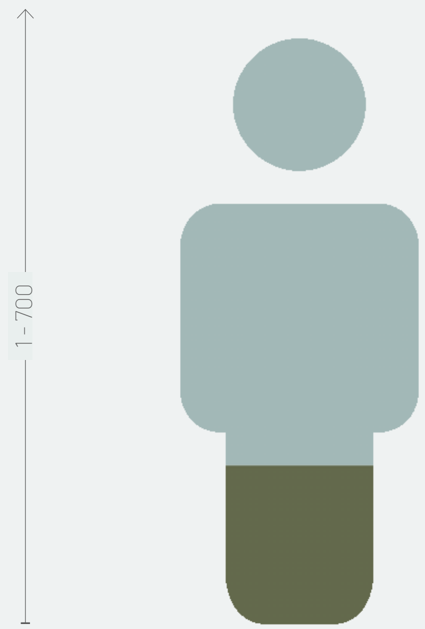



**Figure R04.3: Emissions of kg $CO_2$eq./person/year**
The span of the vertical axis is 1 to 700 kg $CO_2$eq./person/year

41 m²/person

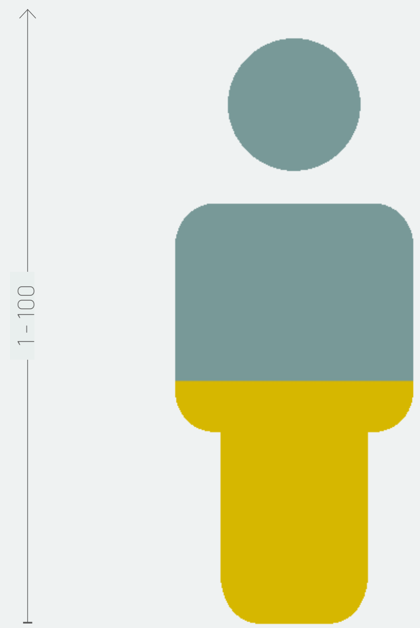



**Figure R04.4: m²/person**
The span of the vertical axis is 1 to 100 m²/person.

## 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 $CO_2$eq./m²/year.

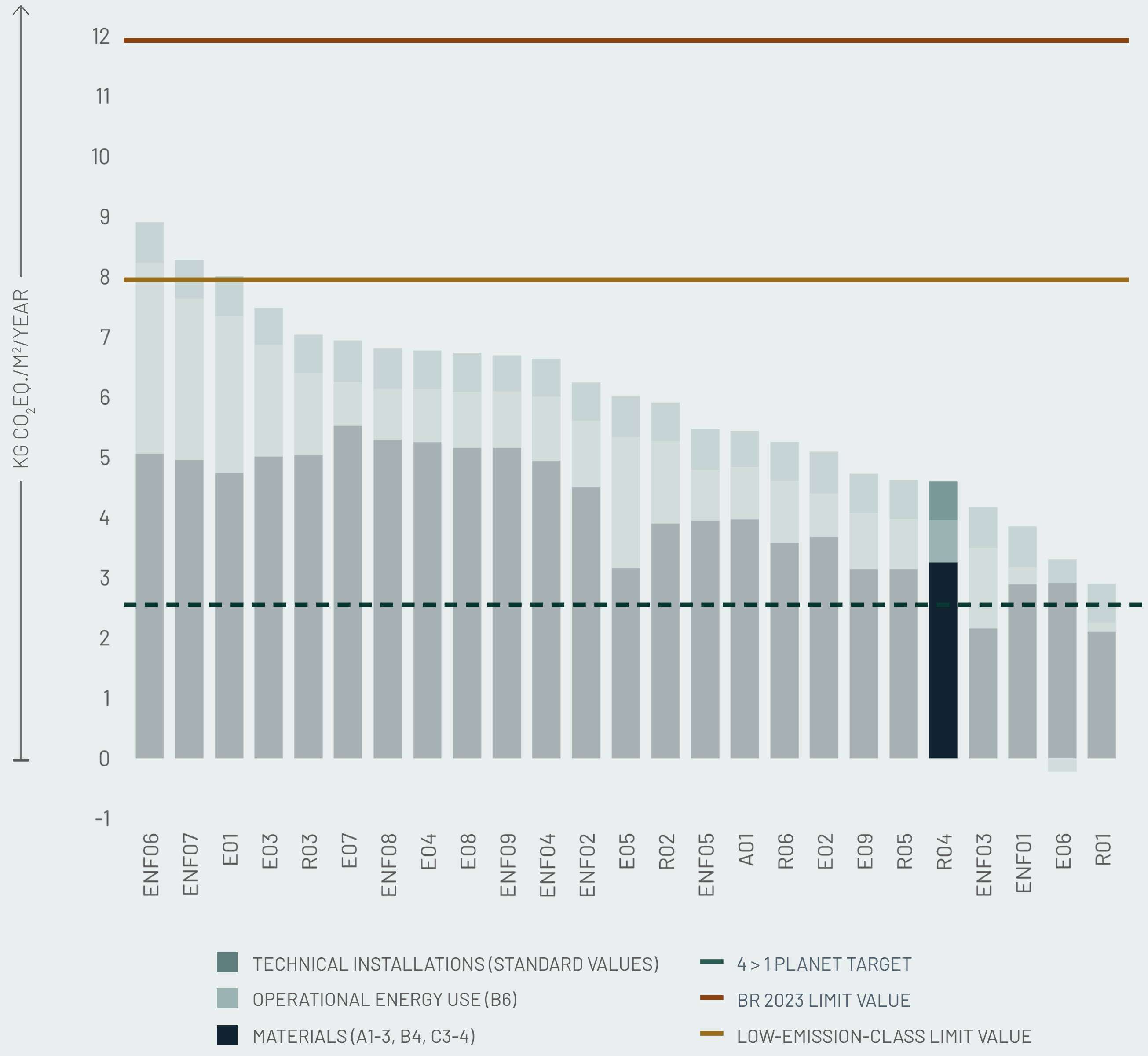



**Figure R04.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.





## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in $CO_2$eq./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.

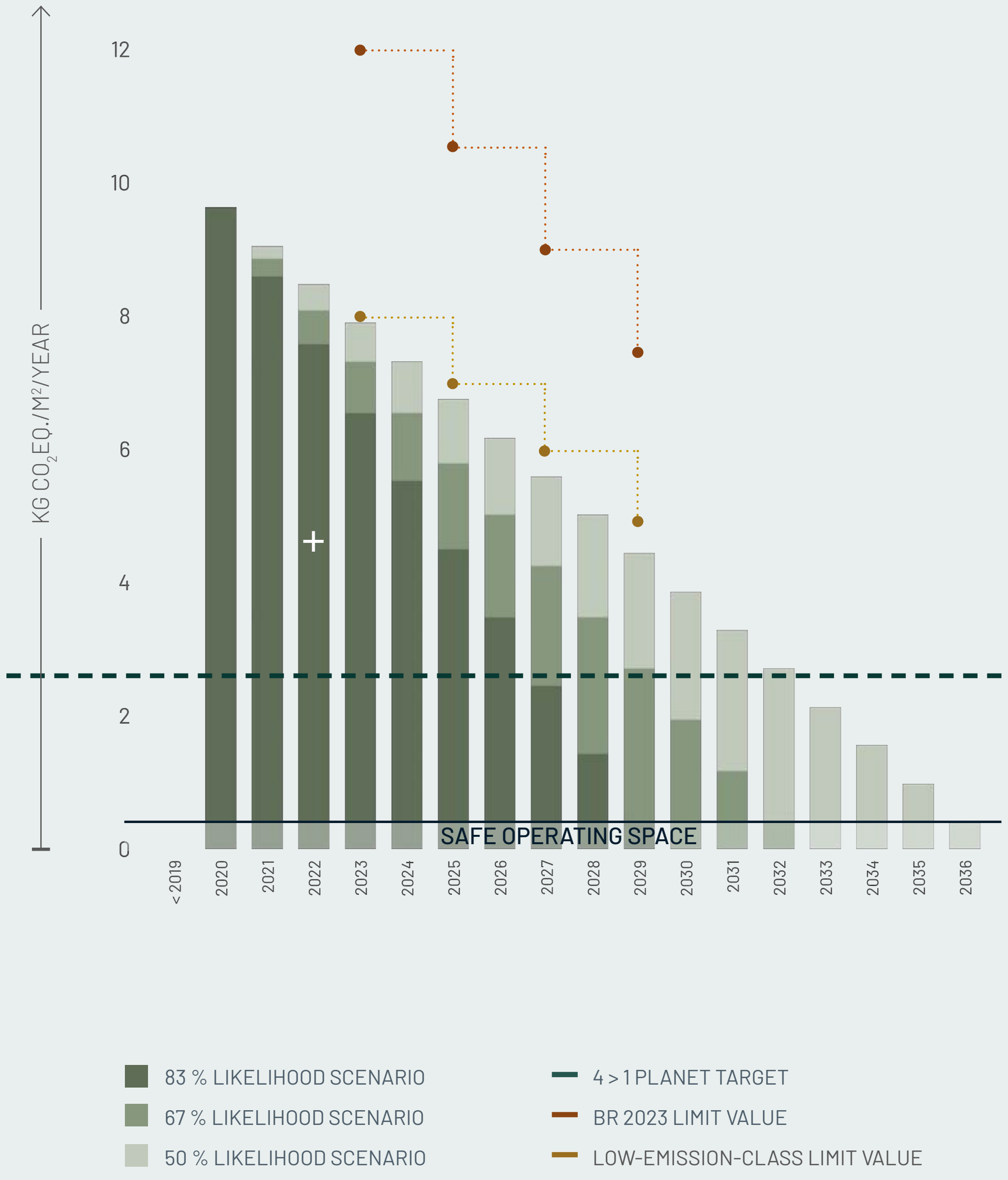
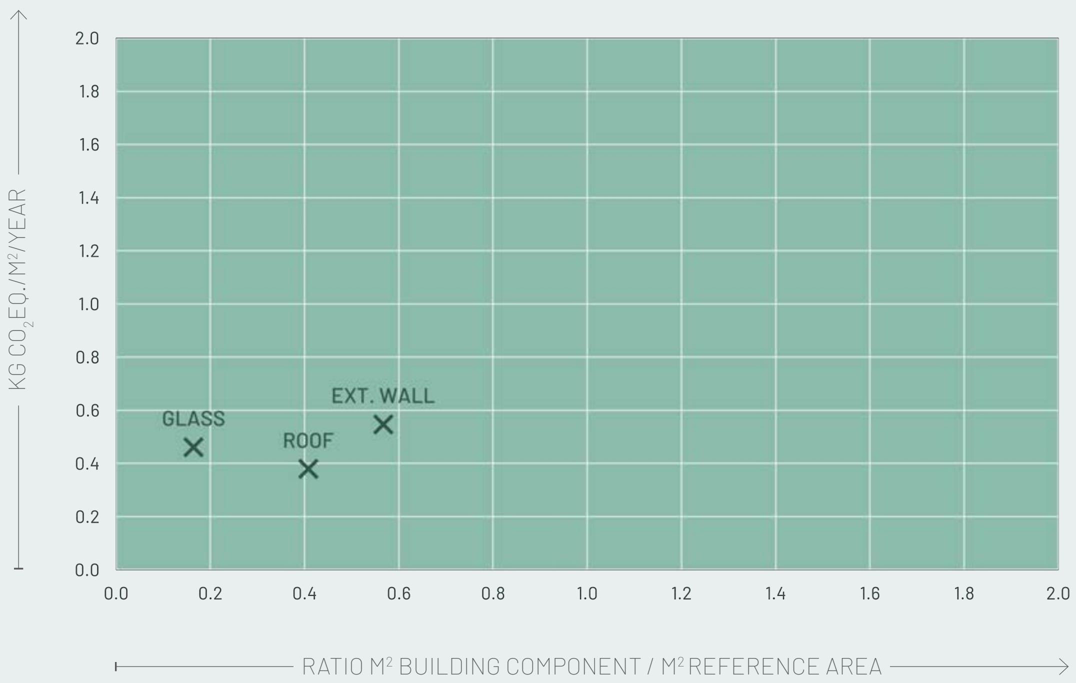



**Figure R04.6: Reduction Roadmap**
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg $CO_2$eq/m²/year, and the 'safe operating space'.

## RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS




## ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

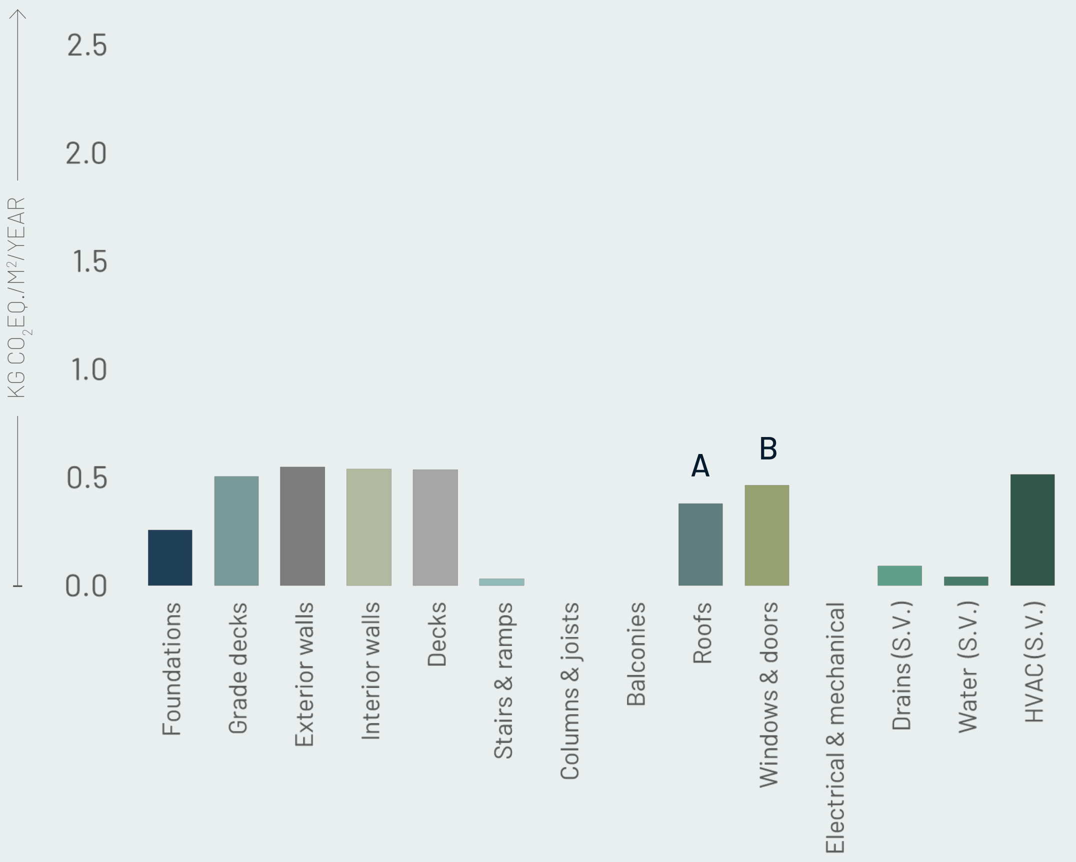



**Figure R04.7: $CO_2$ accounting for building components**
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades,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



R04: Danmarksgrunden

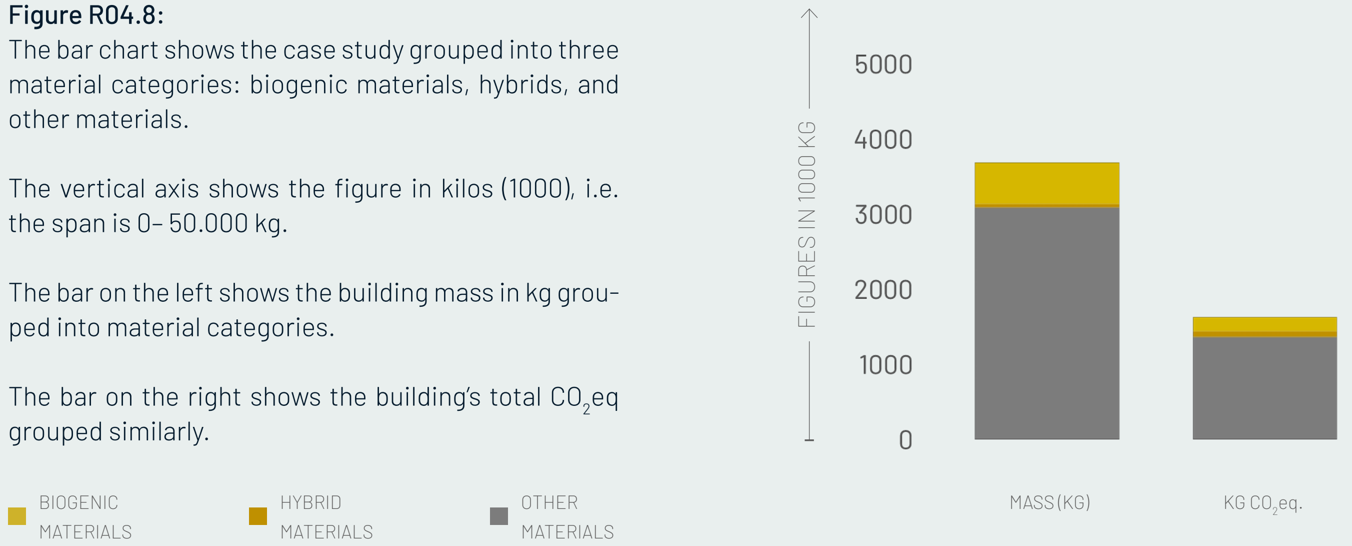
## SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

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

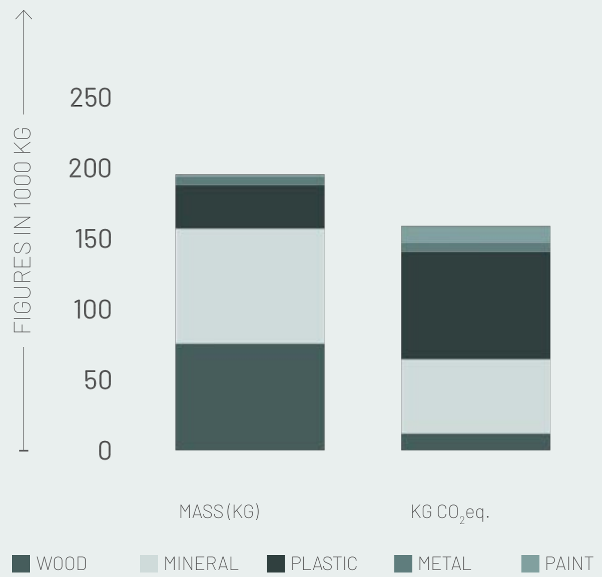
The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

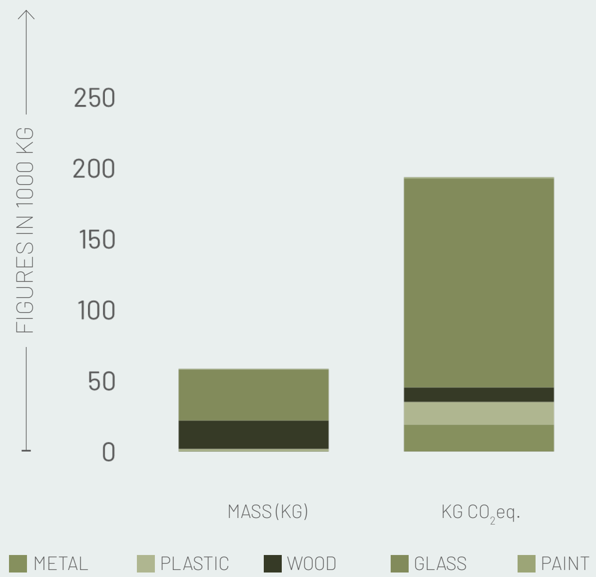
The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total $CO_2$eq grouped similarly.




## MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG $CO_2$EQ.




### 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)

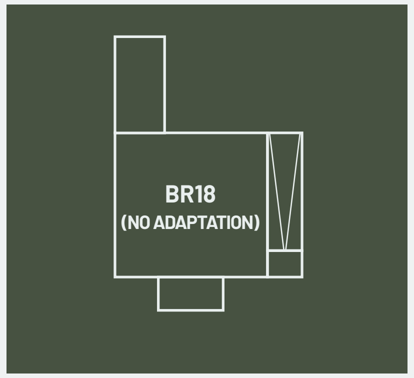
Glass door, exterior, triple-layer
(glulam + aluminium + plastic)

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 m²
**Reference area:** 4788 m²
**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 m² with room for 216 occupants, which gives a space allocation of approx. 22 m²/person. This is on the low side in the case collection.

Cassette

2 storeys



# R05: Skråningen I

4,62 kg $CO_2$eq./m²/year


**Figure R05.1:** 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 terraced housing in the case collection.

906.298 kg $CO_2$eq.

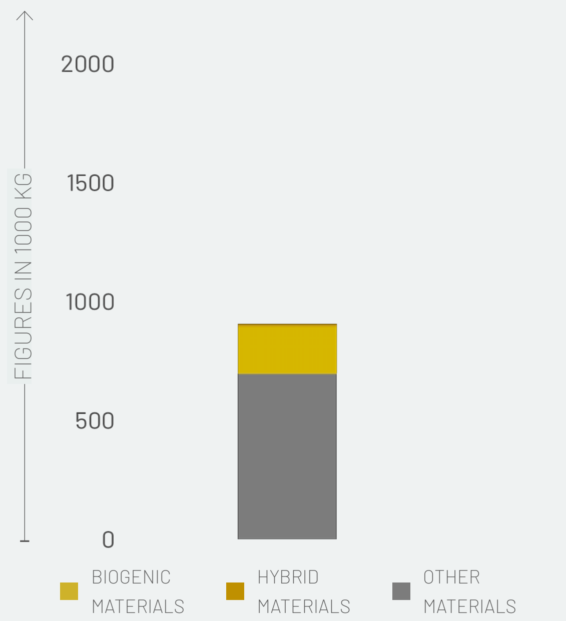



**Figure R05.2:** Total emission of kg $CO_2$eq.
The stacked bar chart shows the overall emission of kg $CO_2$eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

102 kg $CO_2$eq./person/year

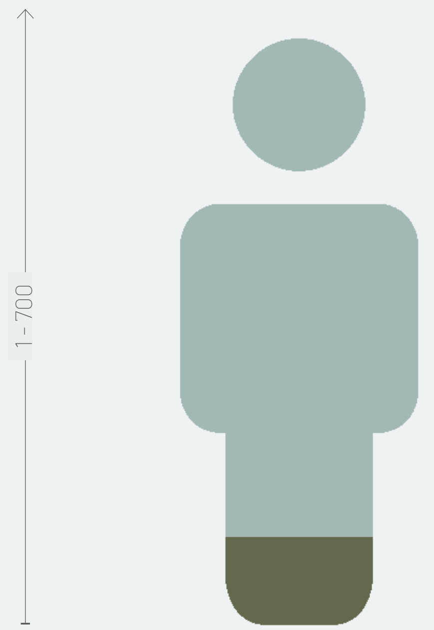



**Figure R05.3:** Emissions of kg $CO_2$eq./person/year
The span of the vertical axis is 1 to 700 kg $CO_2$eq./person/year

22 m²/person

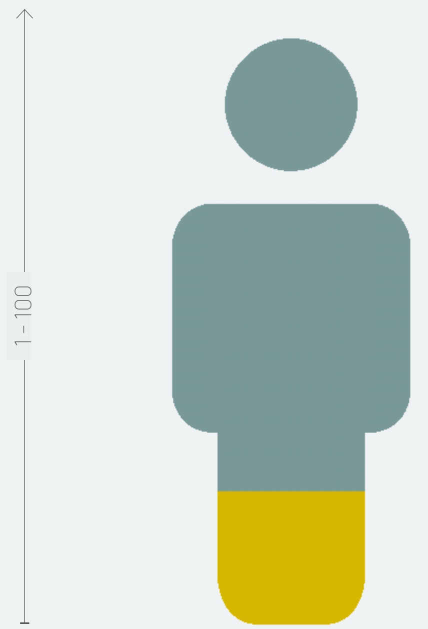



**Figure R05.4:** m²/person
The span of the vertical axis is 1 to 100 m²/person.

# 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 $CO_2$eq./m²/year.

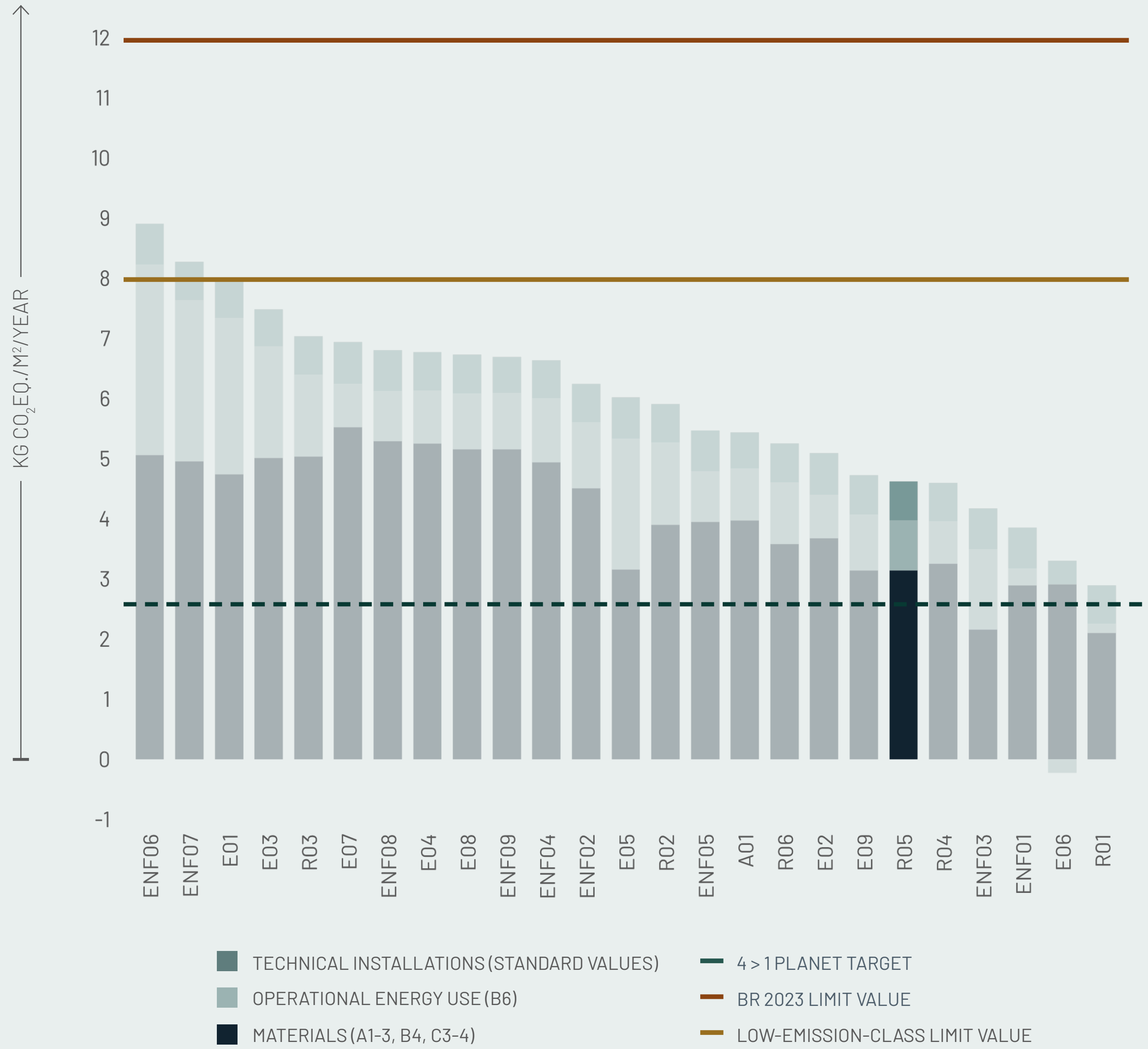



**Figure R05.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.



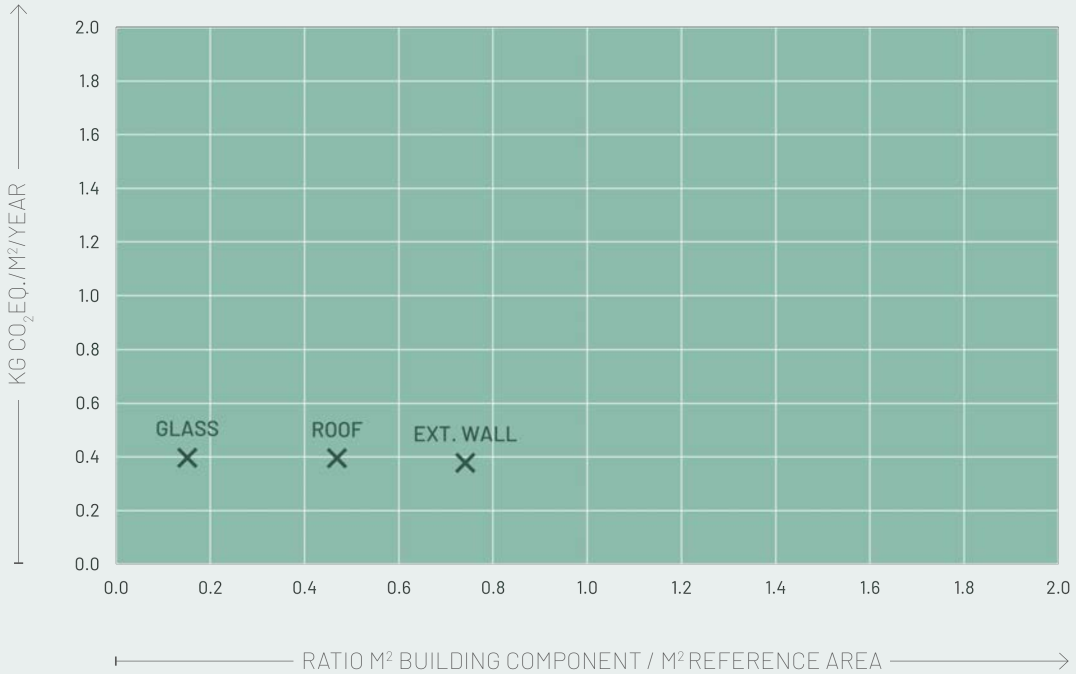
# R05: Skråningen I

## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in $CO_2$eq./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 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 $CO_2$eq./m²/year, and the 'safe operating space'.

## RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS




## ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

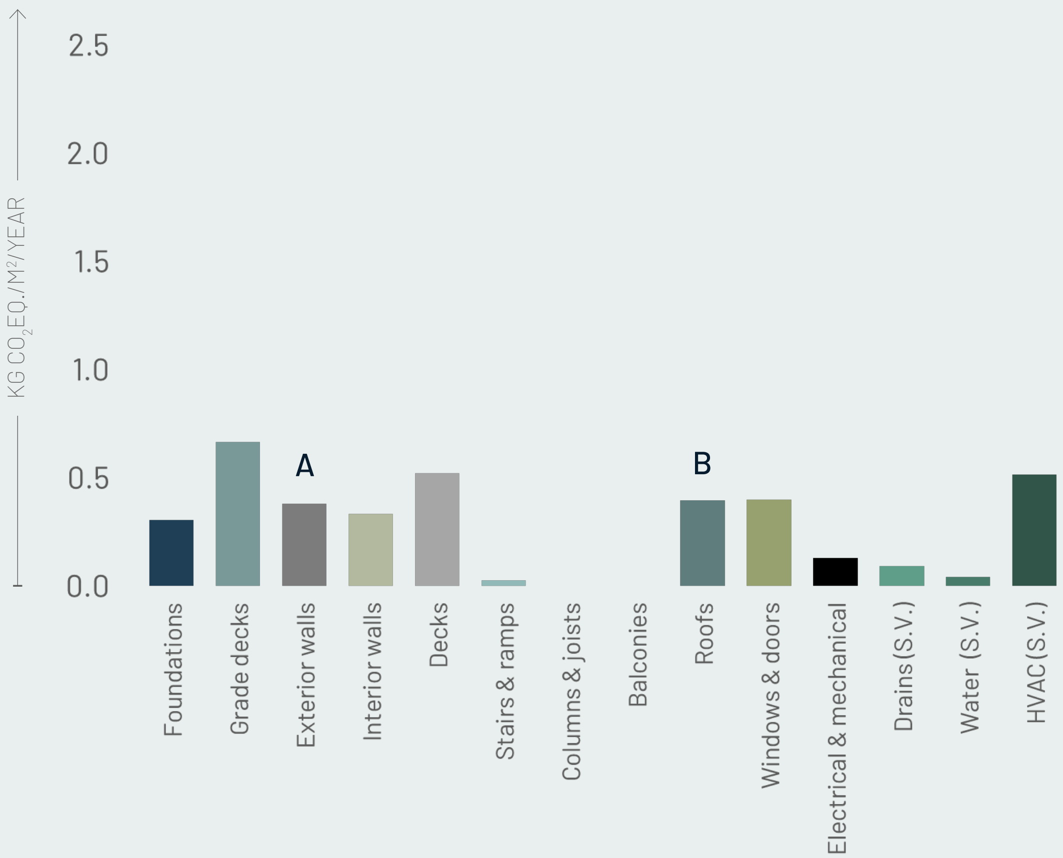



**Figure R05.7: $CO_2$ accounting for building components**
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades,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



R05: Skråningen I

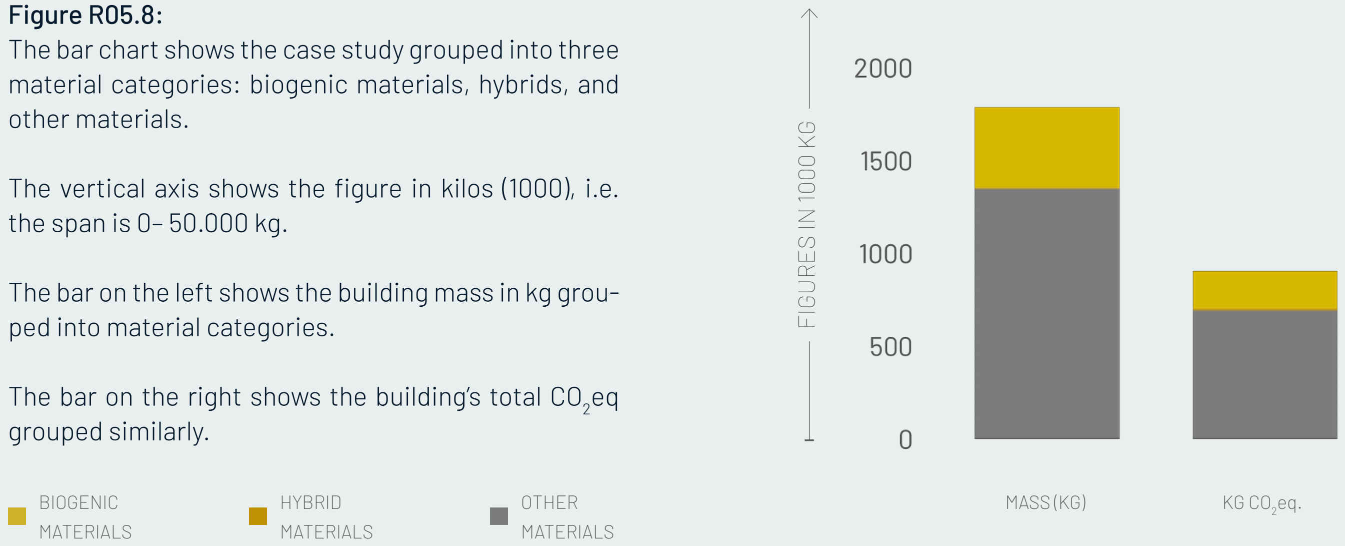
## SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

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

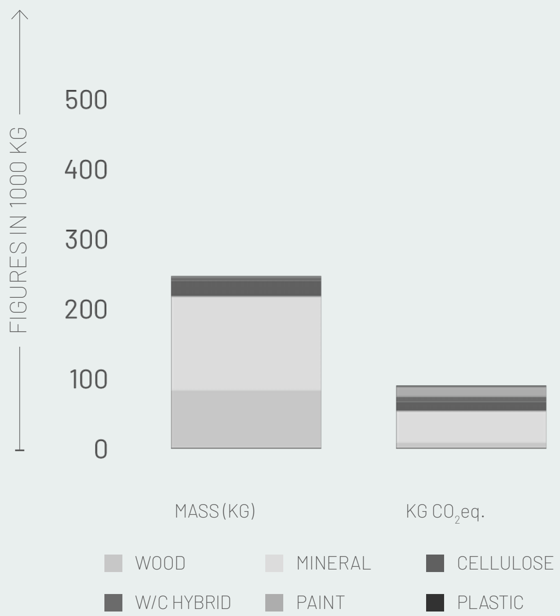
The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

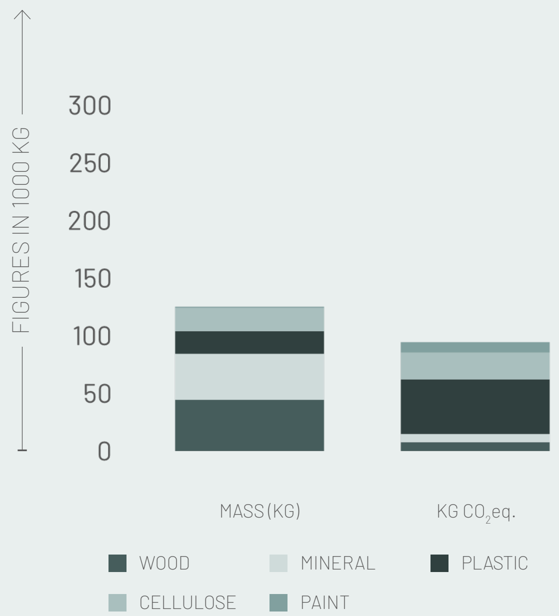
The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total $CO_2$eq grouped similarly.




## MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG $CO_2$EQ.




### A. EXTERIOR WALL

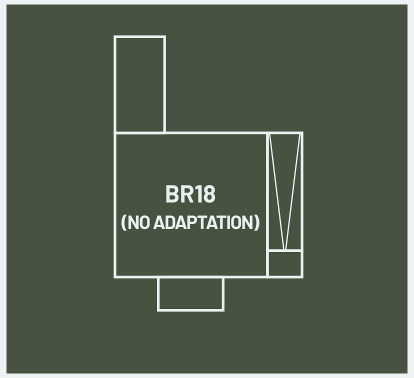
Wooden cladding
Wooden strips
Cement-bonded particle board
Fibre cement
Timber frame
Cellulose insulation
Vapour barrier
Wooden strips
Mineral wool insulation
Gypsum plasterboard

### 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 $CO_2$eq/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 $CO_2$eq./$m^2$/year

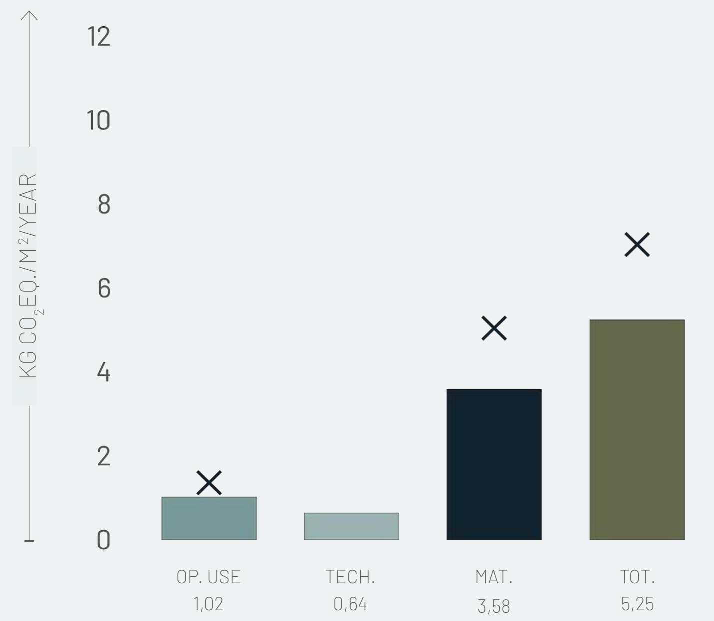



**Figure R06.1: Emissions of kg $CO_2$eq./$m^2$/year**
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg $CO_2$eq./$m^2$/year in terraced housing in the case collection.

1.071.358 kg $CO_2$eq.

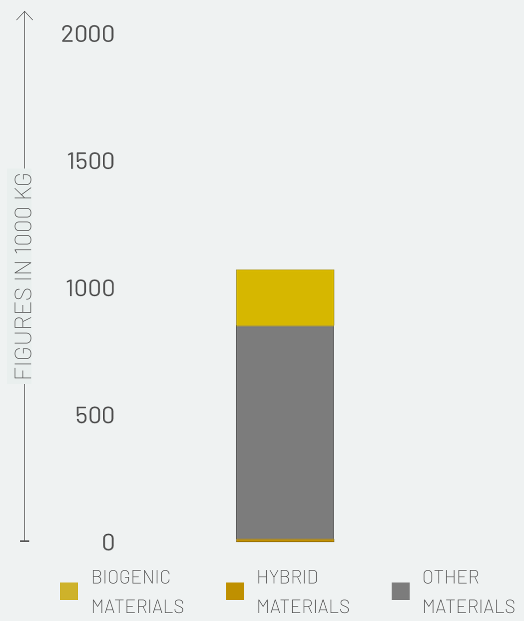



**Figure R06.2: Total emission of kg $CO_2$eq.**
The stacked bar chart shows the overall emission of kg $CO_2$eq. in the case study grouped into the three material categories: other, hybrids, and biogenic.

120 kg $CO_2$eq./person/year

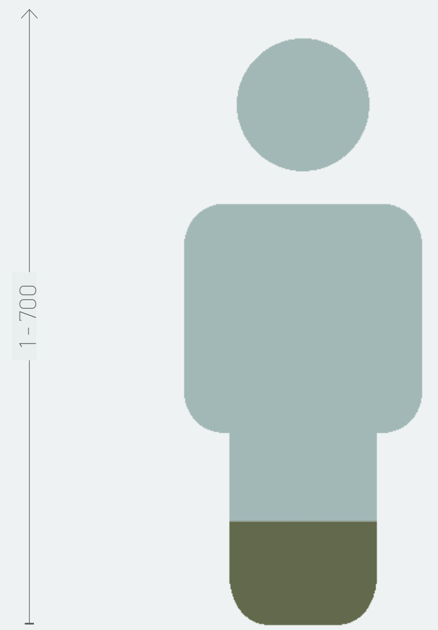



**Figure R06.3: Emissions of kg $CO_2$eq./person/year**
The span of the vertical axis is 1 to 700 kg $CO_2$eq./person/year

23 $m^2$/person

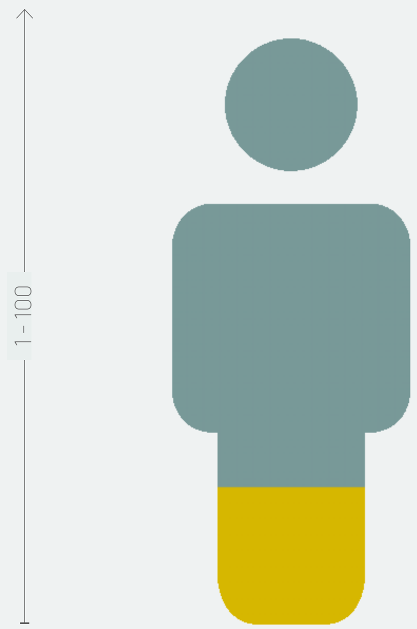



**Figure R06.4: $m^2$/person**
The span of the vertical axis is 1 to 100 $m^2$/person.

# 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 $CO_2$eq./m²/year.

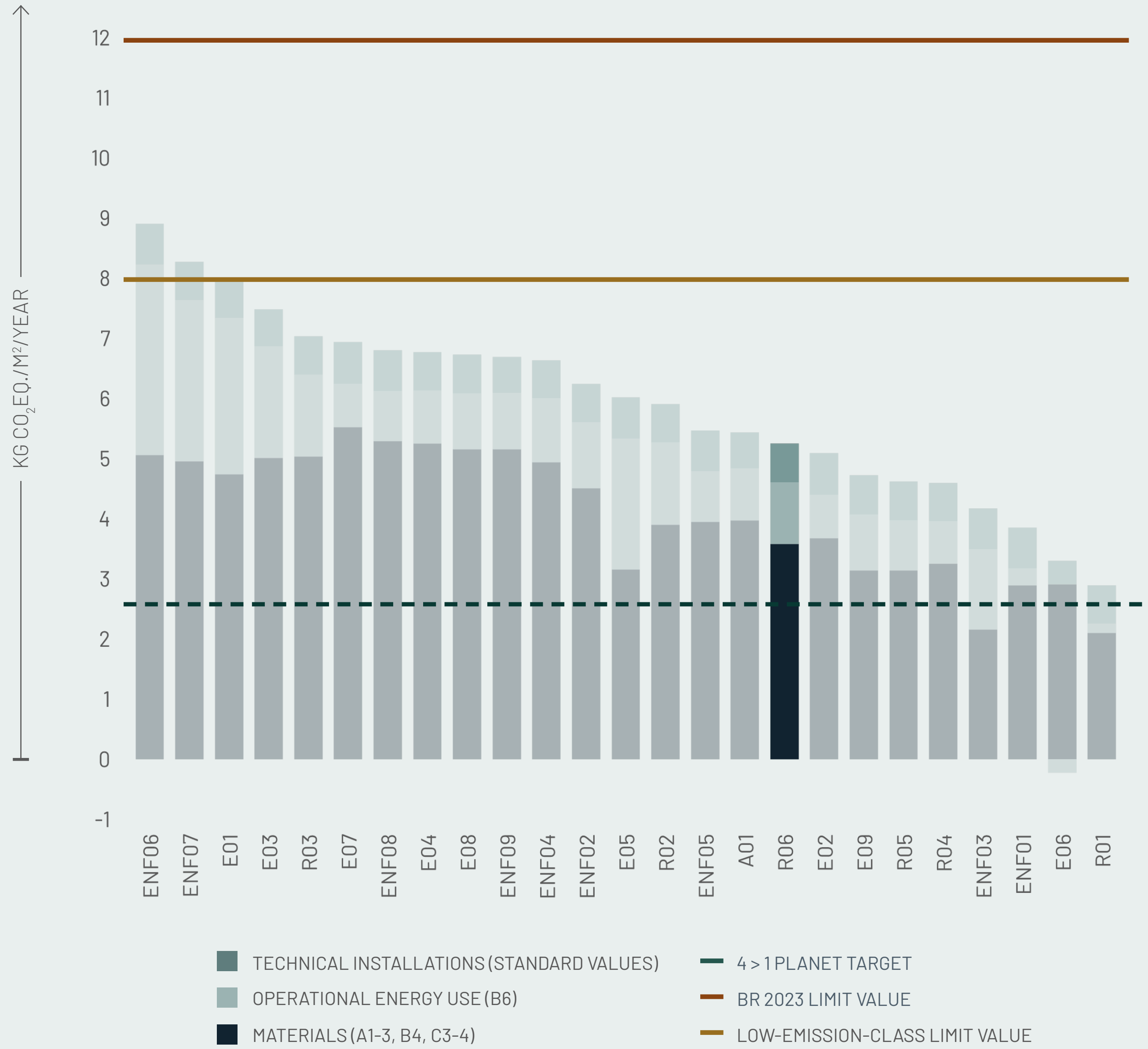



**Figure R06.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.



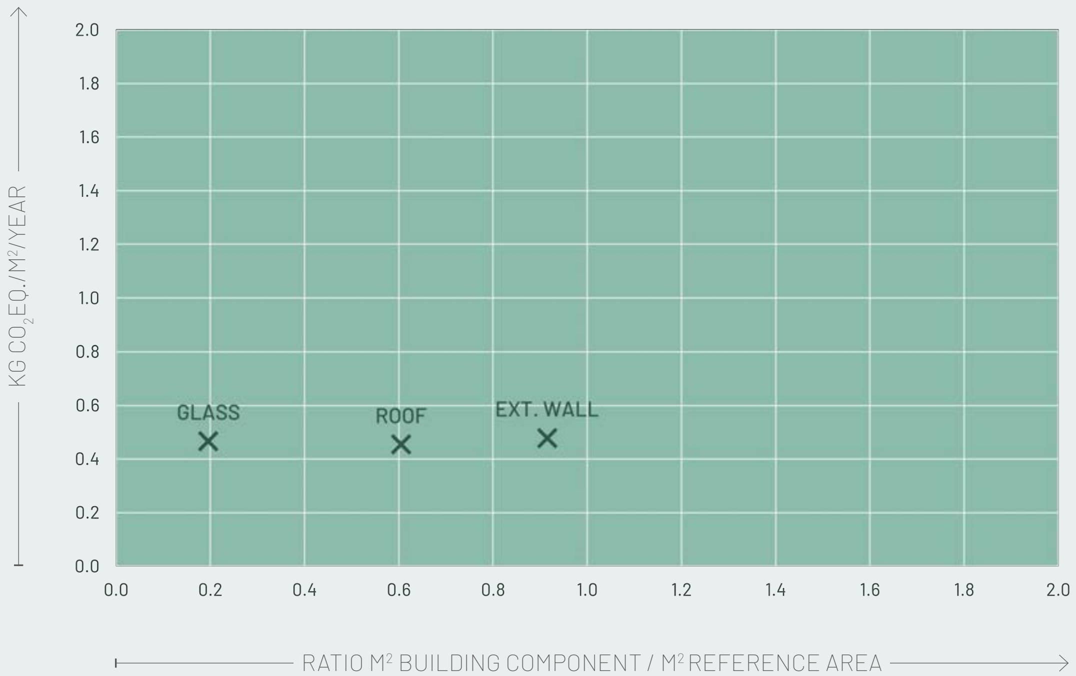
# R06: Skråningen II

## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in $CO_2$eq./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 $CO_2$eq./m²/year, and the 'safe operating space'.

## RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS




## ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

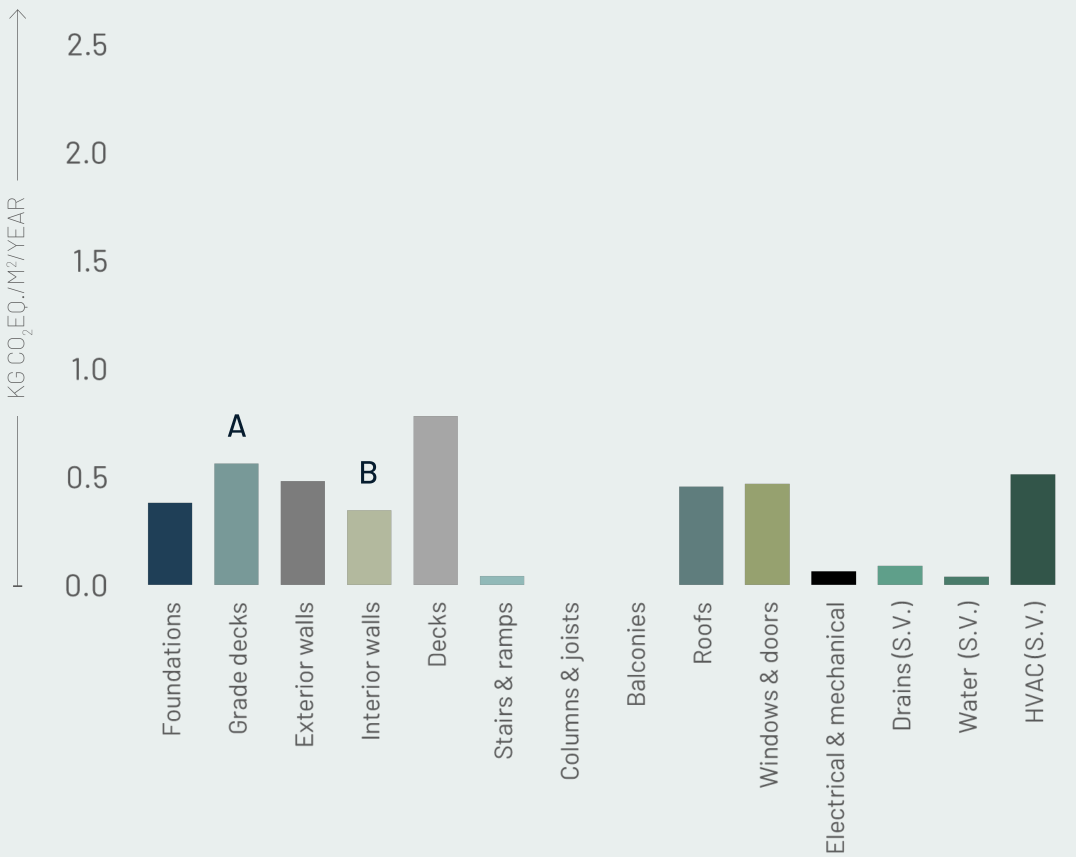



**Figure R06.7: $CO_2$ accounting for building components**
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades,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



R06: Skråningen II

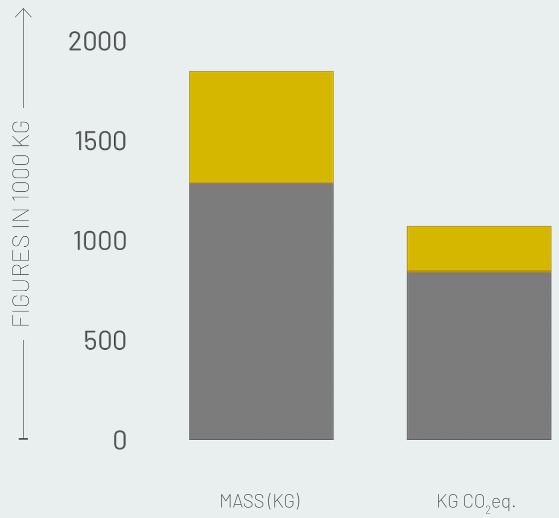
## SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

**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.

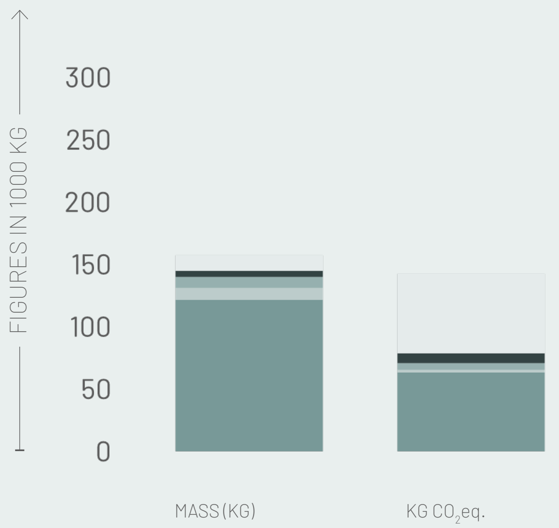
The bar on the left shows the building mass in kg grouped into material categories.

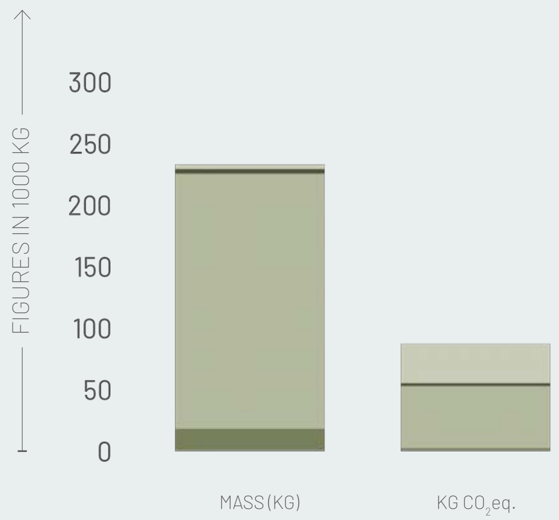
The bar on the right shows the building's total $CO_2$eq grouped similarly.




BIOGENIC MATERIALS · HYBRID MATERIALS · OTHER MATERIALS

## MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG $CO_2$EQ.




### A. GRADE DECK

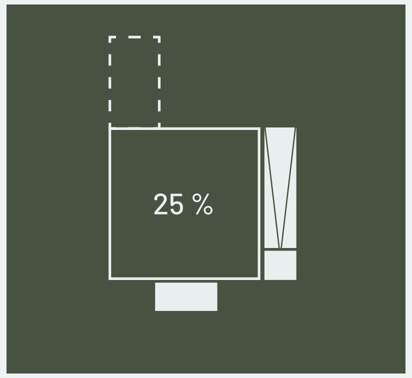
Particle board (reuse)
Cement-bonded particle board
Vapour barrier
Timber frame
Loose-fill cellulose insulation
EPS insulation

### 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 m$^2$ |
| **Reference area:** | 579 m$^2$ |
| **Use:** | Residential |
| **Occupants:** | 18 |
| **Year (calculated):** | 2022 |
| **Heating:** | District heating |
| **Solar cells:** | Yes |





## DESCRIPTION

MiniCO$_2$ 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 MiniCO$_2$ 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.

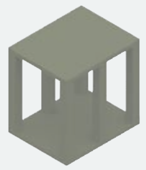
The five-storey building is built on pile footings and a reinforced concrete foundation plate. Concrete grade deck with EPS insulation.

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.

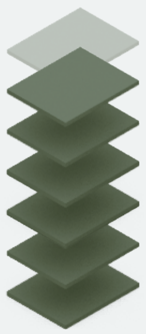
Ribbed storey decks with CLT and glulam with cellulose insulation. A special focal point has been to meet acoustic requirements in storey partitions, which can be a challenge when not using concrete.

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 m$^2$ with room for 18 occupants, which gives a space allocation of approx. 31 m$^2$/person. This is average for the case collection.



Hybrid



5 storeys



# E01: MiniCO2 Etagehus TRÆ

8,01 kg CO$_2$eq./m$^2$/year


**Figure E01.1: Emissions of kg CO$_2$eq./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$_2$eq./m$^2$/year in multi-storey housing in the case collection.

156.713 kg CO$_2$eq.

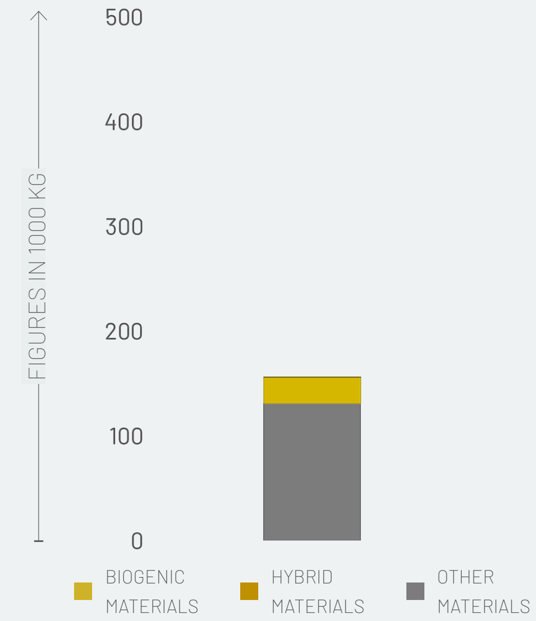



**Figure E01.2: Total emission of kg CO$_2$eq.**
The stacked bar chart shows the overall emission of kg CO$_2$eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

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

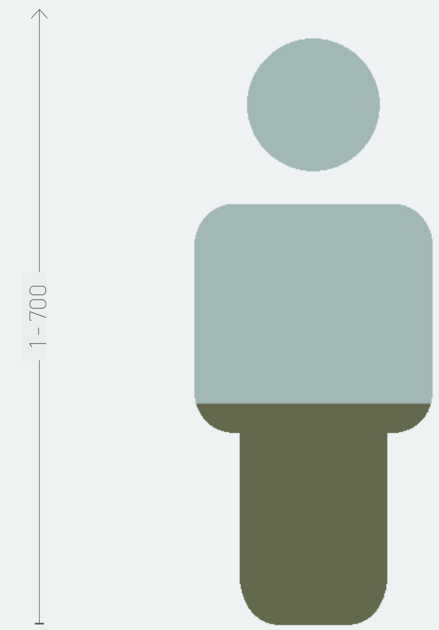



**Figure R01.3: Emissions of kg CO$_2$eq./person/year**
The span of the vertical axis is 1 to 700 kg CO$_2$eq./person/year

31 m$^2$/person

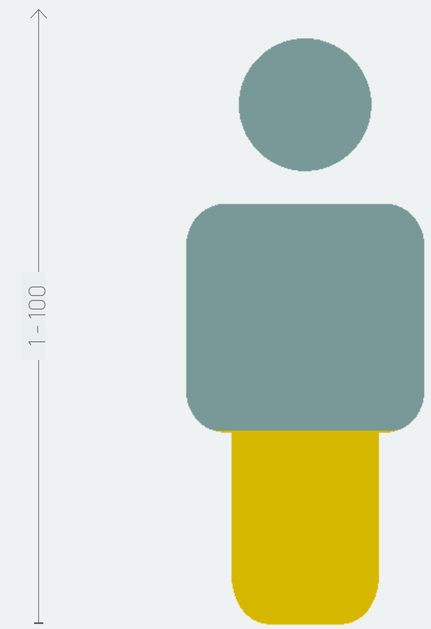



**Figure R01.4: m$^2$/person**
The span of the vertical axis is 1 to 100 m$^2$/person.

# 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 $CO_2$eq./m²/year.

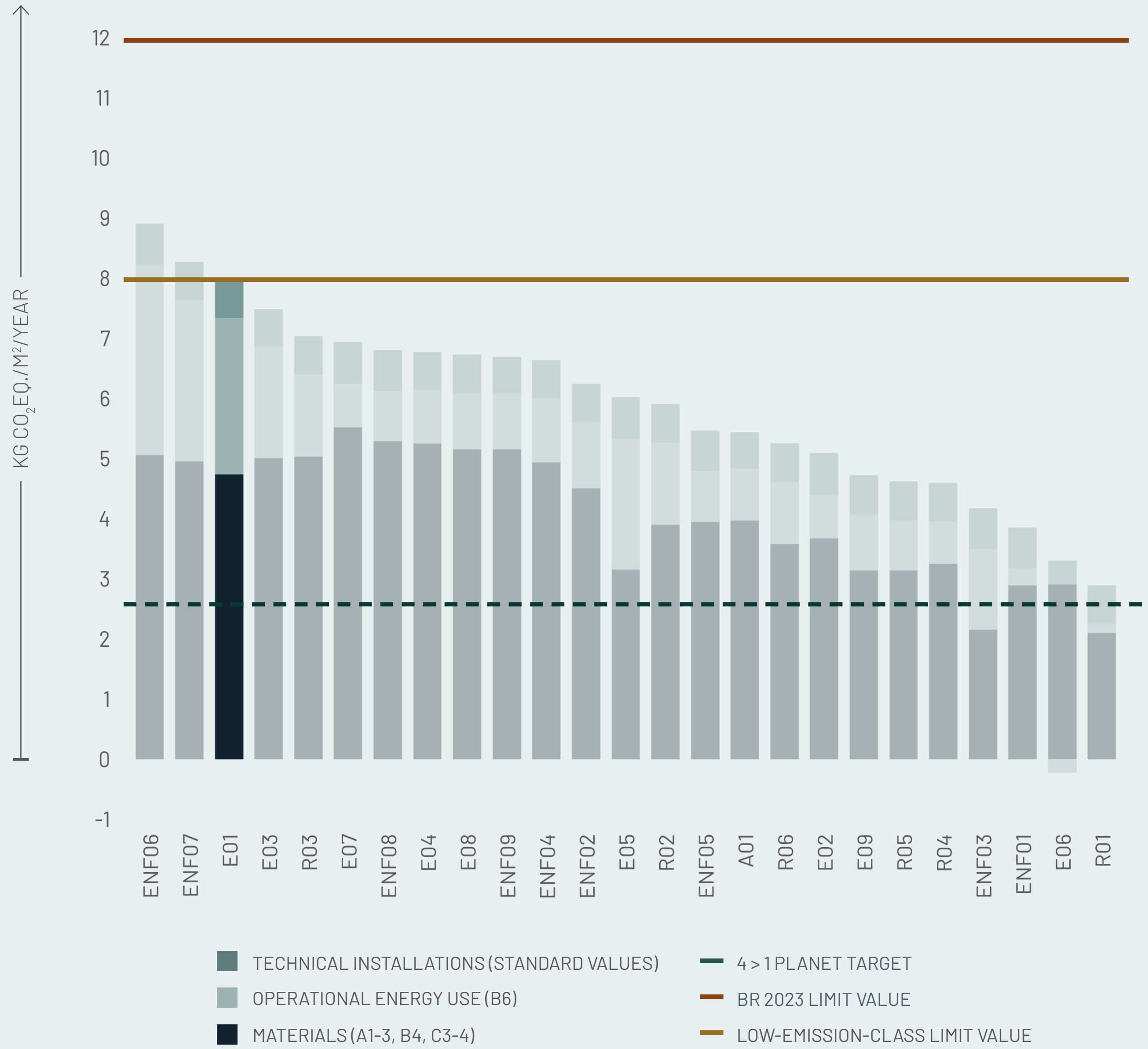



**Figure E01.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.



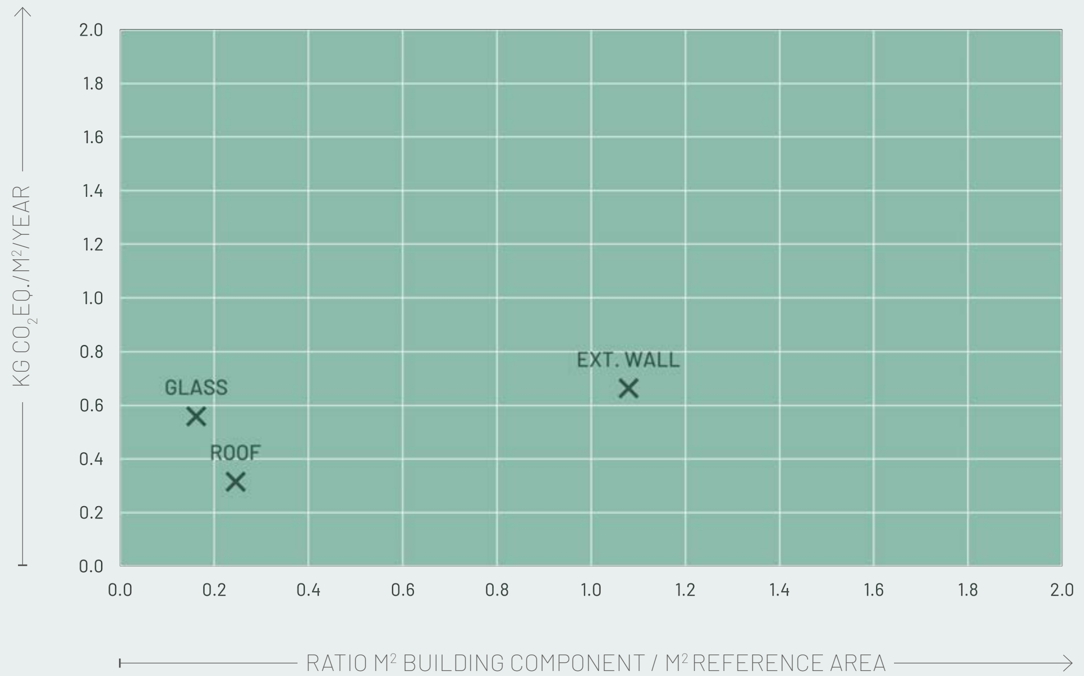
# E01: MiniCO2 Etagehus TRÆ

## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in $CO_2$eq./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 $CO_2$eq./m²/year, and the 'safe operating space'.

## RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS




## ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

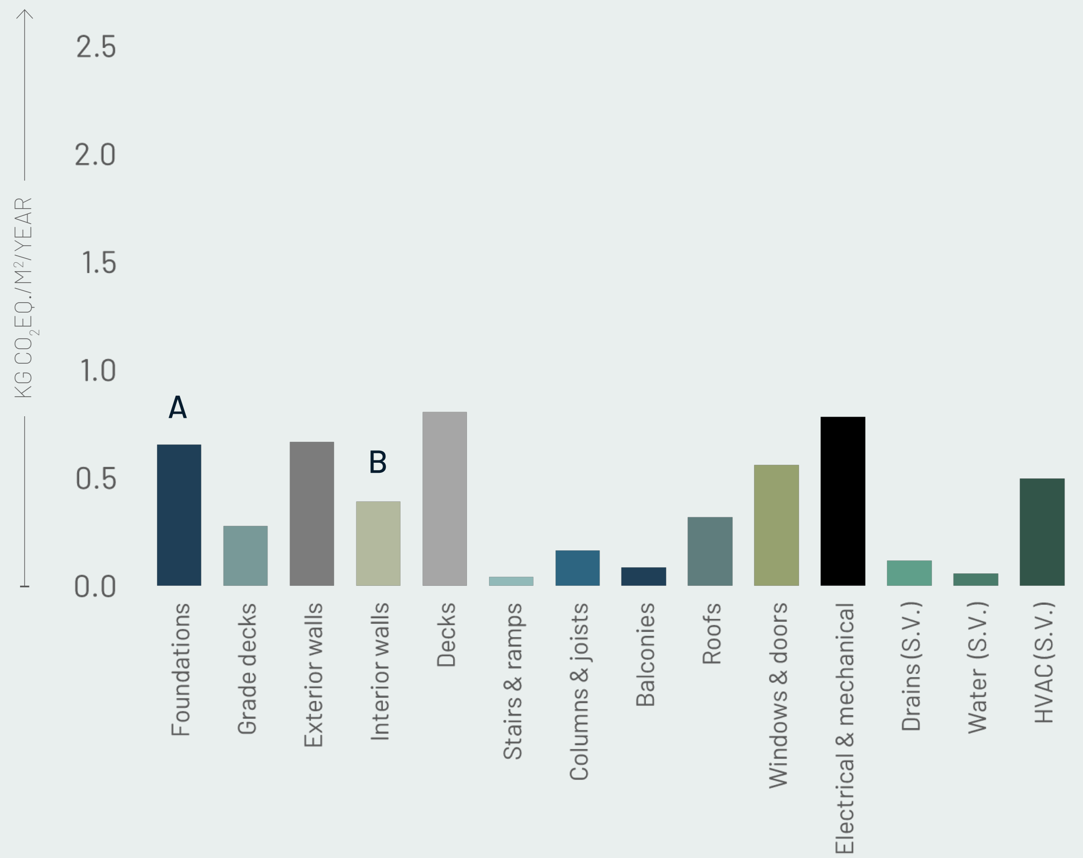



**Figure E01.7: $CO_2$ accounting for building components**
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades,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



E01: MiniCO2 Etagehus TRÆ

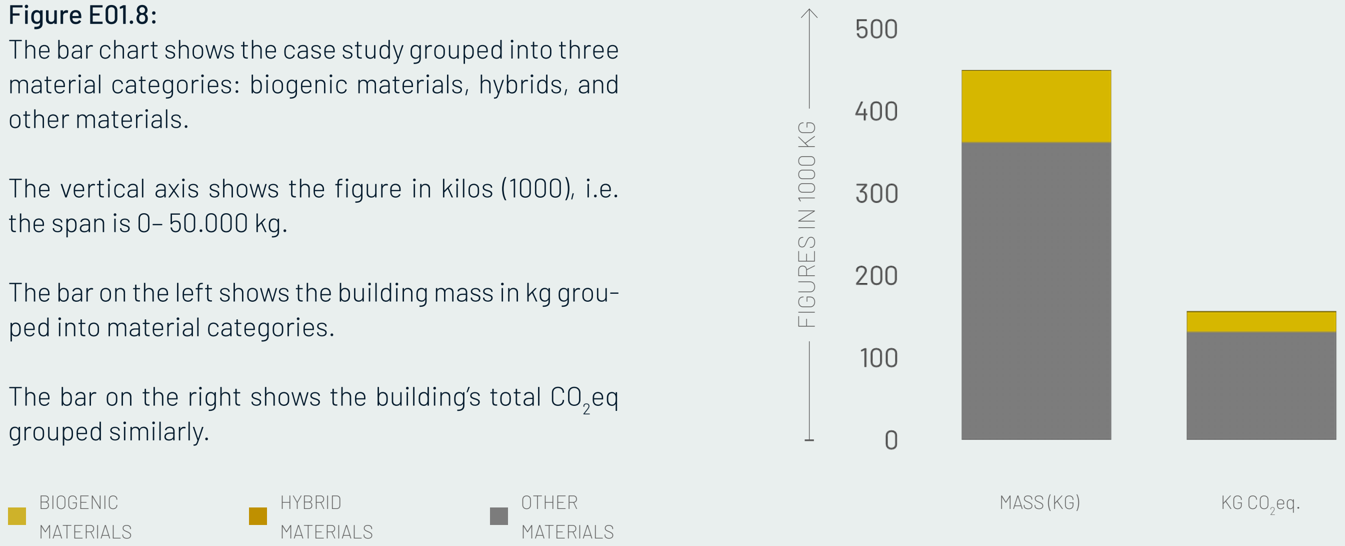
## SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

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

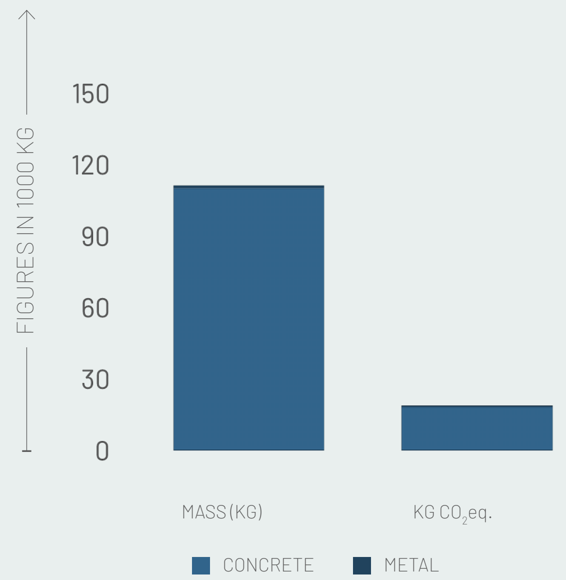
The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

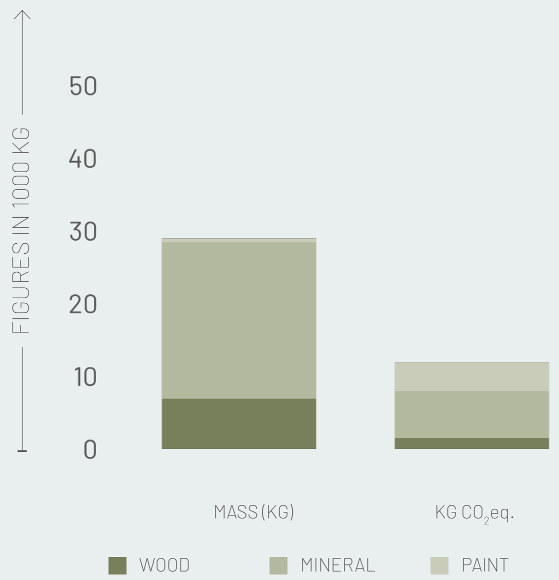
The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total $CO_2$eq grouped similarly.




## MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG $CO_2$EQ.




### A. FOUNDATION

Reinforced concrete pile footings
Continuous concrete foundations

### B. INTERIOR WALLS

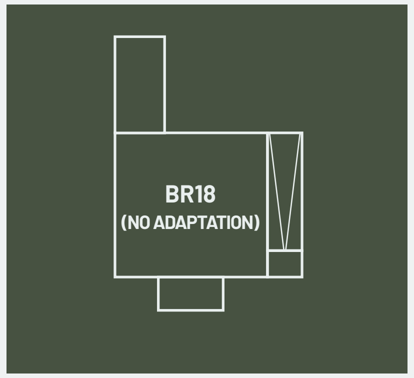
Interior wall types:

CLT interior wall
Timber frame with glass wool insulation

Surface:

Fibre gypsum boards Paint


| | |
|---|---|
| **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

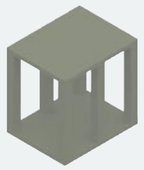
Tankefuld II is the second phase of a housing scheme comprising 44 housing units. The unit types are flexible and vary, based on five different housing types between 41-97 m². Special emphasis has been on developing a new urban area with focus on sustainability.

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 $CO_2$eq./m²/year

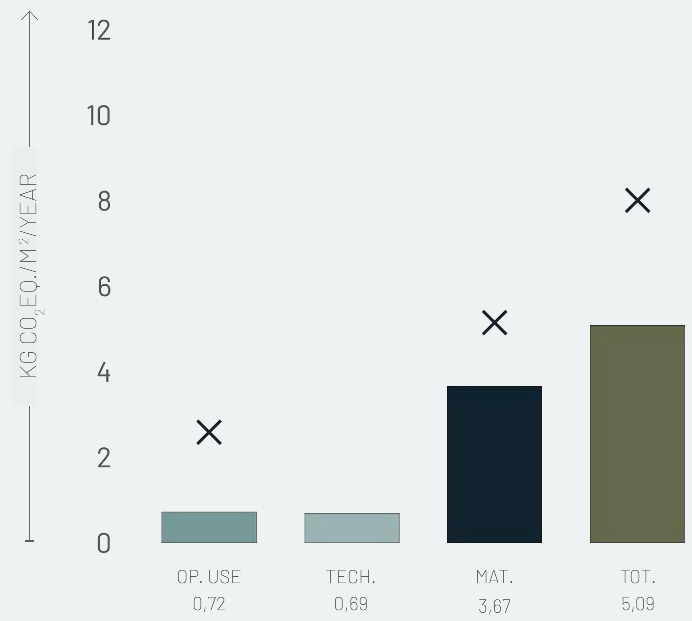



**Figure E02.1: Emissions of kg $CO_2$eq./m²/year**
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg $CO_2$eq./m²/year in multi-storey housing in the case collection.

622.575 kg $CO_2$eq.

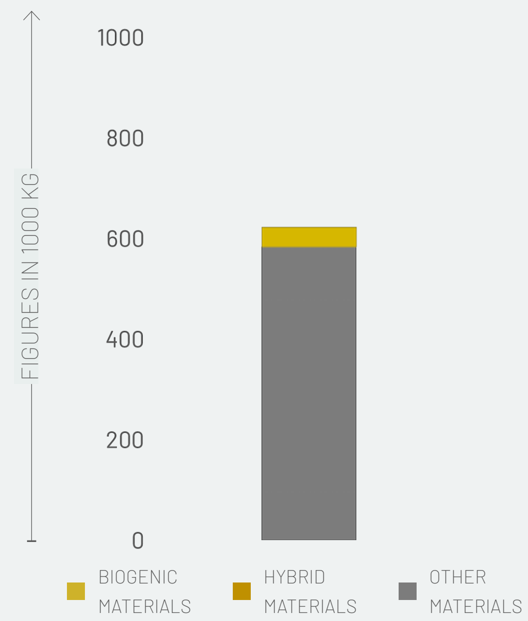



**Figure E02.2: Total emission of kg $CO_2$eq.**
The stacked bar chart shows the overall emission of kg $CO_2$eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

113 kg $CO_2$eq./person/year

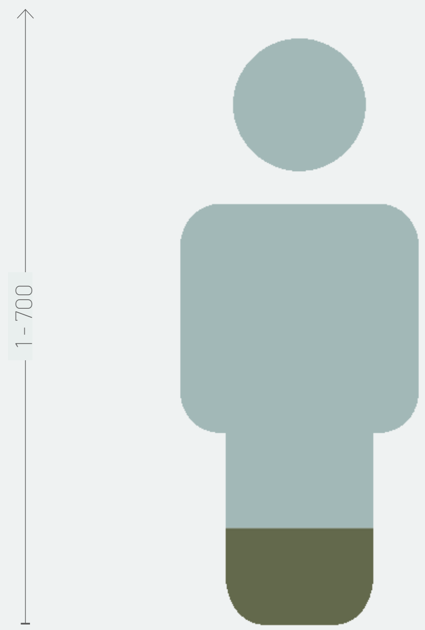



**Figure E02.3: Emissions of kg $CO_2$eq./person/year**
The span of the vertical axis is 1 to 700 kg $CO_2$eq./person/year

22 m² / person

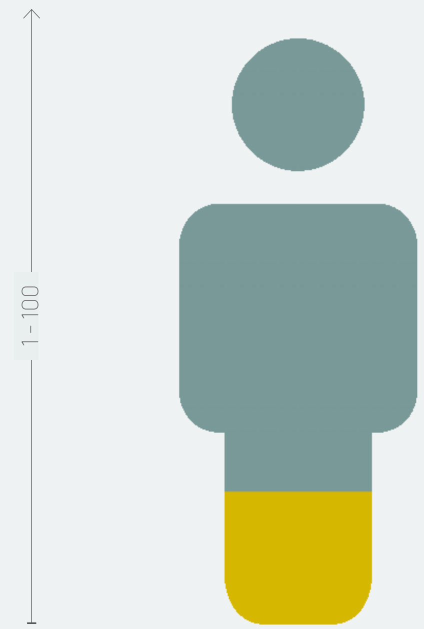



**Figure E02.4: m²/person**
The span of the vertical axis is 1 to 100 m²/person.

# 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 $CO_2$eq./m²/year.

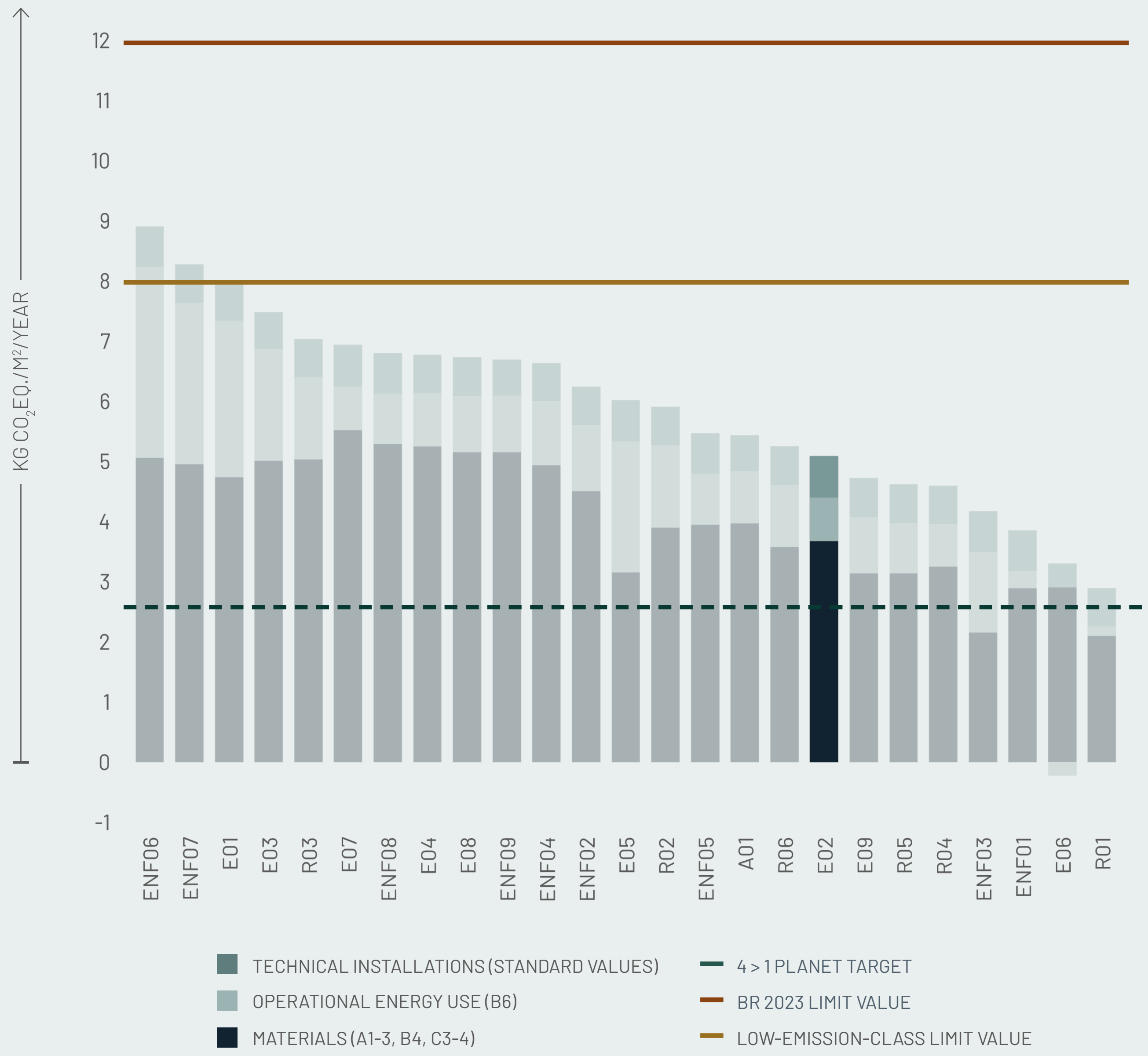



**Figure E02.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.



# E02: Tankefuld II

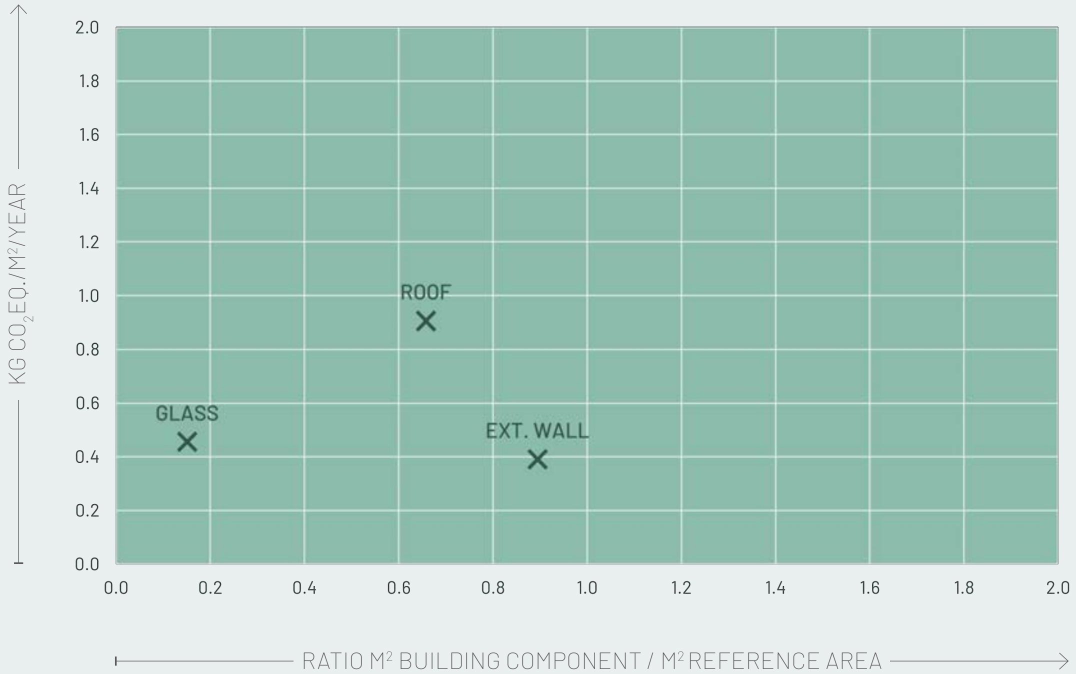
## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in $CO_2$eq./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 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 $CO_2$eq./m²/year, and the 'safe operating space'.

# E02: Tankefuld II

## RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS




## ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

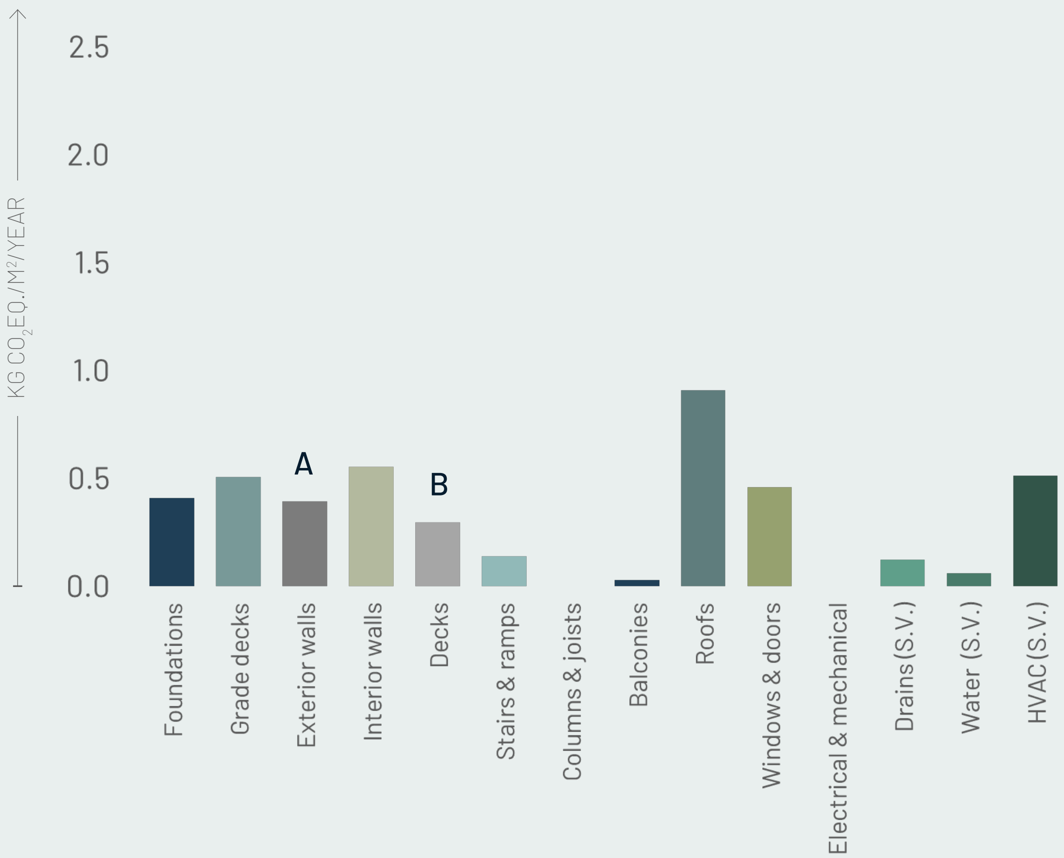



**Figure E02.7: $CO_2$ accounting for building components**
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades,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



# E02: Tankefuld II

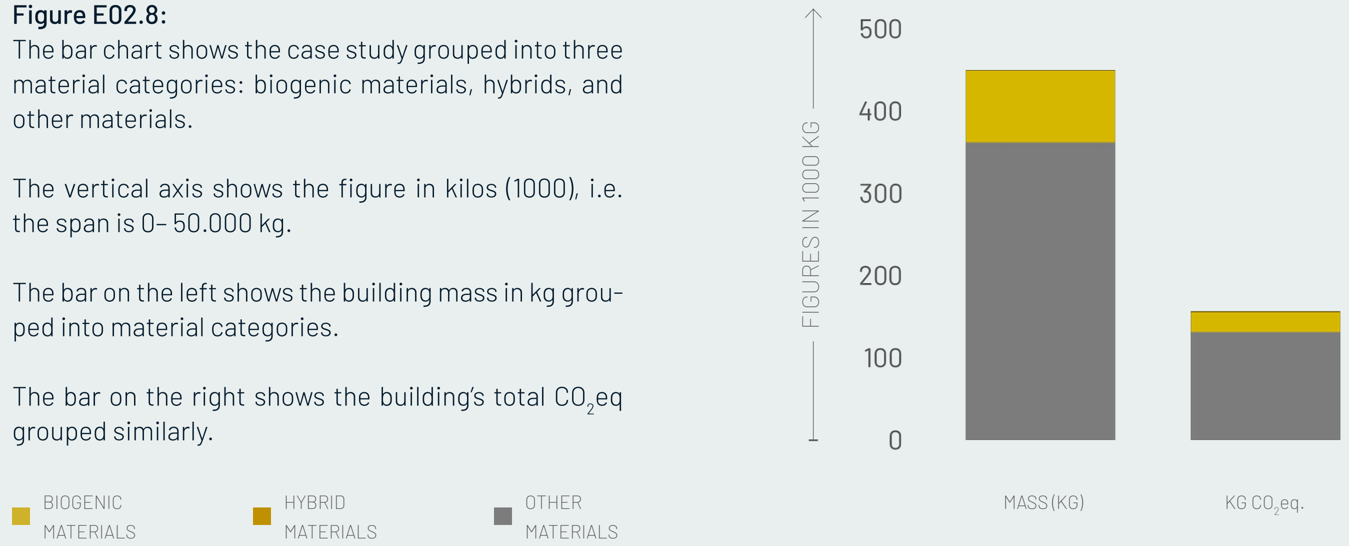
## SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

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

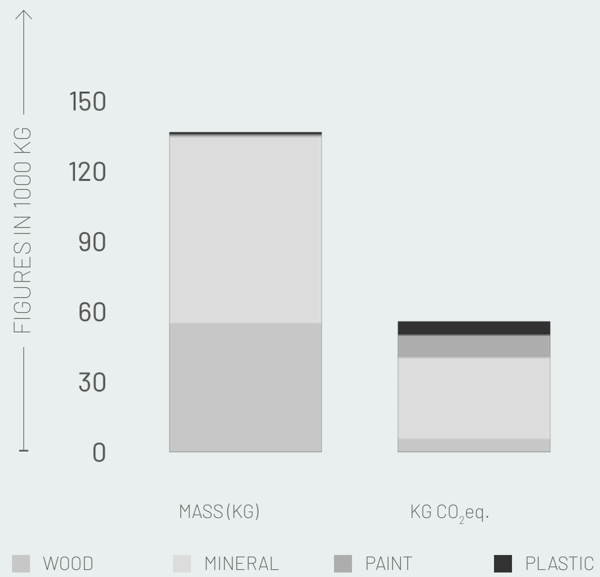
The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

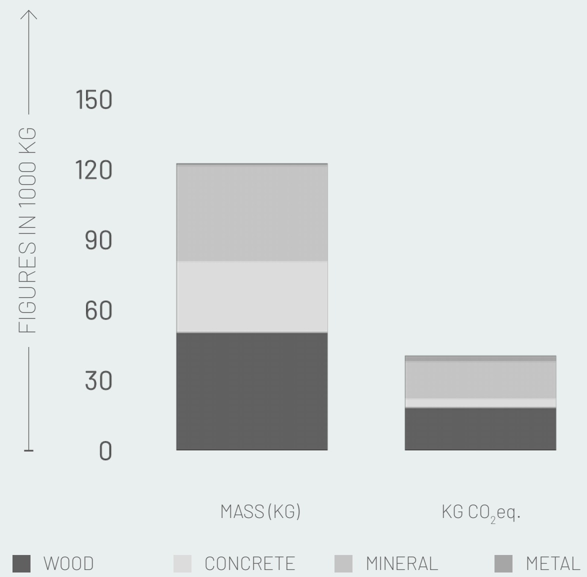
The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total $CO_2$eq grouped similarly.




## MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG $CO_2$EQ.




### A. EXTERIOR WALL

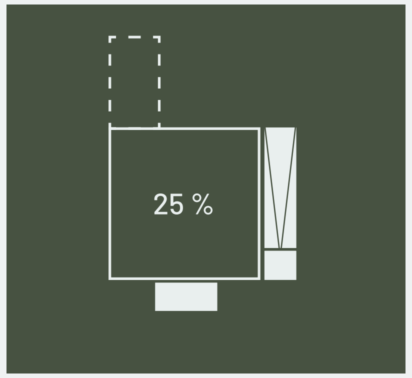
Fibre-cement boards
Wooden strips
Fibre-cement boards
Timber frame
Glass wool insulation
Vapour barrier
Timber frame
Glass wool insulation
Gypsum plasterboard x 2

### 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 $m^2$ |
| **Reference area:** | 6647 $m^2$ |
| **Use:** | Residential |
| **Occupants:** | 189 |
| **Year (calculated):** | 2022 |
| **Heating:** | District heating |
| **Solar cells:** | Yes |





## DESCRIPTION

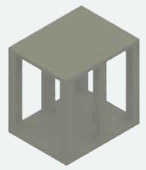
Store Solvænget is a housing scheme and the first of its kind in Denmark to carry the Swan Ecolabel. Swan Ecolabel requirements include the use of certified timber and attempst at avoiding substances that are harmful to health and the environment have been focal points in this construction project. The 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.

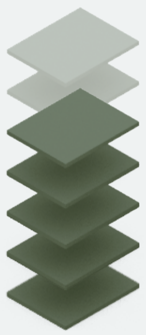
The house is constructed with supporting structures in timber with wood-fibre insulation. Storey partitions and partitions between housing units are timber-frame structures with cement particle board, mineral wool insulation, and fire-rated gypsum boards. Interior surfaces have gypsum board facings, 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 $m^2$ with room for 189 occupants, which gives a space allocation of approx. 31 $m^2$/person. This is average for the case collection.



Hybrid



3-4 storeys



# E03: Store Solvænget

7,48 kg $CO_2$eq./$m^2$/year


**Figure E03.1: Emissions of kg $CO_2$eq./$m^2$/year**
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg $CO_2$eq./$m^2$/year in multi-storey housing in the case collection.

1.868.212 kg $CO_2$eq.

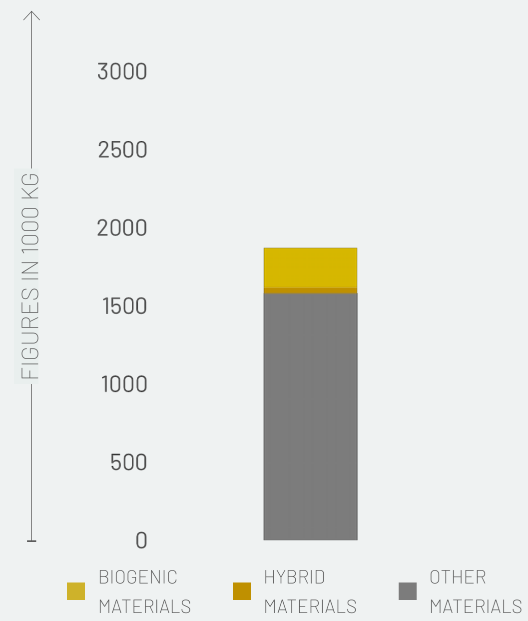



**Figure E03.2: Total emission of kg $CO_2$eq.**
The stacked bar chart shows the overall emission of kg $CO_2$eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

263 kg $CO_2$eq./person/year

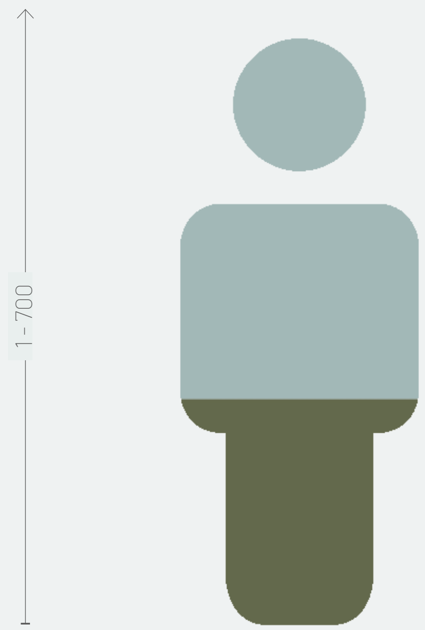



**Figure E03.3: Emissions of kg $CO_2$eq./person/year**
The span of the vertical axis is 1 to 700 kg $CO_2$eq./person/year

31 $m^2$/person

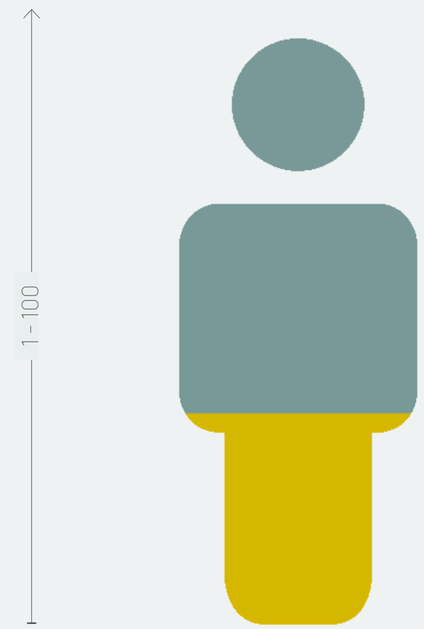



**Figure E03.4: $m^2$/person**
The span of the vertical axis is 1 to 100 $m^2$/person.

# 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 $CO_2$eq./m$^2$/year.

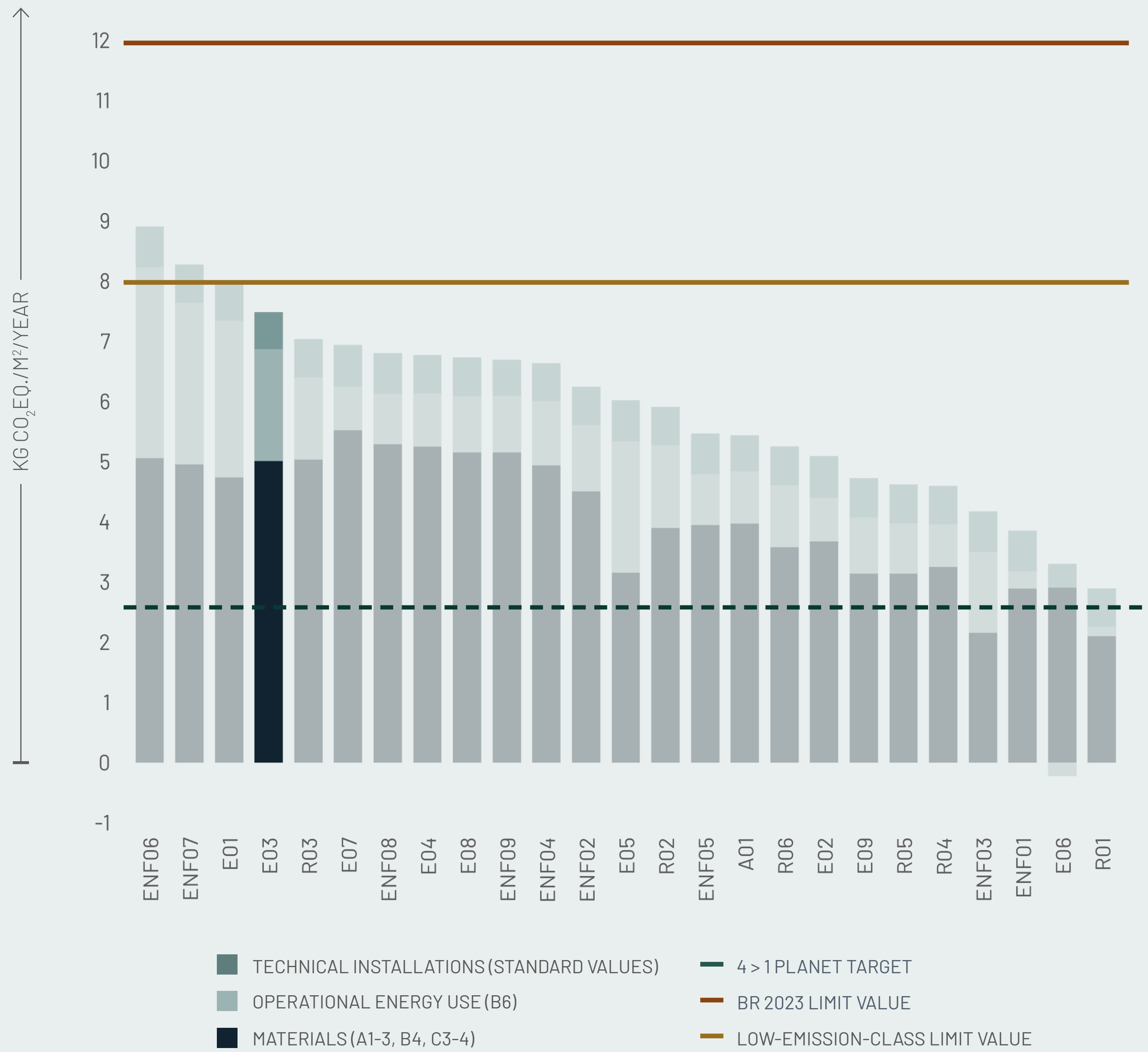



**Figure E03.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m$^2$/year. The horizontal axis shows the 25 best practice cases.



# E03: Store Solvænget

## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in $CO_2$eq./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 within the fastest reduction rate: the 83% likelihood scenario.

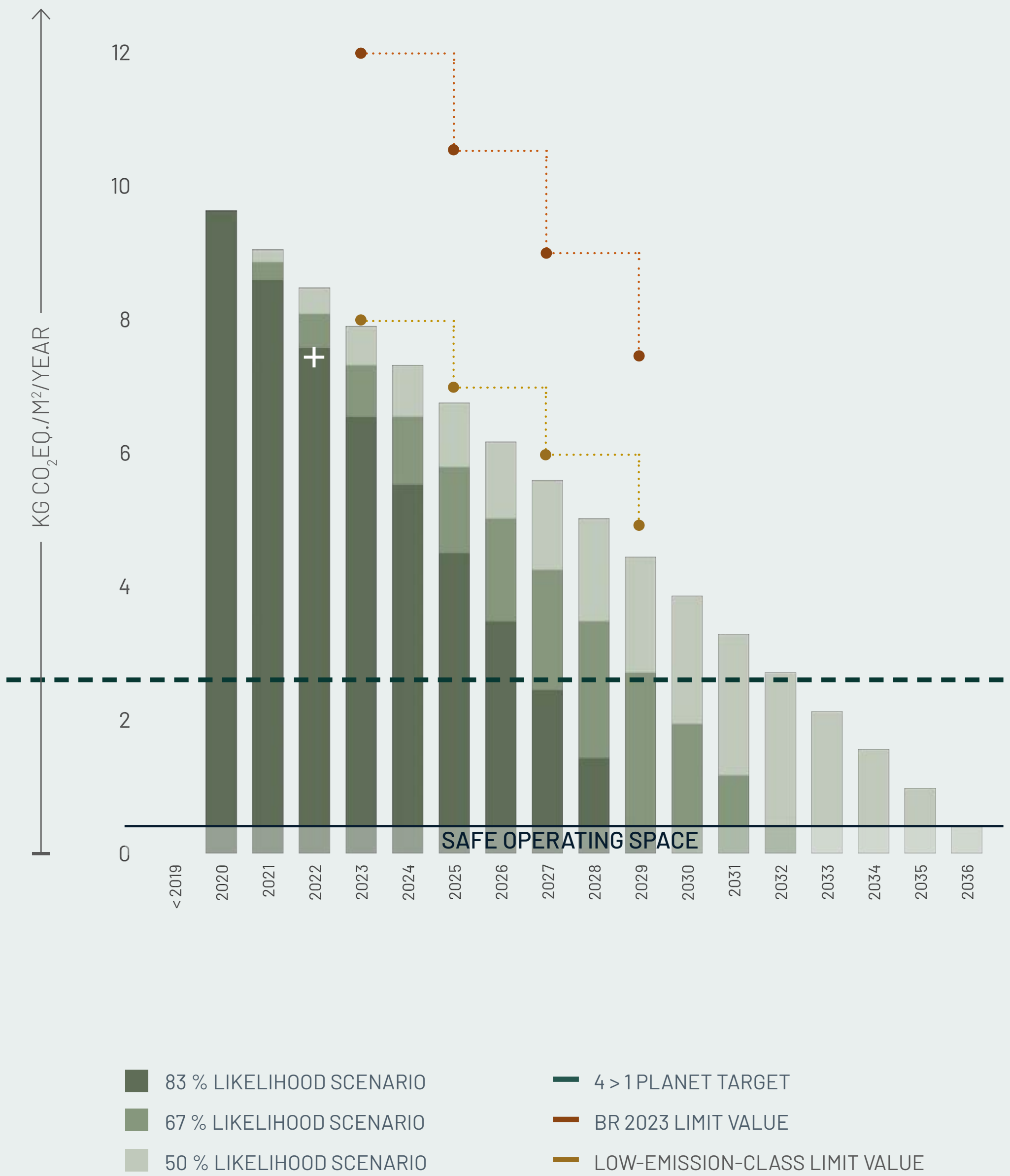
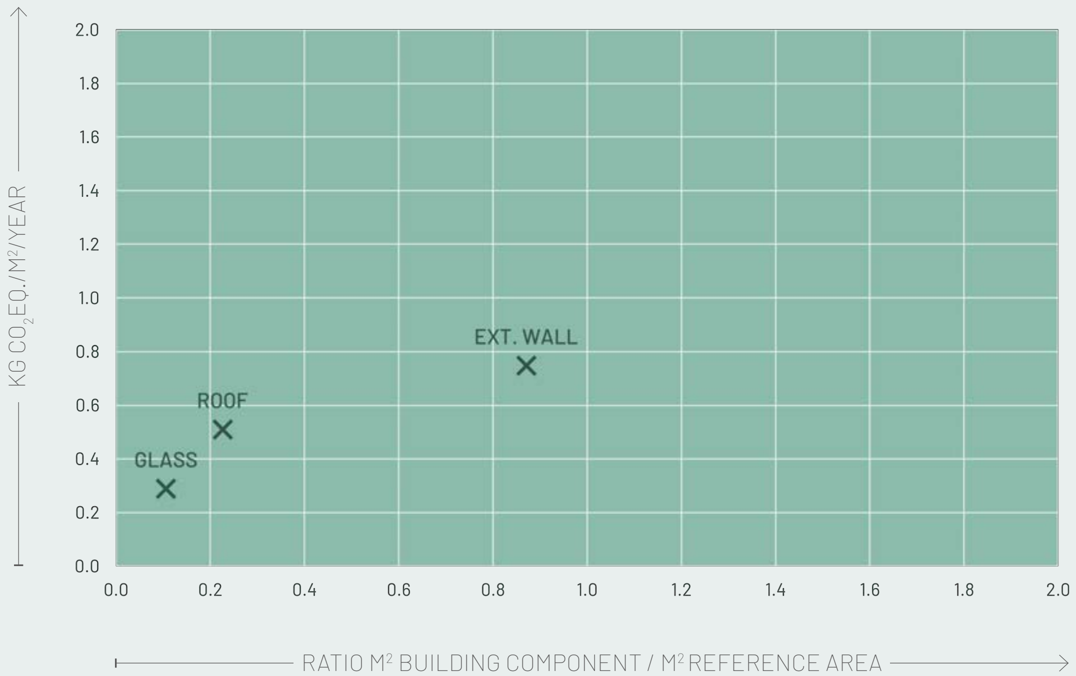



**Figure E03.6: Reduction Roadmap**
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg $CO_2$eq./m$^2$/year, and the 'safe operating space'.

# E03: Store Solvænget

## RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS




## ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

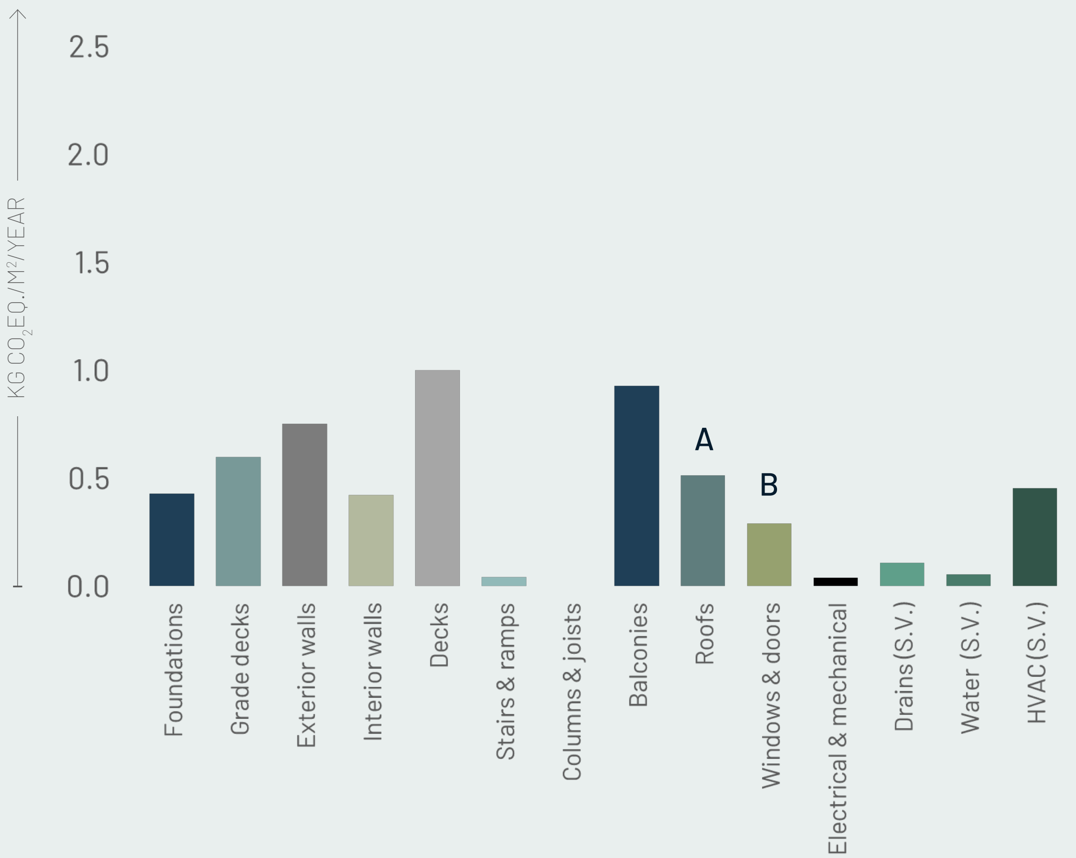



**Figure E03.7: $CO_2$ accounting for building components**
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades,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



# E03: Store Solvænget

## SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

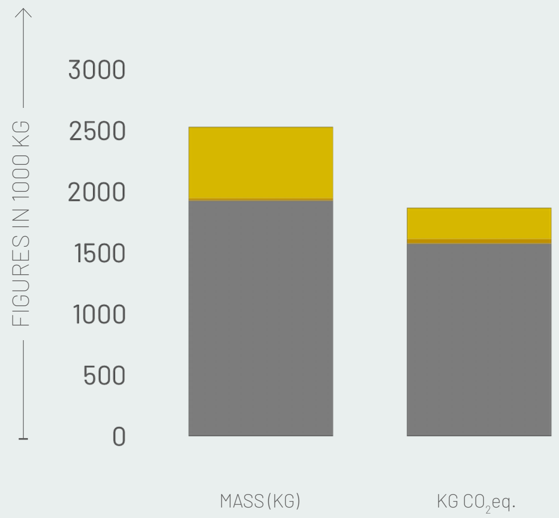
**Figure E03.8:**
The bar chart shows the case study grouped into three material categories: biogenic materials, hybrids, and other materials.

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

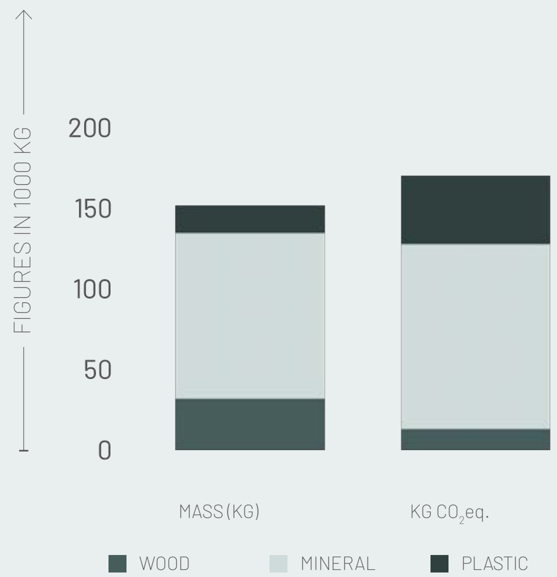
The bar on the left shows the building mass in kg grouped into material categories.

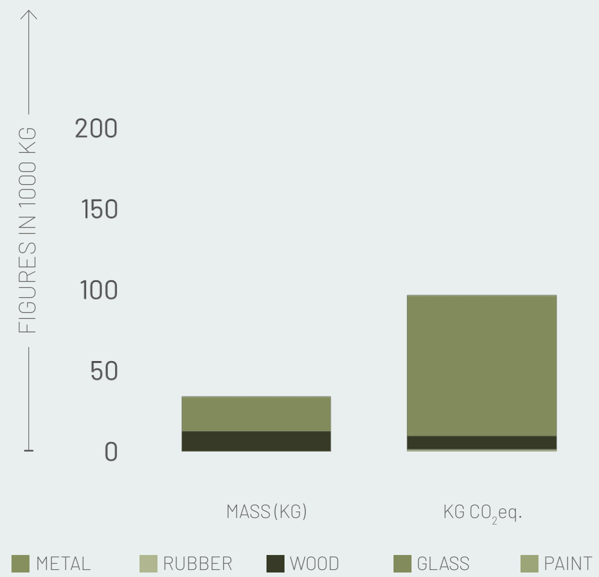
The bar on the right shows the building's total $CO_2$eq grouped similarly.

BIOGENIC MATERIALS | HYBRID MATERIALS | OTHER MATERIALS




## MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG $CO_2$EQ.




### 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

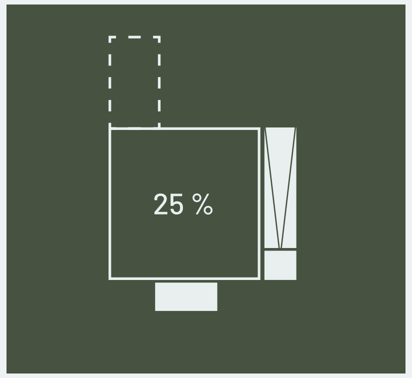
RATIO:

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

# E04: Ibihaven



| | |
|---|---|
| **Developer:** | Tetris A/S |
| **Architect:** | Sangberg |
| **Engineer:** | Artelia<br>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

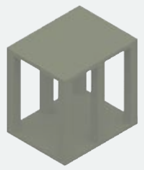
Ibihaven is a cohousing scheme for adults and senior citizens, based on a vision of independence, community, and nature. $CO_2$ emissions and recycling potential governed the choice of materials. A special focal area was to evolve methods which, in future, will meet the client's goal of maximum emissions 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 $CO_2$eq./m²/year


**Figure E04.1: 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 multi-storey housing in the case collection.

1.713.283 kg $CO_2$eq.

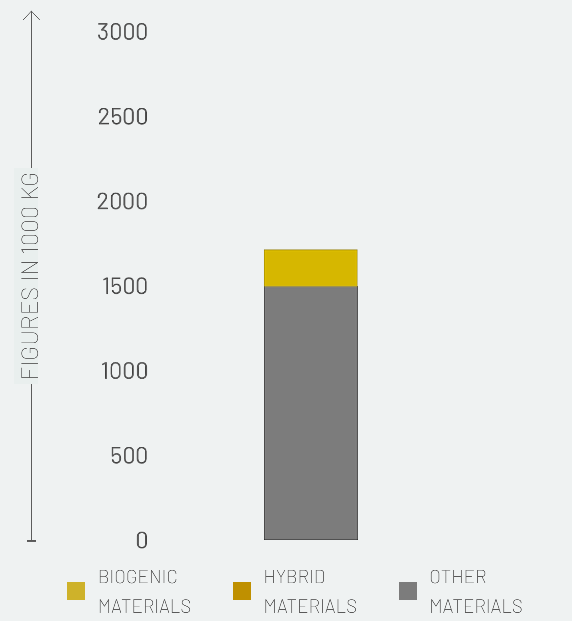



**Figure E04.2: Total emission of kg $CO_2$eq.**
The stacked bar chart shows the overall emission of kg $CO_2$eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

177 kg $CO_2$eq./person/year

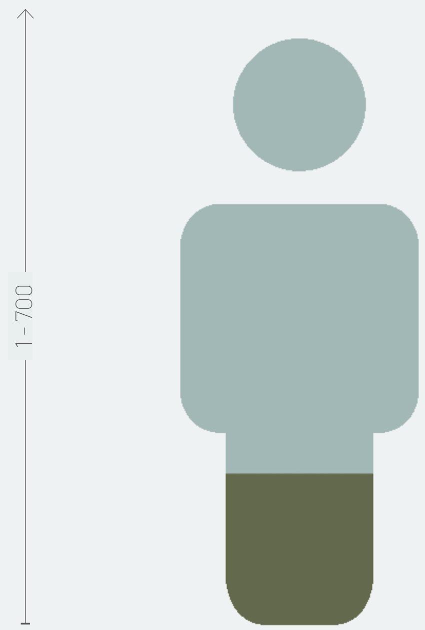



**Figure E04.3: Emissions of kg $CO_2$eq./person/year**
The span of the vertical axis is 1 to 700 kg $CO_2$eq./person/year

26 m²/person

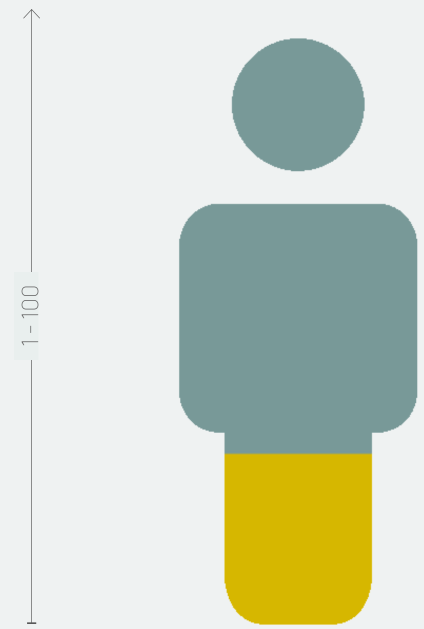



**Figure E04.4: m²/person**
The span of the vertical axis is 1 to 100 m²/person.

# 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 $CO_2$eq./m²/year.

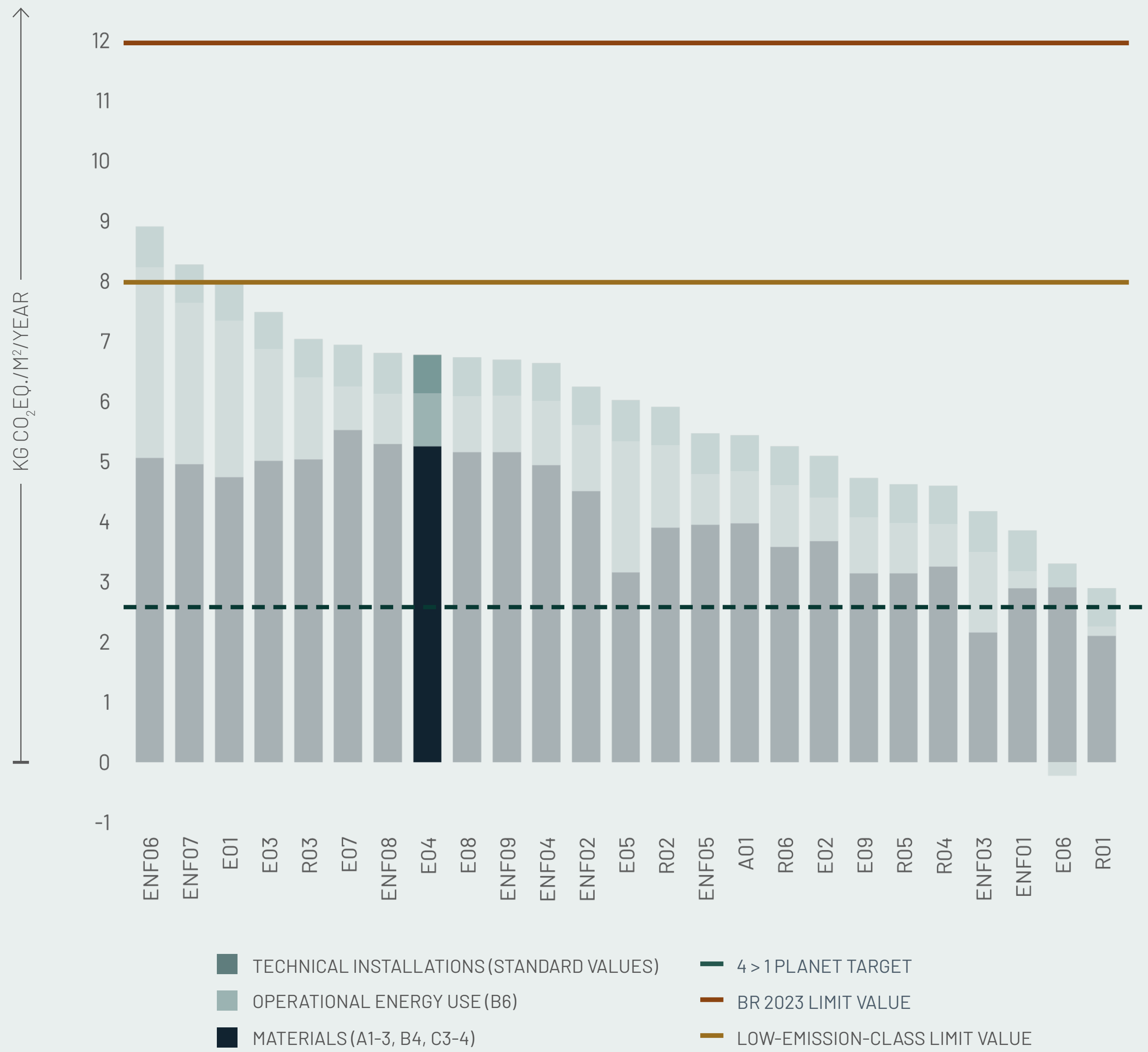



**Figure E04.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.



# E04: Ibihaven

## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in $CO_2$eq./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.

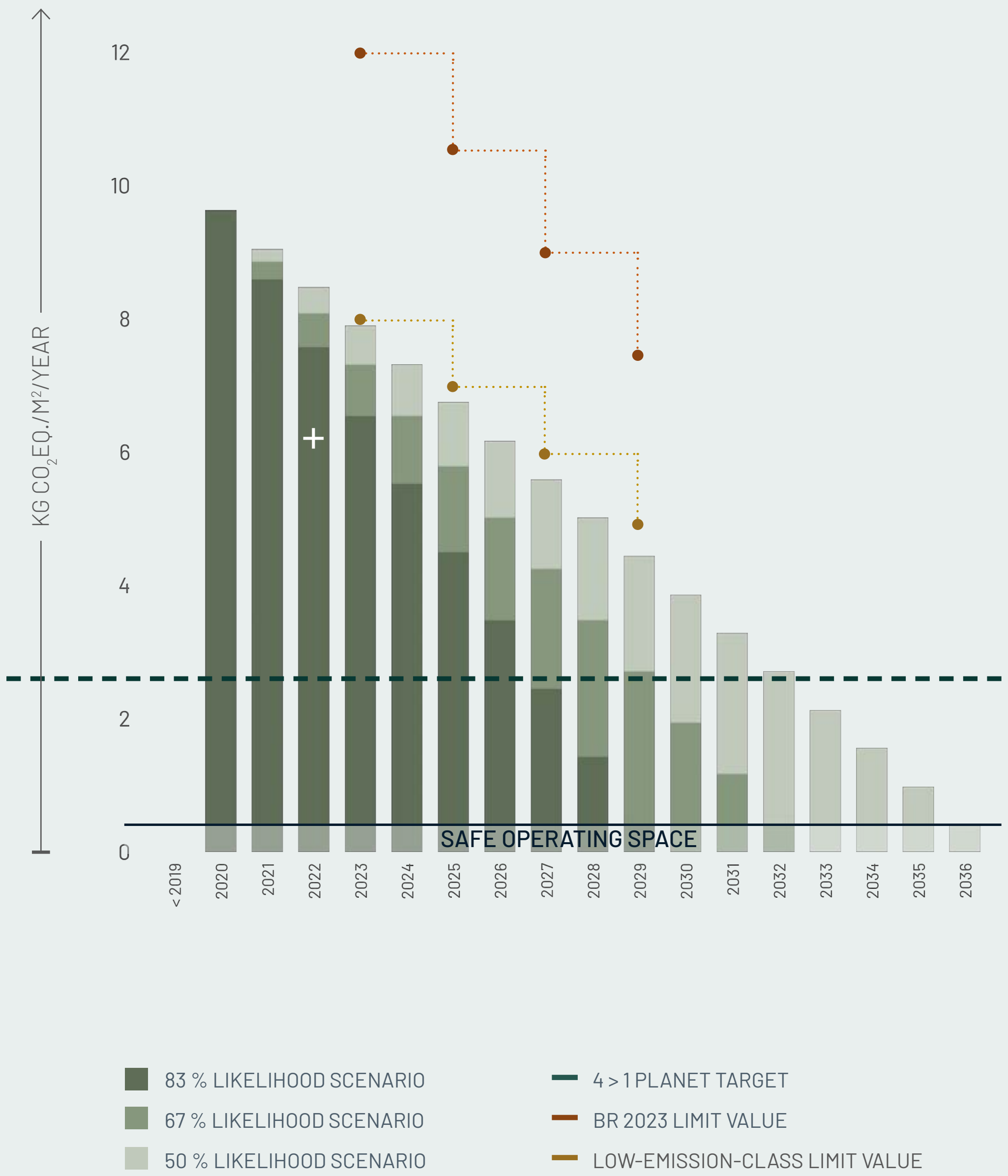
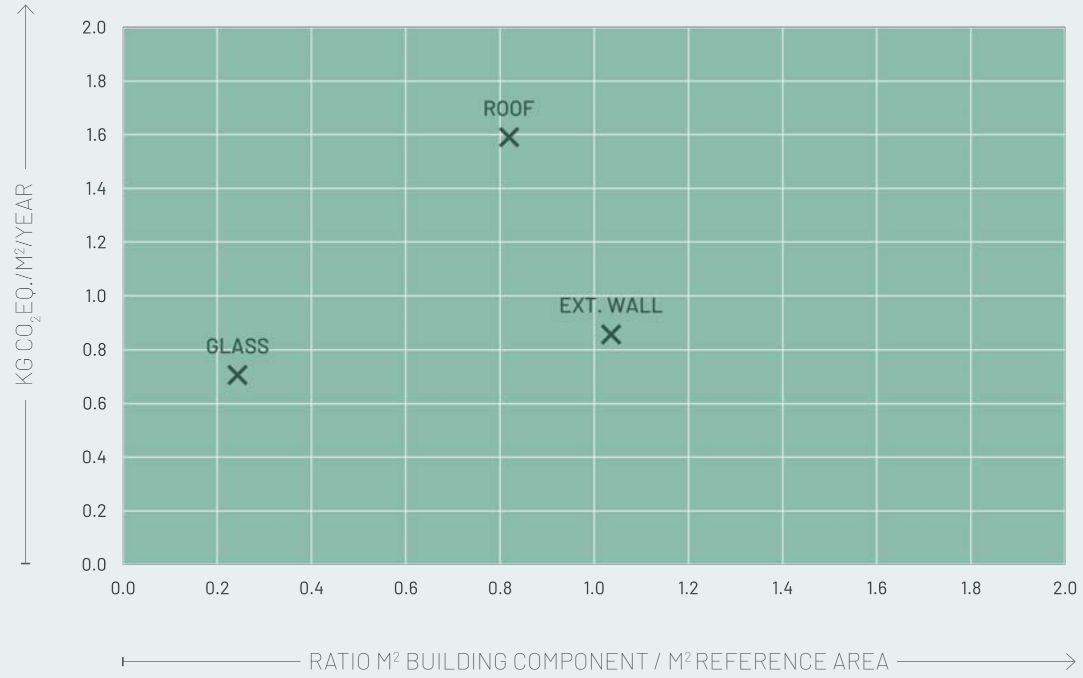



**Figure E04.6: Reduction Roadmap**
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg $CO_2$eq./m²/year, and the 'safe operating space'.

# E04: Ibihaven

## RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS




## ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

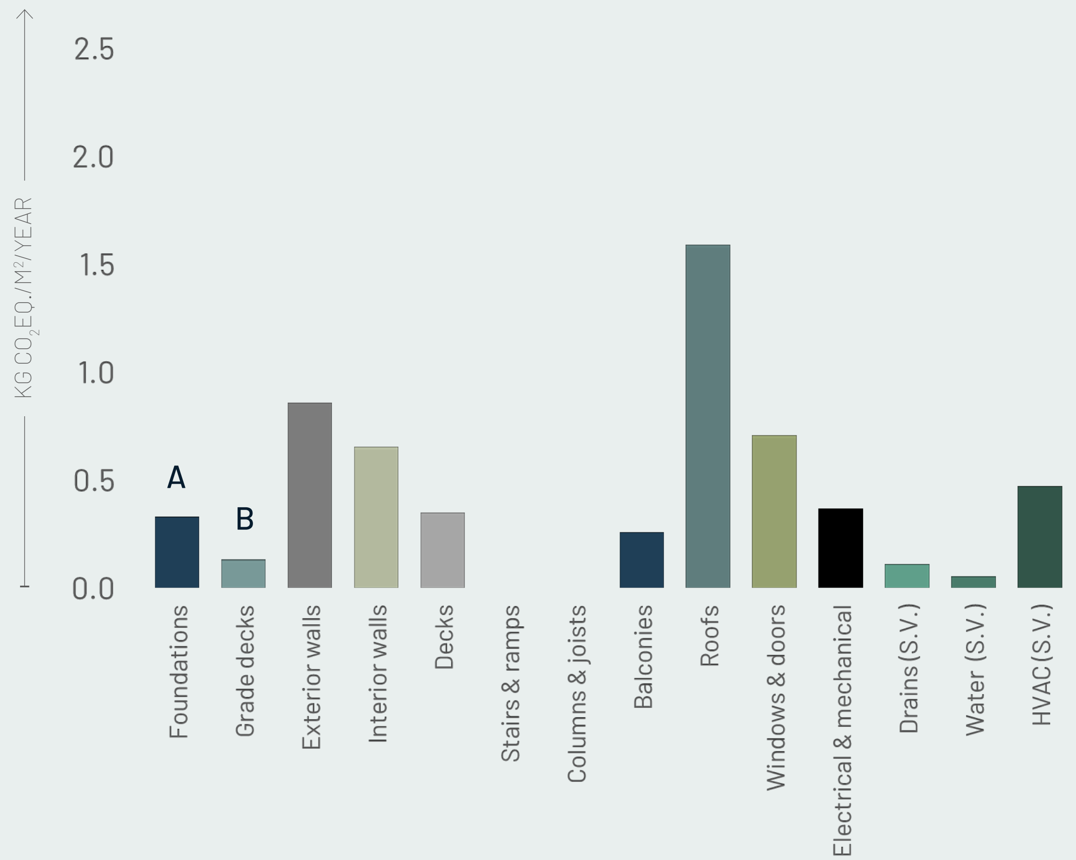



**Figure E04.7: $CO_2$ accounting for building components**
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades,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



# E04: Ibihaven

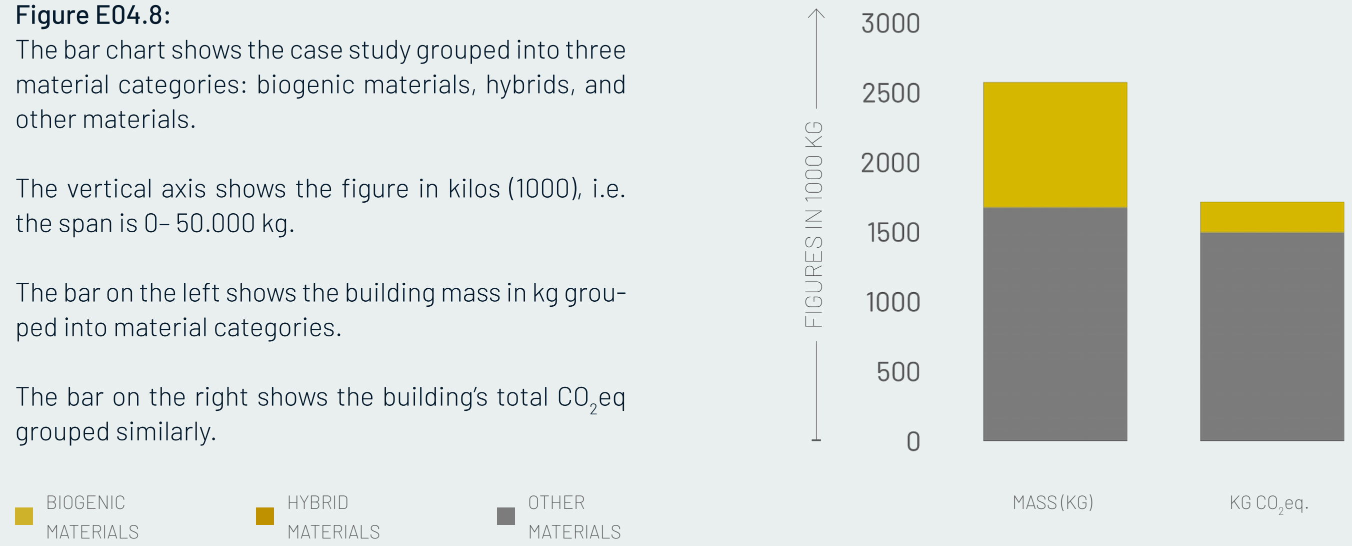
## SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

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

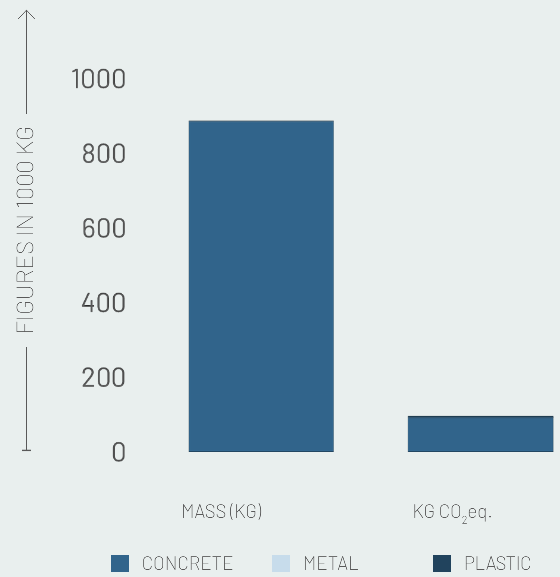
The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

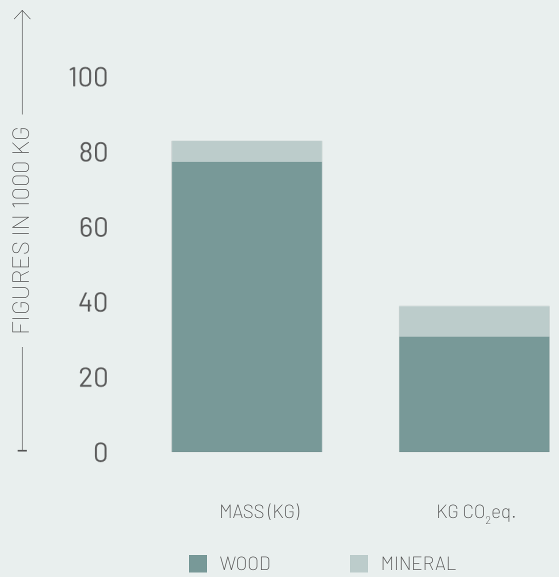
The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total $CO_2$eq grouped similarly.




## MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG $CO_2$EQ.




### A. FOUNDATION

Continuous footing, concrete

152 kg material/m² ref. area

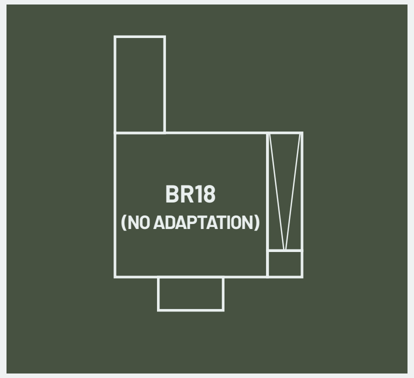
### B. GRADE DECK

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.

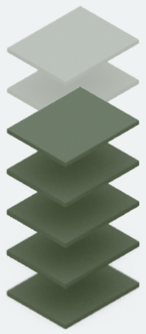
The two-to-four-storey buildings are built on concrete foundations and insulated with PIR with a self-compacting concrete deck insulated with EPS. The cassettes are installed on the grade deck, separated from this by a layer of PIR insulation.

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 $CO_2$eq./$m^2$/year

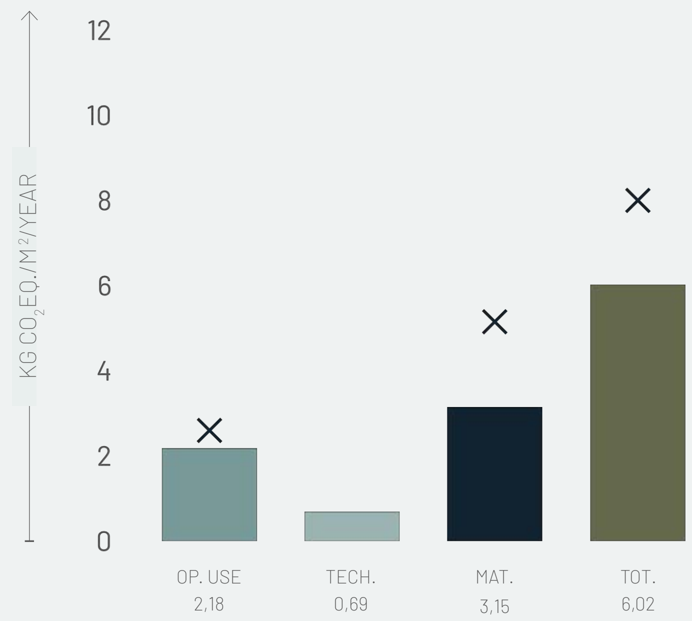



**Figure E05.1: Emissions of kg $CO_2$eq./$m^2$/year**
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg $CO_2$eq./$m^2$/year in multi-storey housing in the case collection.

3.368.417 kg $CO_2$eq.

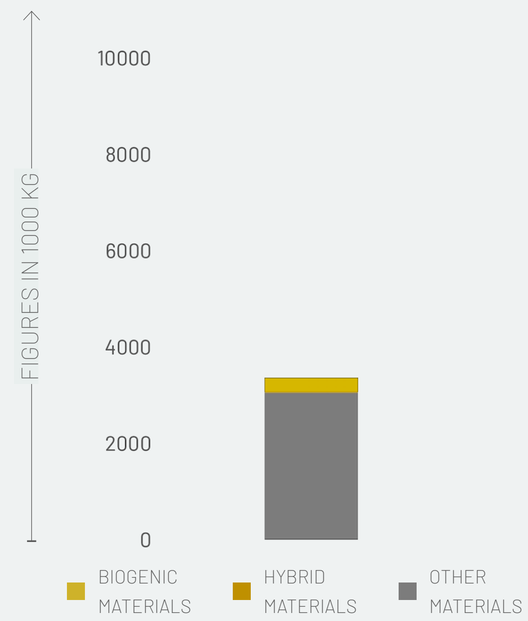



**Figure E05.2: Total emission of kg $CO_2$eq.**
The stacked bar chart shows the overall emission of kg $CO_2$eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

203 kg $CO_2$eq./person/year

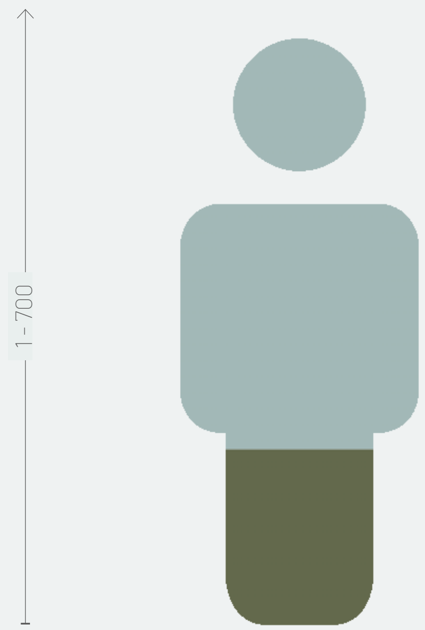



**Figure E05.3: Emissions of kg $CO_2$eq./person/year**
The span of the vertical axis is 1 to 700 kg $CO_2$eq./person/year

34 $m^2$/person

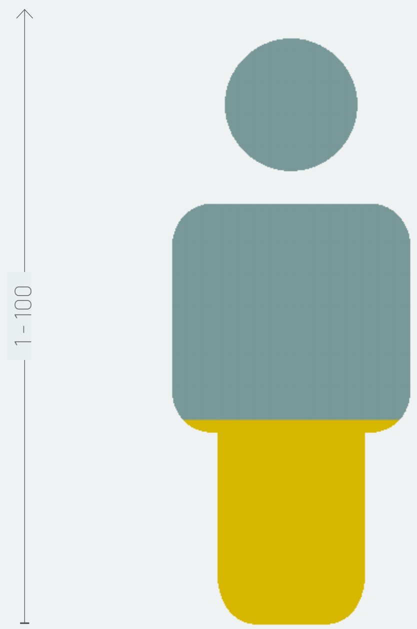



**Figure E05.4: $m^2$/person**
The span of the vertical axis is 1 to 100 $m^2$/person.

# 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 $CO_2$eq./m²/year.

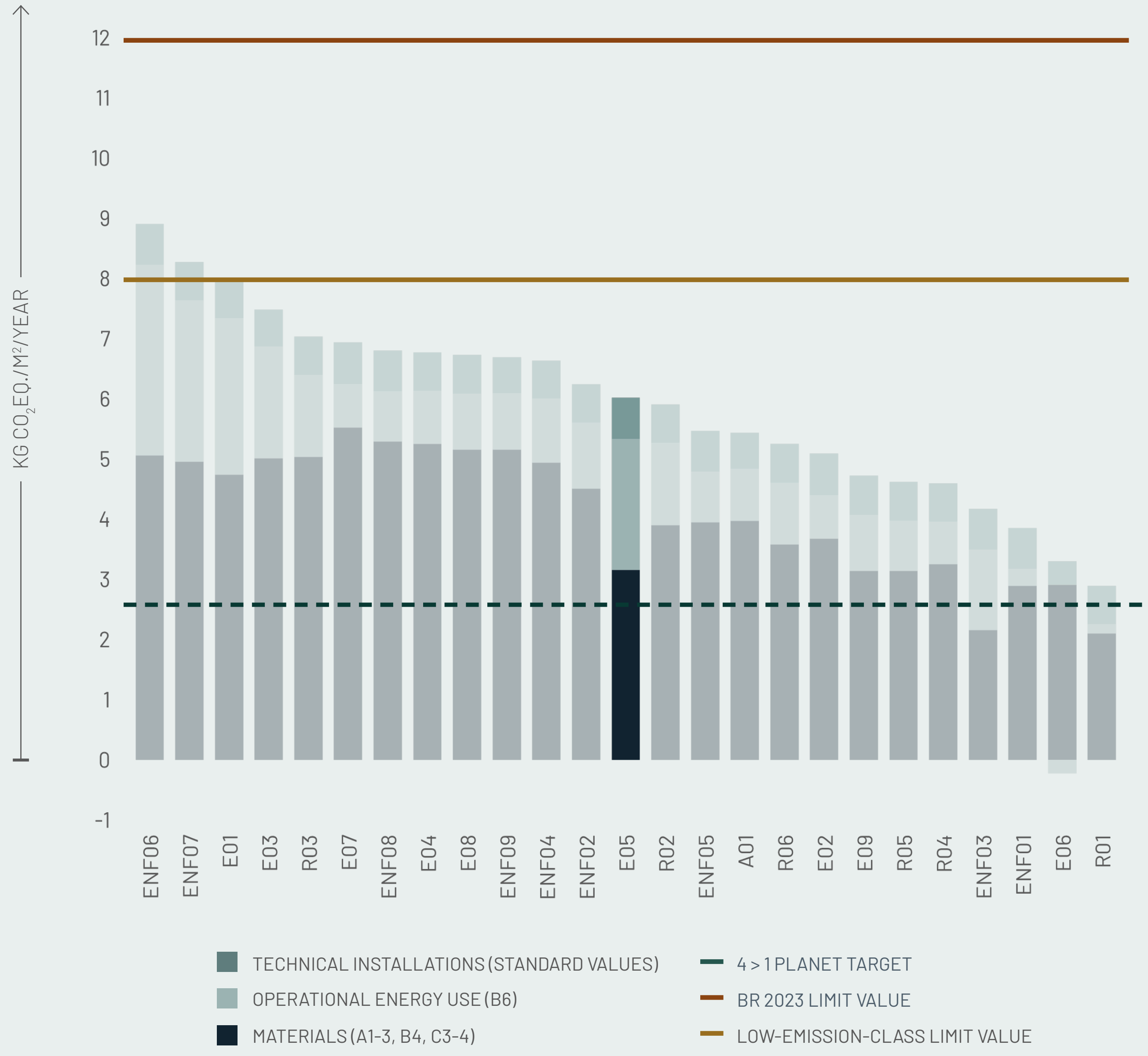



**Figure E05.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.



# E05: Studio [ Home ] Lyngby

## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in $CO_2$eq./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.

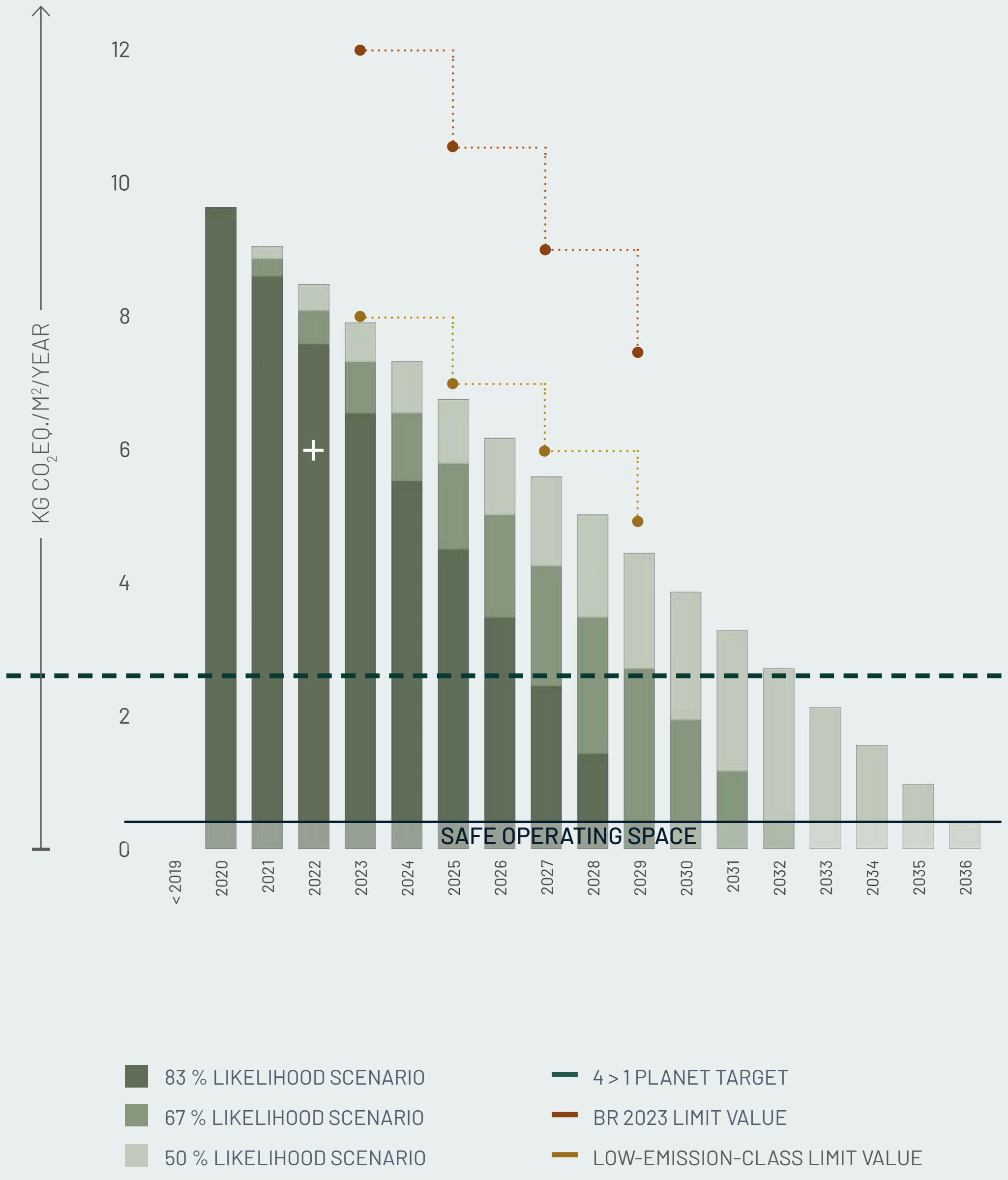
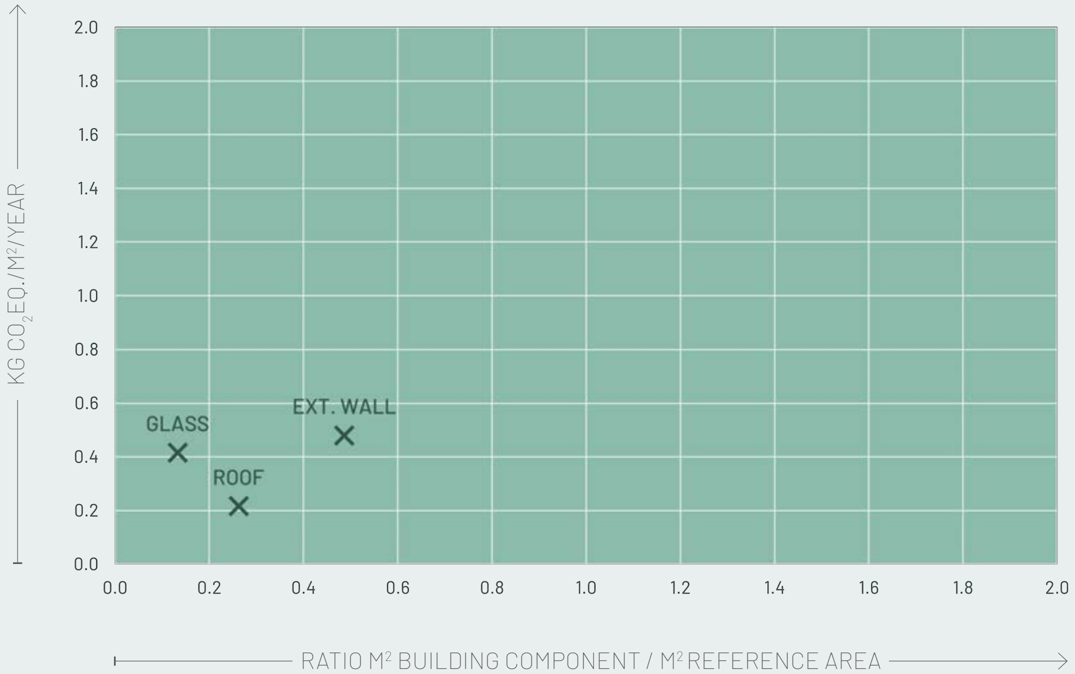



**Figure E05.6: Reduction Roadmap**
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg $CO_2$eq./m²/year, and the 'safe operating space'.

# E05: Studio [Home] Lyngby

## RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS




## ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

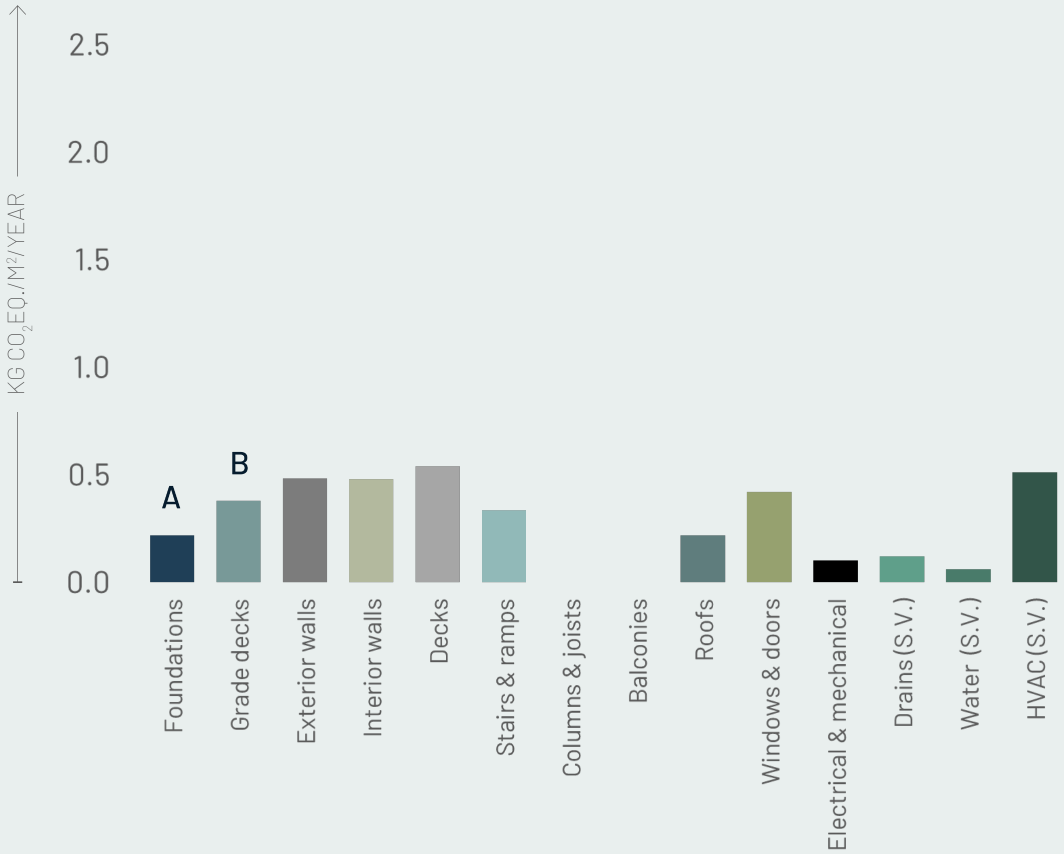



**Figure E05.7: $CO_2$ accounting for building components**
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades,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



# E05: Studio [Home] Lyngby

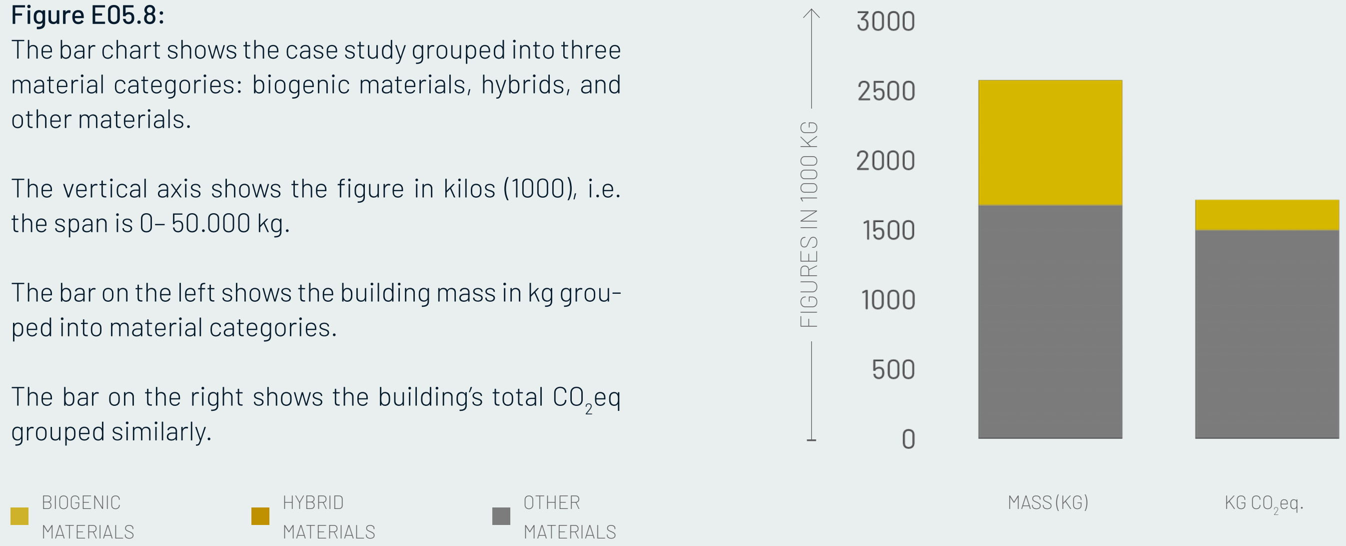
## SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

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

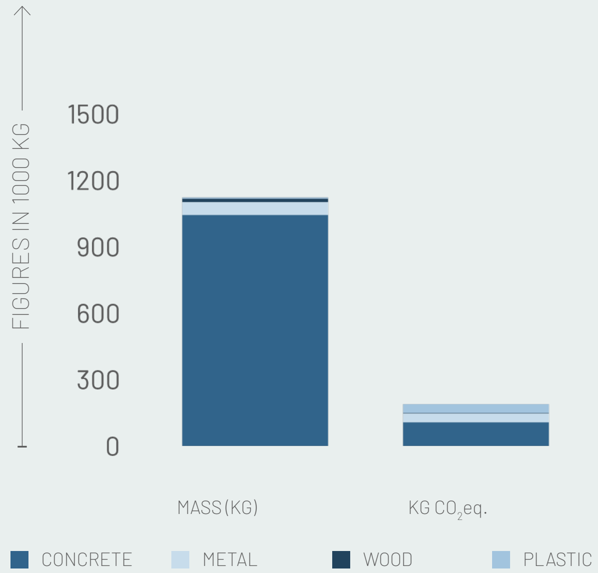
The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

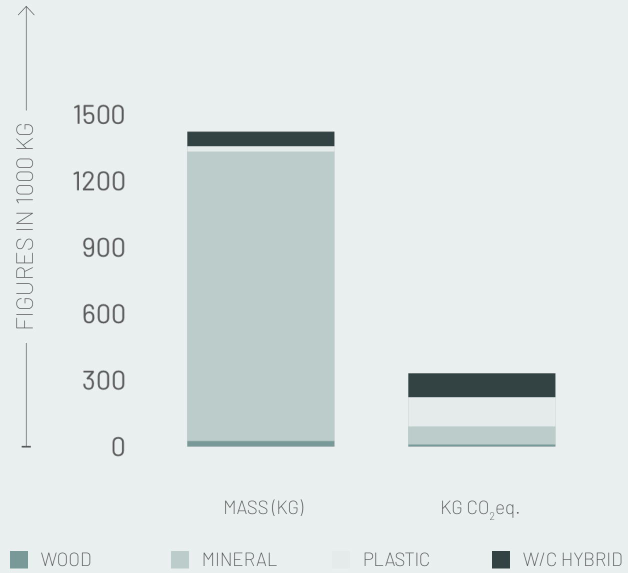
The bar on the left shows the building mass in kg grouped into material categories.

The bar on the right shows the building's total $CO_2$eq grouped similarly.




## MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG $CO_2$EQ.




### A. FOUNDATION

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

64 kg material/m² ref. area

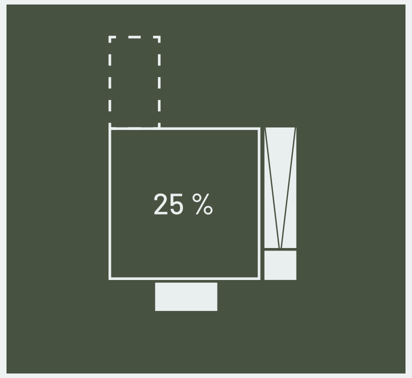
### B. GRADE DECK

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

# E06: Fjordudsigten



| | |
|---|---|
| **Developer:** | Ringkøbing - Skjern Boligforening |
| **Architect:** | BJERG Arkitektur |
| **Year (built):** | 2021 |
| **Floor area:** | 335 $m^2$ |
| **Reference area:** | 343 $m^2$ |
| **Use:** | Residential |
| **Occupants:** | 8 / block |
| **Year (calculated):** | 2022 |
| **Heating:** | Compact system |
| **Solar cells:** | Yes |




## DESCRIPTION

Fjordudsigten is a housing scheme comprising 80 housing units in Ringkøbing K, a new nature-friendly urban area in Ringkøbing. 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. One special focal point was to reduce the need for operational energy in the housing units. Another to reduce the need for operational energy by reducing heating needs.

The housing units follow the Passivhus-plus standard and are designed as highly insulated and compact units with small surface areas to minimise heat loss. The position of windows was also an important parameter for optimal use of heat from solar inflow and daylight. Emissions are further reduced by using a so-called compact system.

The two-to-three-storey buildings are built on foundations of lightweight aggregate blocks with EPS insulation with a grade deck hybrid of concrete and timber with EPS insulation.

The housing is constructed in prefabricated modules, supporting structures in timber, and insulated with glass wool. Slate and timber-clad facades.

The case is a pixie case due to not having standard values for technical installations. Thereby, having other conditions for the environmantal assessment than the other projects in this report.

The analysed housing block totals 335 $m^2$ with room for 8 occupants, which gives a space allocation of approx. 42 $m^2$/person. This is on the high side in the case collection.

Cassette

2 storeys





# E06: Fjordudsigten

3,3 kg $CO_2$eq./$m^2$/year

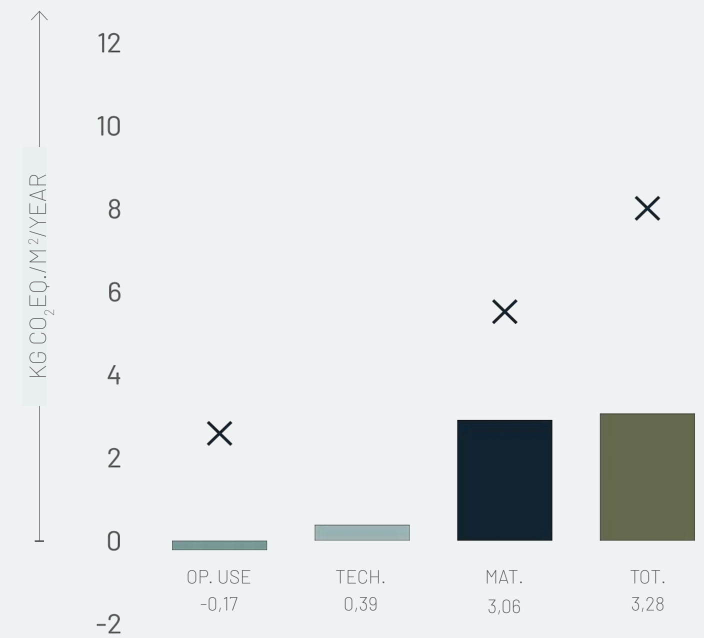



**Figure E06.1: Emissions of kg $CO_2$eq./$m^2$/year**
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg $CO_2$eq./$m^2$/year in multi-storey housing in the case collection.

56.252 kg $CO_2$eq.

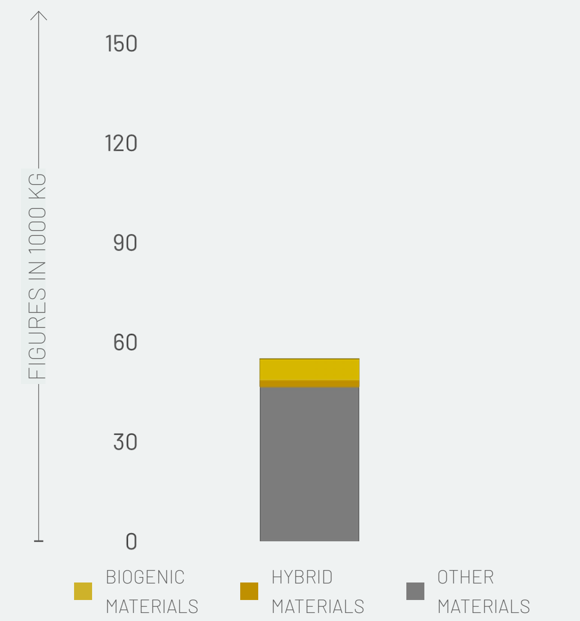



**Figure E06.2: Total emission of kg $CO_2$eq.**
The stacked bar chart shows the overall emission of kg $CO_2$eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

128 kg $CO_2$eq./person/year

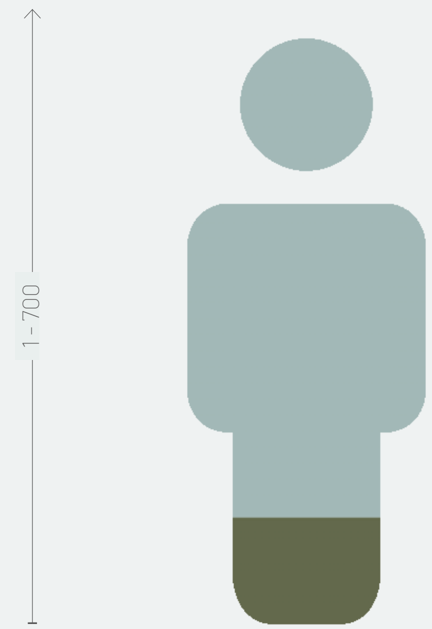



**Figure E06.3: Emissions of kg $CO_2$eq./person/year**
The span of the vertical axis is 1 to 700 kg $CO_2$eq./person/year

42 $m^2$/person

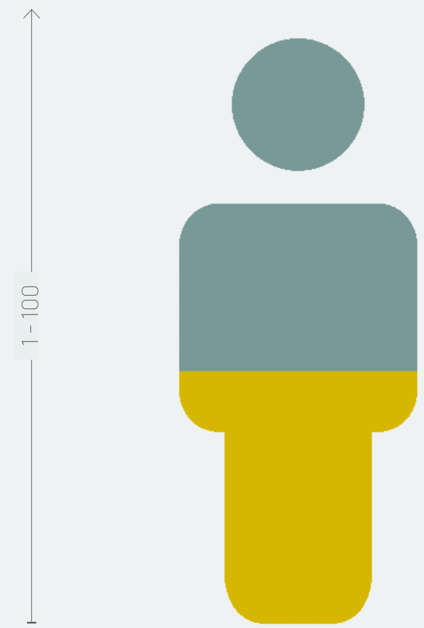



**Figure E06.4: $m^2$/person**
The span of the vertical axis is 1 to 100 $m^2$/person.

## 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 $CO_2$eq./m²/year.

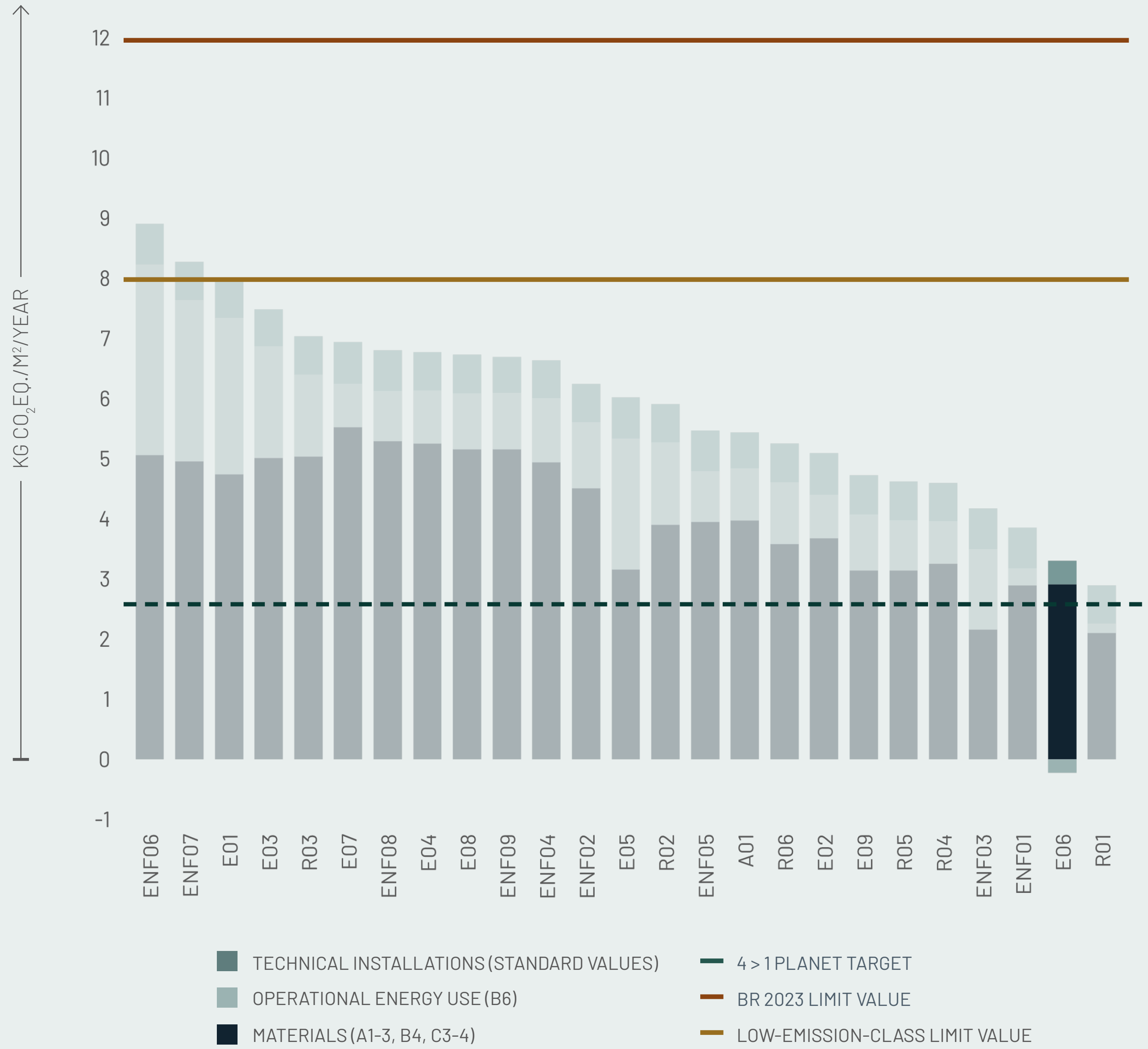



**Figure E06.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.



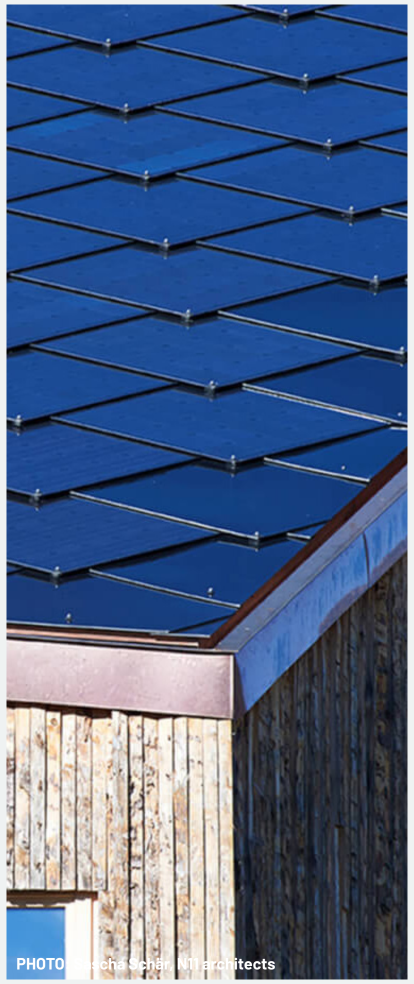


## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

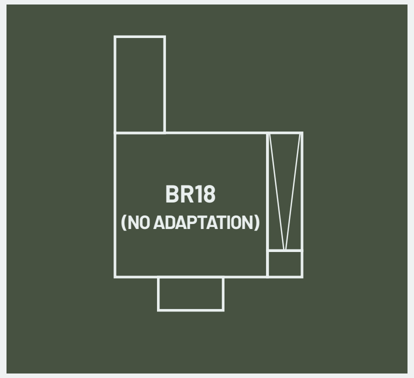
Environmental impact is shown in $CO_2$eq./m²/year. The life-cycle assessment is based on 2022 as the year of occupancy and the case findings are represented by a white plus sign. The diagram shows the position of this case study in relation to the Reduction Roadmap, where it is well within the fastest reduction rate: the 83% likelihood scenario.


**Figure E06.6: Reduction Roadmap**
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg $CO_2$eq./m²/year, and the 'safe operating space'.

# 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

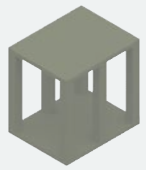
## DESCRIPTION

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.

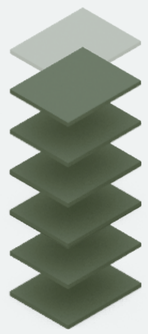
The five-storey building is built on a reinforced concrete foundation slab with a stamped clay surface. The house is built with supporting structures of glulam columns and CLT. Storey partitions are concrete and timber composites with flax insulation and anhydrite cladding. The sloping roof and exterior 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 $CO_2$eq./m²/year

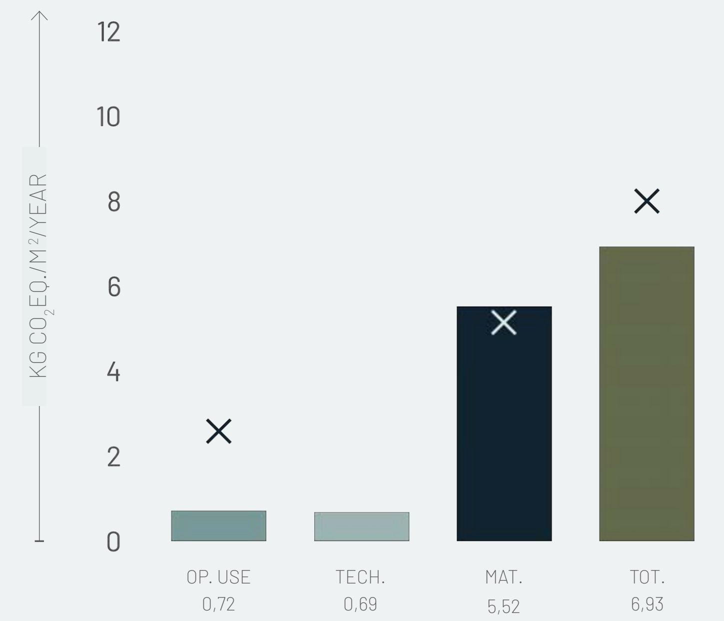



**Figure E07.1: Emissions of kg $CO_2$eq./m²/year**
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg $CO_2$eq./m²/year in multi-storey housing in the case collection. This case has the case collection's highest emissions of kg $CO_2$eq./m²/year from materials, but as it is an international case, it is not used as reference (X).

166.481 kg $CO_2$eq.

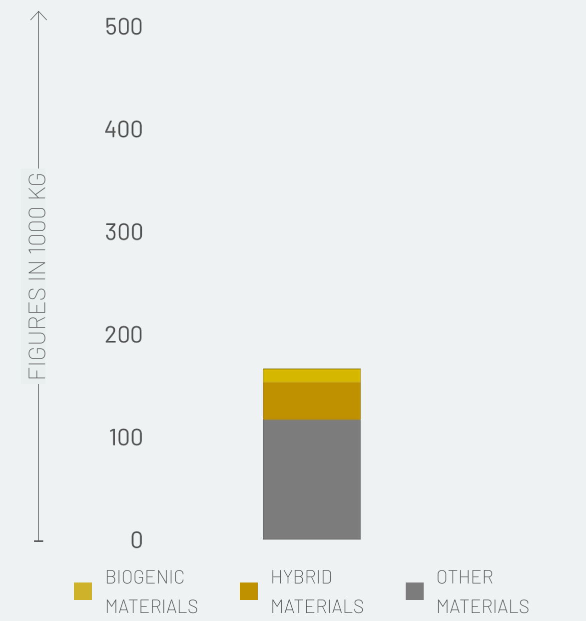



**Figure E07.2: Total emission of kg $CO_2$eq.**
The stacked bar chart shows the overall emission of kg $CO_2$eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

676 kg $CO_2$eq./person/year

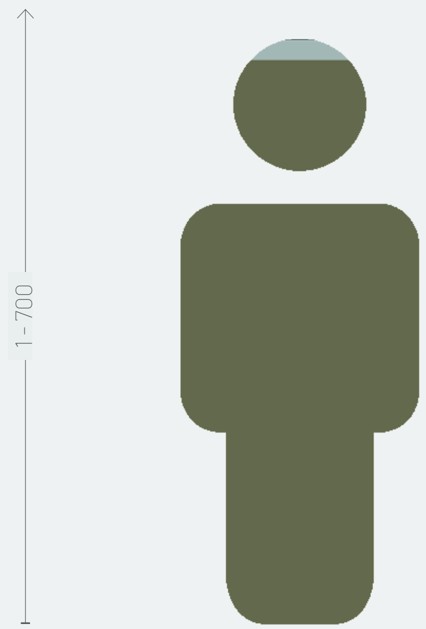



**Figure E07.3: Emissions of kg $CO_2$eq./person/year**
The span of the vertical axis is 1 to 700 kg $CO_2$eq./person /year

45 - 98 m²/person

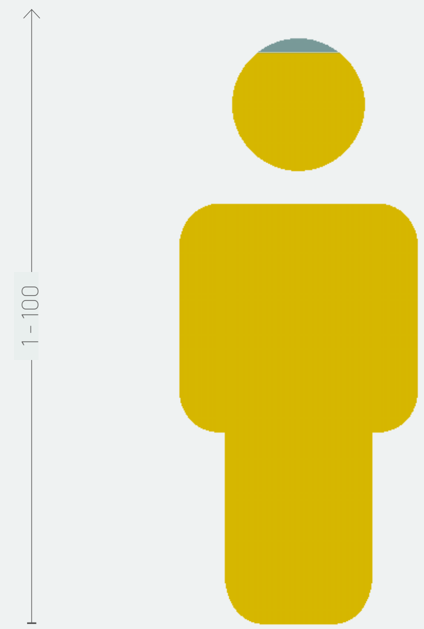



**Figure E07.4: m²/person**
The span of the vertical axis is 1 to 100 m²/person.

# 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 $CO_2$eq./m²/year.

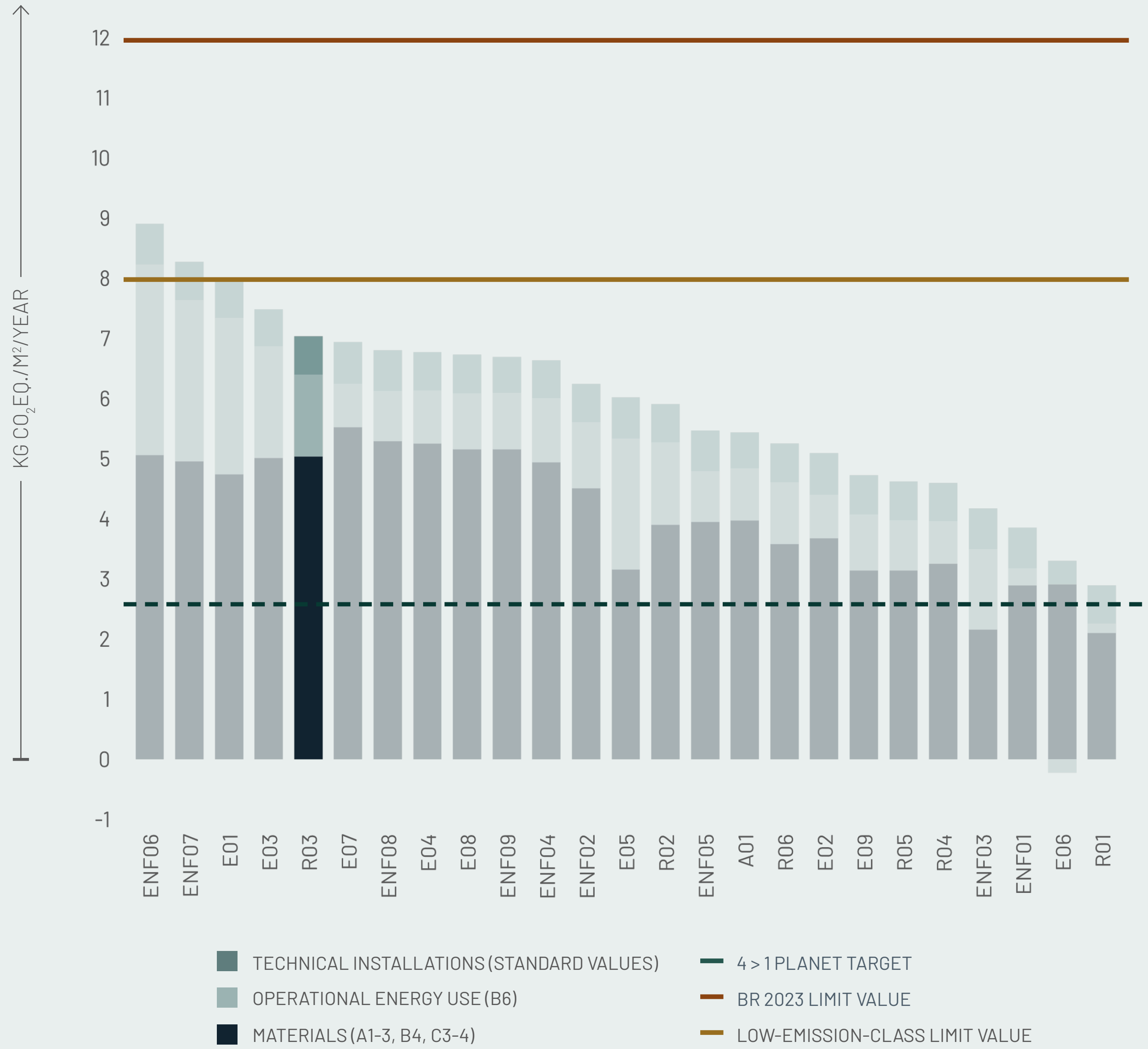



**Figure E07.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.

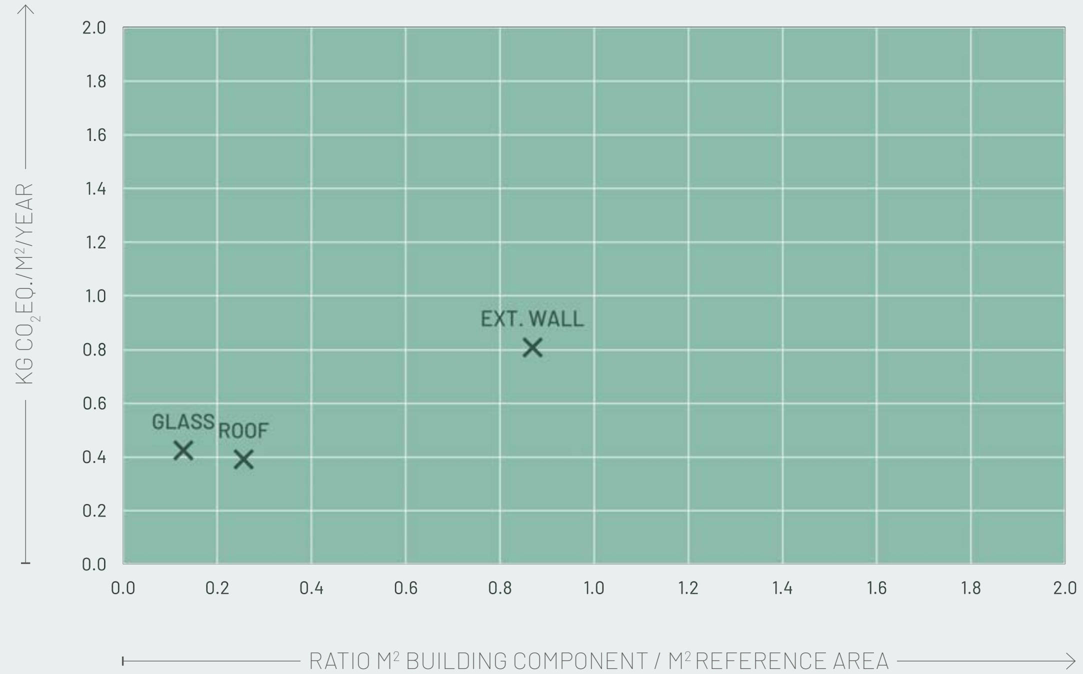
# E07: N11 SolarHouse

## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in $CO_2$eq./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 $CO_2$eq./m²/year, and the 'safe operating space'.

## RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS




## ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

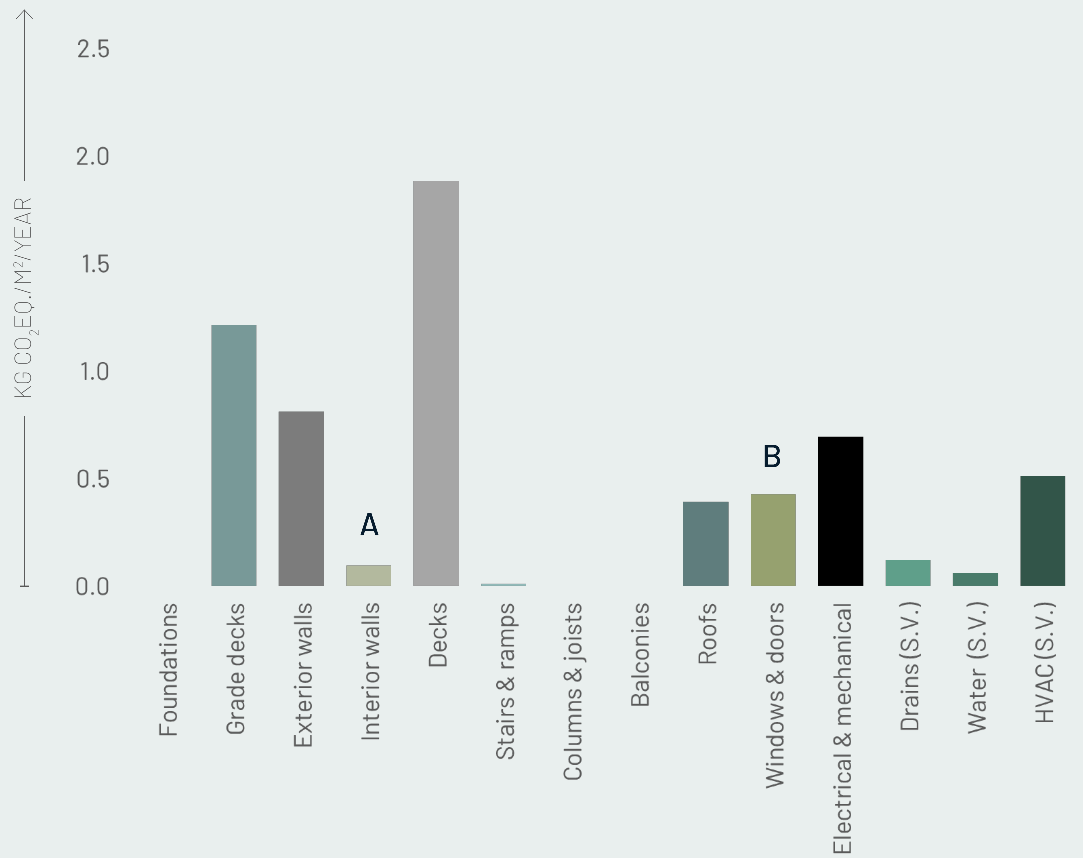



**Figure E07.7: $CO_2$ accounting for building components**
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades,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



E07: N11 SolarHouse

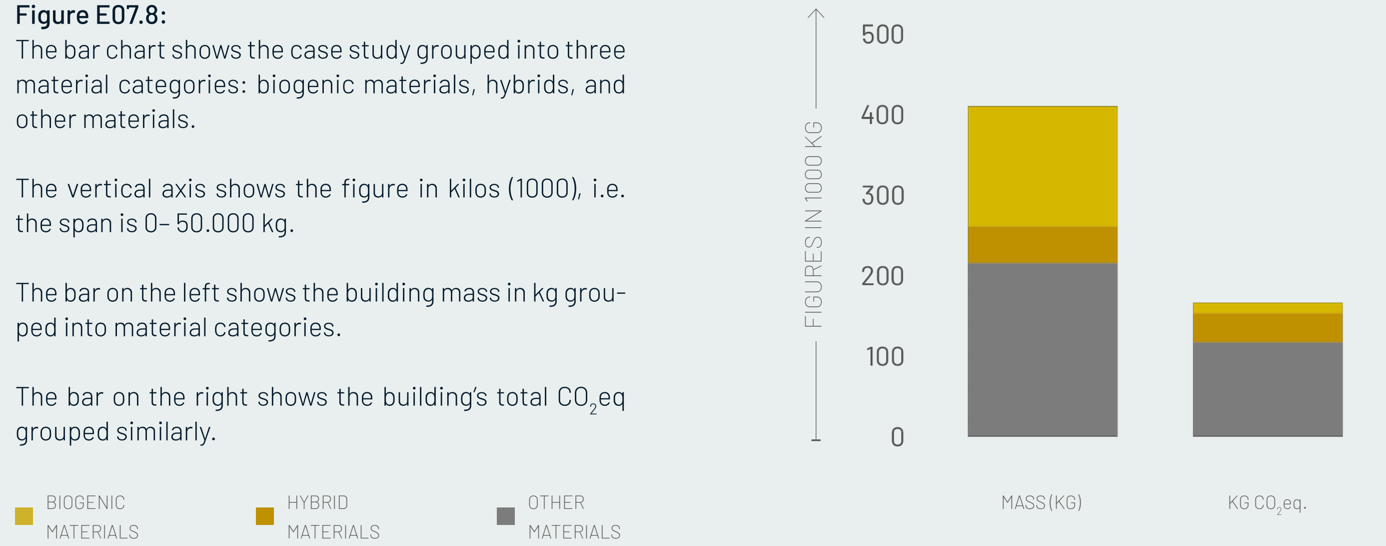
## SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

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

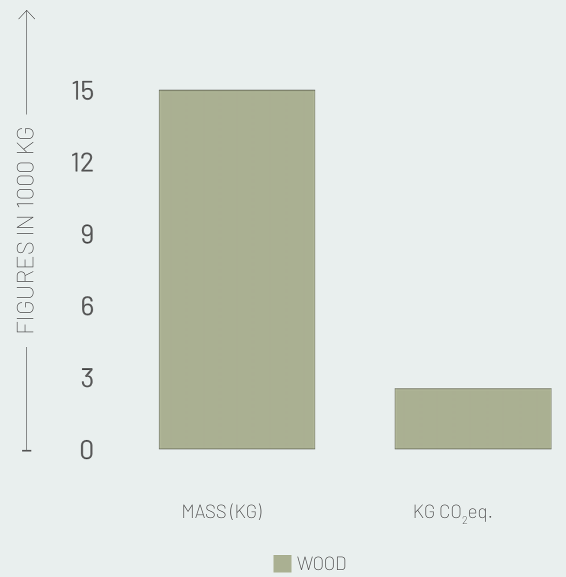
The vertical axis shows the figure in kilos (1000), i.e. the span is 0– 50.000 kg.

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 $CO_2$eq grouped similarly.

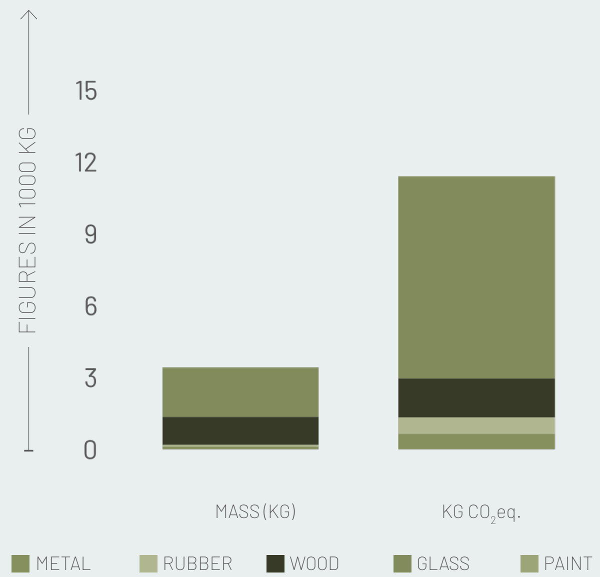



## MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG $CO_2$EQ.




### A. INTERIOR WALLS

CLT, load bearing
CLT, non-load bearing




### B. WINDOWS AND DOORS

CONSTRUCTION:

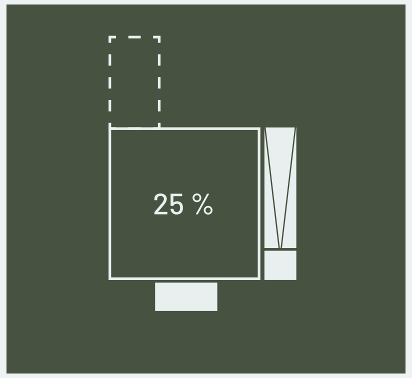
Window in wooden frame (triple glazing)
Wooden door, inside
Aluminium door, outside

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 $CO_2$eq./m²/year


**Figure E08.1: 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 multi-storey housing in the case collection.

### 44.797 kg $CO_2$eq.

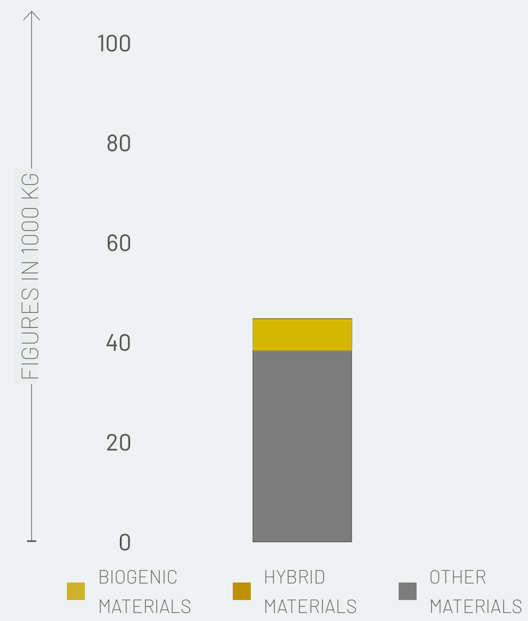



**Figure E08.2: Total emission of kg $CO_2$eq.**
The stacked bar chart shows the overall emission of kg $CO_2$eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

### 130 kg $CO_2$eq./person/year

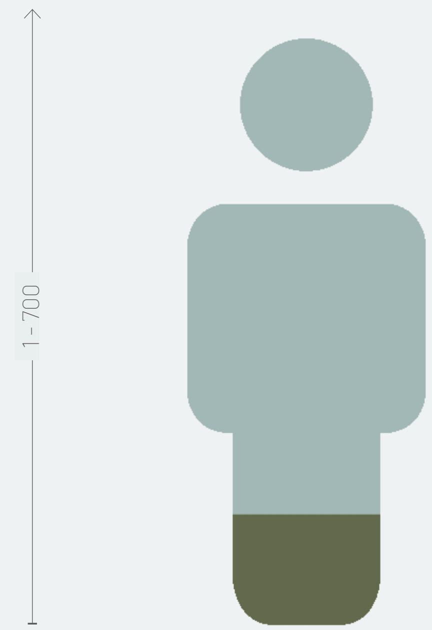



**Figure E08.3: Emissions of kg $CO_2$eq./person/year**
The span of the vertical axis is 1 to 700 kg $CO_2$eq./person/year

### 18 - 37 m²/person

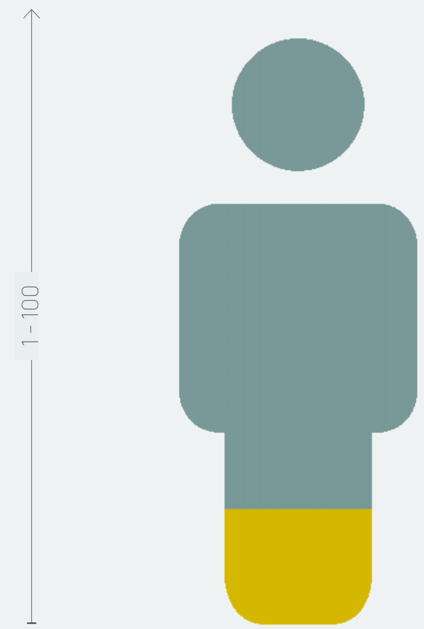



**Figure E08.4: m²/person**
The span of the vertical axis is 1 to 100 m²/person.

# 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 $CO_2$eq./m²/year.

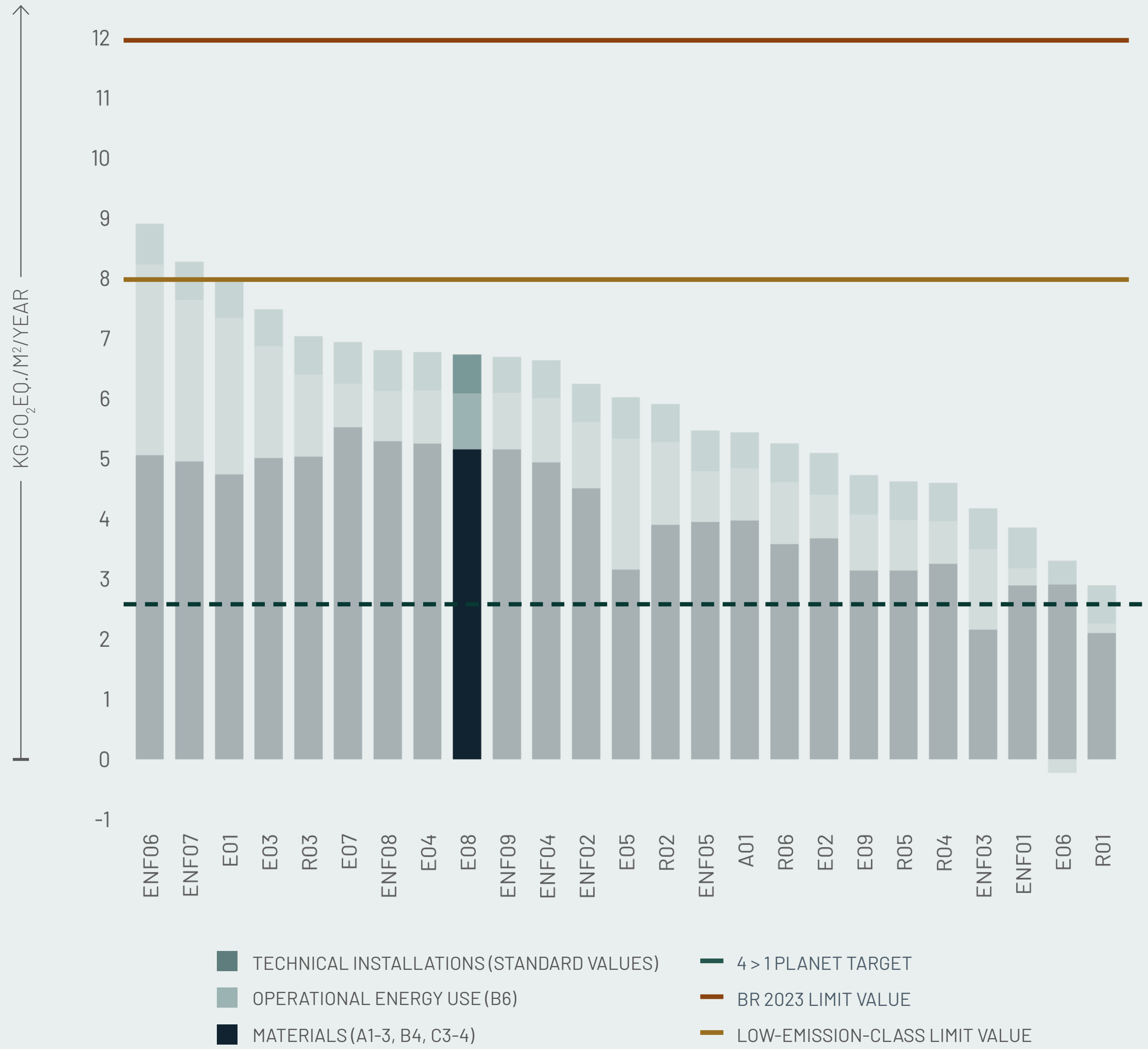



**Figure E08.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.



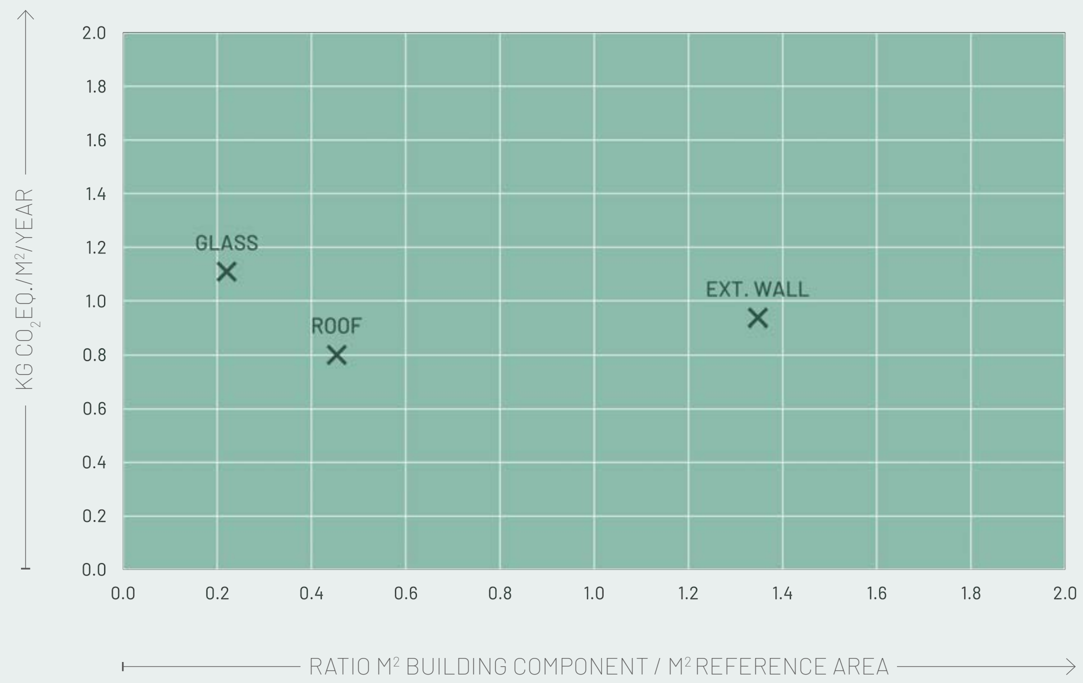
# E08: CPH Village Vesterbro

## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in $CO_2$eq./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 $CO_2$eq./m²/year, and the 'safe operating space'.

## RATIO AND ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS




## ENVIRONMENTAL IMPACT OF BUILDING COMPONENTS

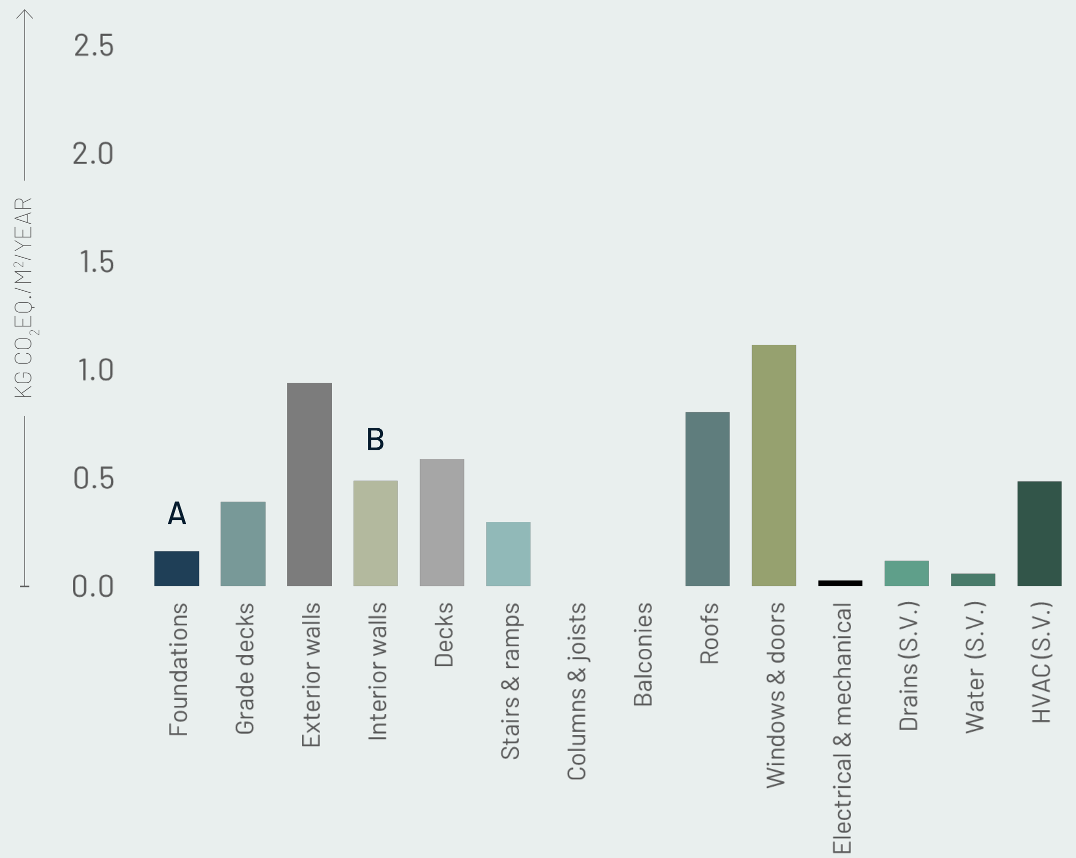



**Figure E08.7: $CO_2$ accounting for building components**
The horizontal axis shows the most central building components, including foundations, grade deck, exterior walls, interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows and glass facades,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





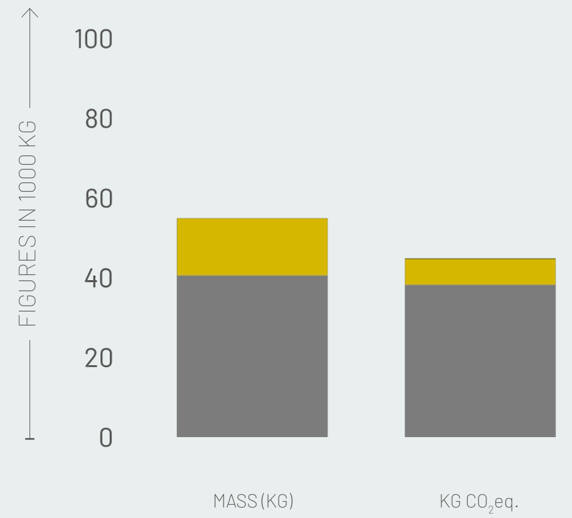
## SHARE OF BIOGENIC MATERIALS: MASS VS. ENVIRONMENTAL IMPACT

**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.

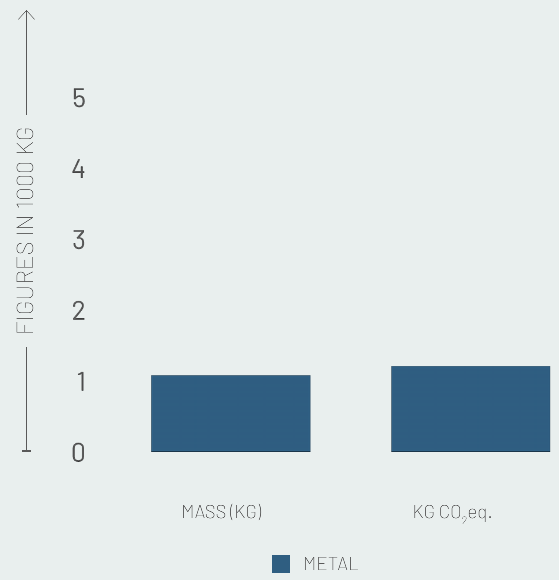
The bar on the left shows the building mass in kg grouped into material categories.

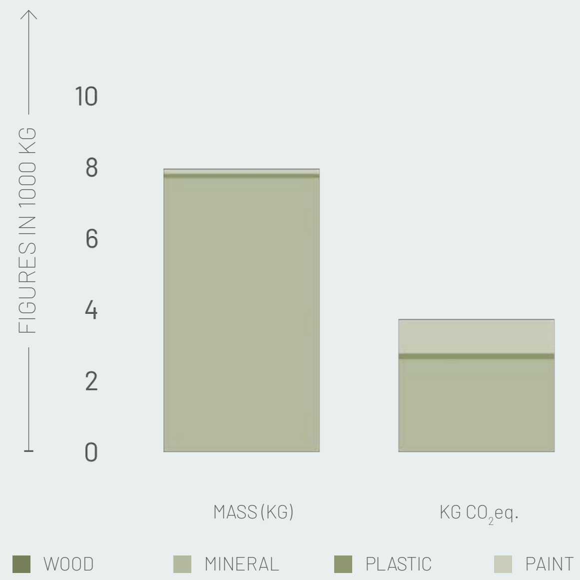
The bar on the right shows the building's total $CO_2$eq grouped similarly.




BIOGENIC MATERIALS    HYBRID MATERIALS    OTHER MATERIALS

## MATERIAL MASS VS. TOTAL MATERIAL EMISSIONS OF KG $CO_2$EQ.




### A. FOUNDATION

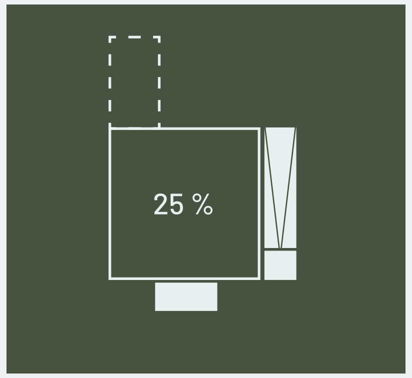
Steel screw-pile foundations

### 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





4,72 kg $CO_2$eq./m²/year

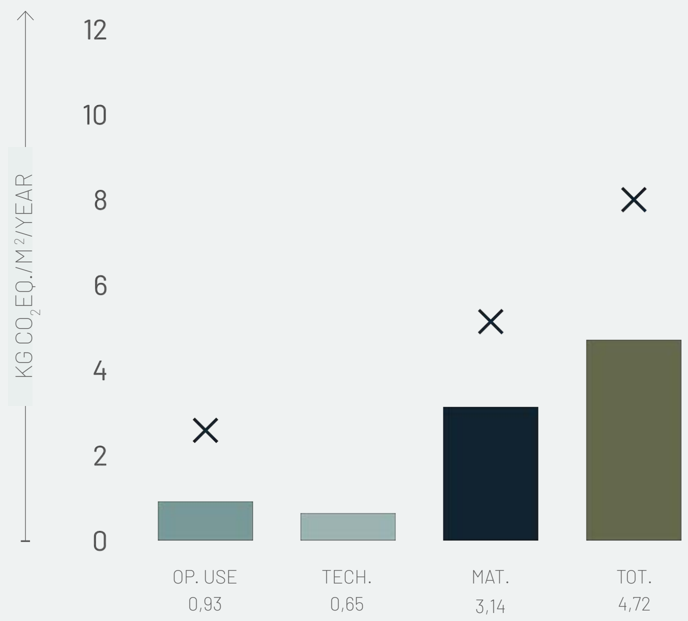



**Figure E09.1: Emissions of kg $CO_2$eq./m²/year**
The bars show the building's environmental impact. Crosses indicate the highest result for operational use, materials, and total emissions of kg $CO_2$eq./m²/year in multi-storey housing in the case collection.

29.282 kg $CO_2$eq.

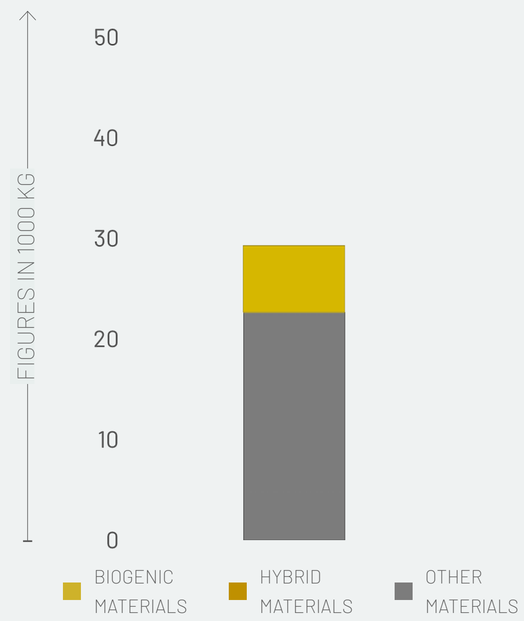



**Figure E09.2: Total emission of kg $CO_2$eq.**
The stacked bar chart shows the overall emission of kg $CO_2$eq in the case study grouped into the three material categories: other, hybrids, and biogenic.

91 kg $CO_2$eq./person/year

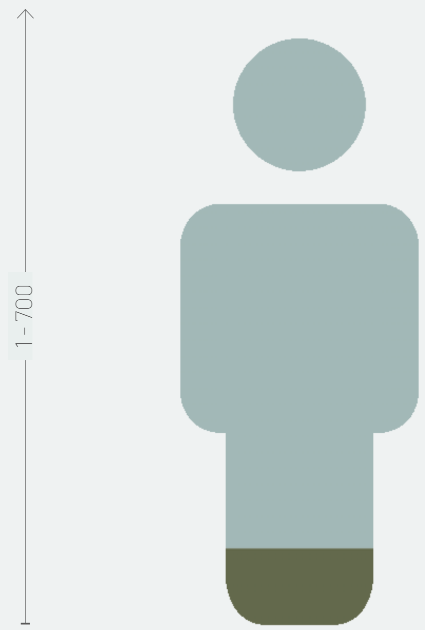



**Figure E09.3: Emissions of kg $CO_2$eq./person/year**
The span of the vertical axis is 1 to 700 kg $CO_2$eq./person/year

18 - 37 m²/person

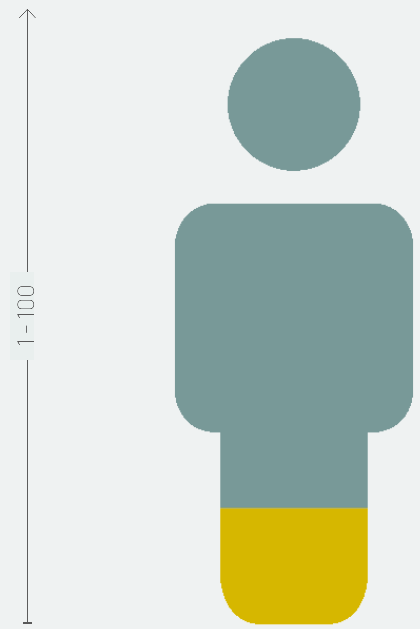



**Figure E09.4: m²/person**
The span of the vertical axis is 1 to 100 m²/person.

## 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 $CO_2$eq./m²/year.

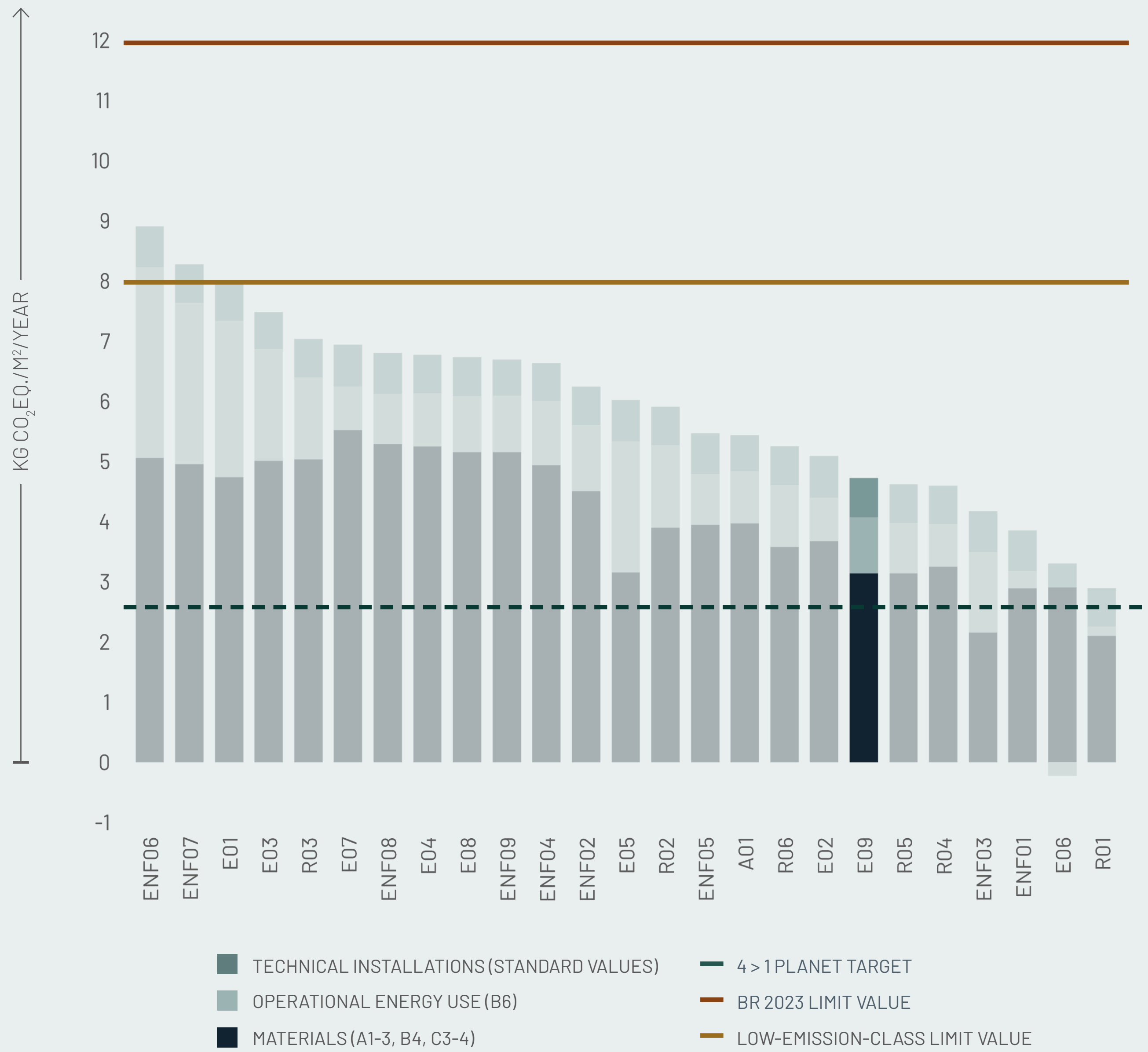



**Figure E09.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.



E09: CPH Village Tunnelfabrikken PIXIE CASE

## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in $CO_2$eq./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.

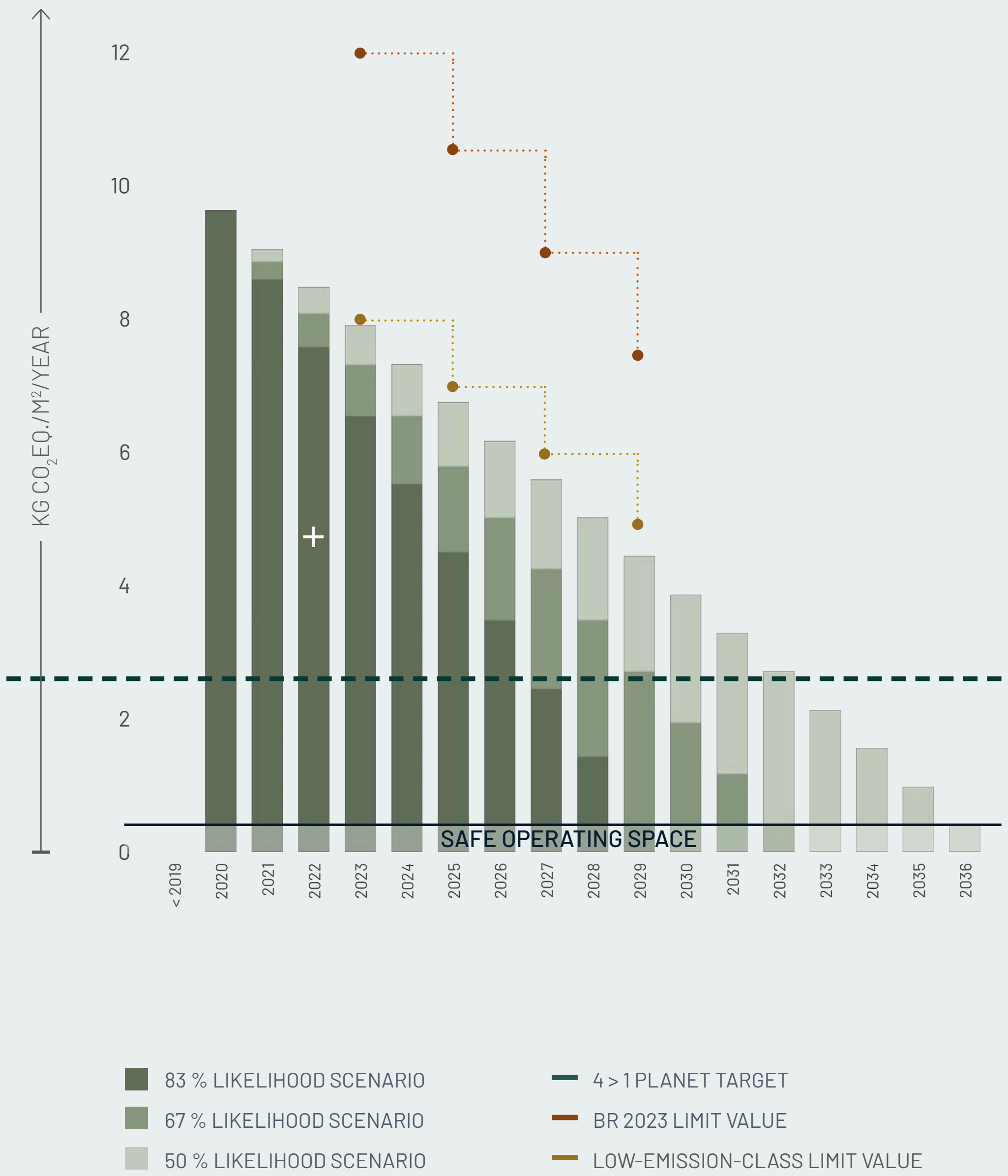
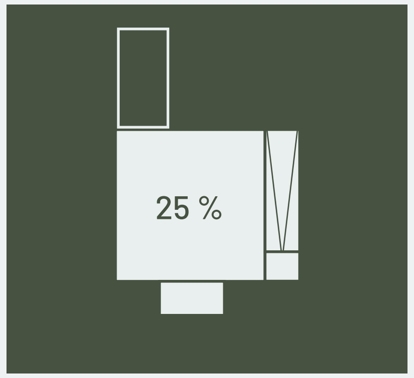



**Figure E09.6: Reduction Roadmap**
The case study in relation to the Reduction Roadmap, limit values, the 4 to 1 planet goal of 2.5 kg $CO_2$eq./m²/year, and the 'safe operating space'.


**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 m²
**Reference area:** 162 m²
**Occupants:** 4
(calc. as single-family house)





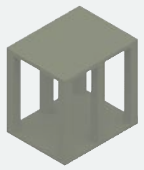
## DESCRIPTION

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/m²/year, the estimated number of occupants is set at 4.



Hybrid

1 storey



A01: Aktivitetshus i Kanalbyen PIXIE CASE

5,43 kg $CO_2$eq./m²/year


**Figure A01.1: 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 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 $CO_2$eq.

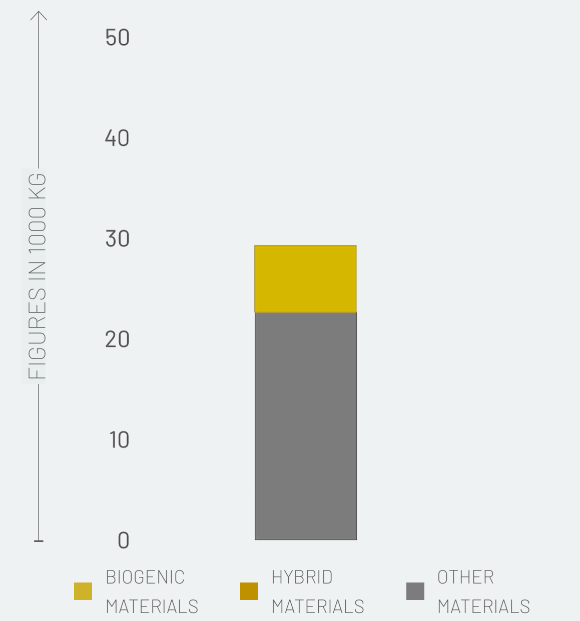



**Figure A01.2: Total emission of kg $CO_2$eq.**
The stacked bar chart shows the overall emission of kg $CO_2$eq in the study grouped into the three material categories: other, hybrids, and biogenic.

220 kg $CO_2$eq./person/year

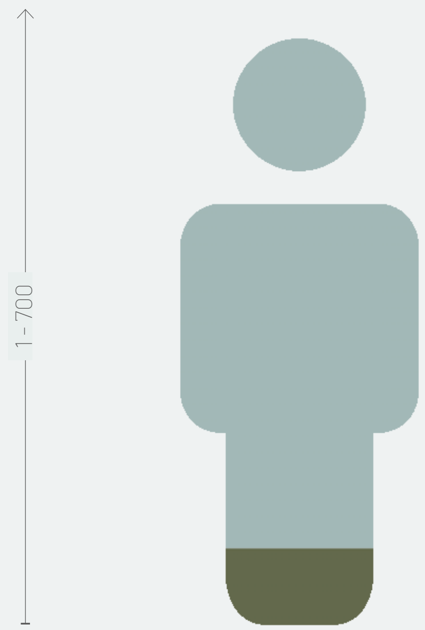



**Figure A01.3: Emissions of kg $CO_2$eq./person/year**
The span of the vertical axis is 1 to 700 kg $CO_2$eq./person/year

36 m²/person

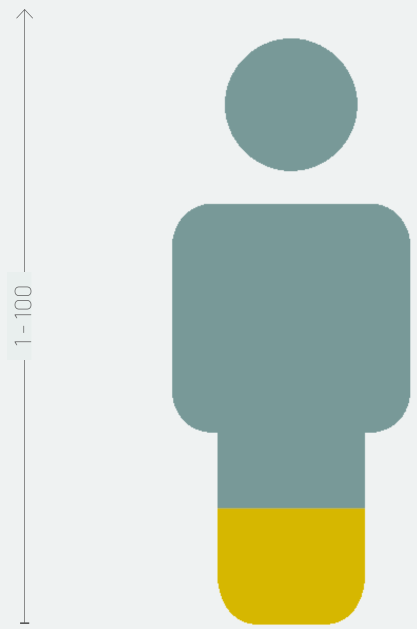



**Figure A01.4: m²/person**
The span of the vertical axis is 1 to 100 m²/person.

## 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 $CO_2$eq./m²/year.

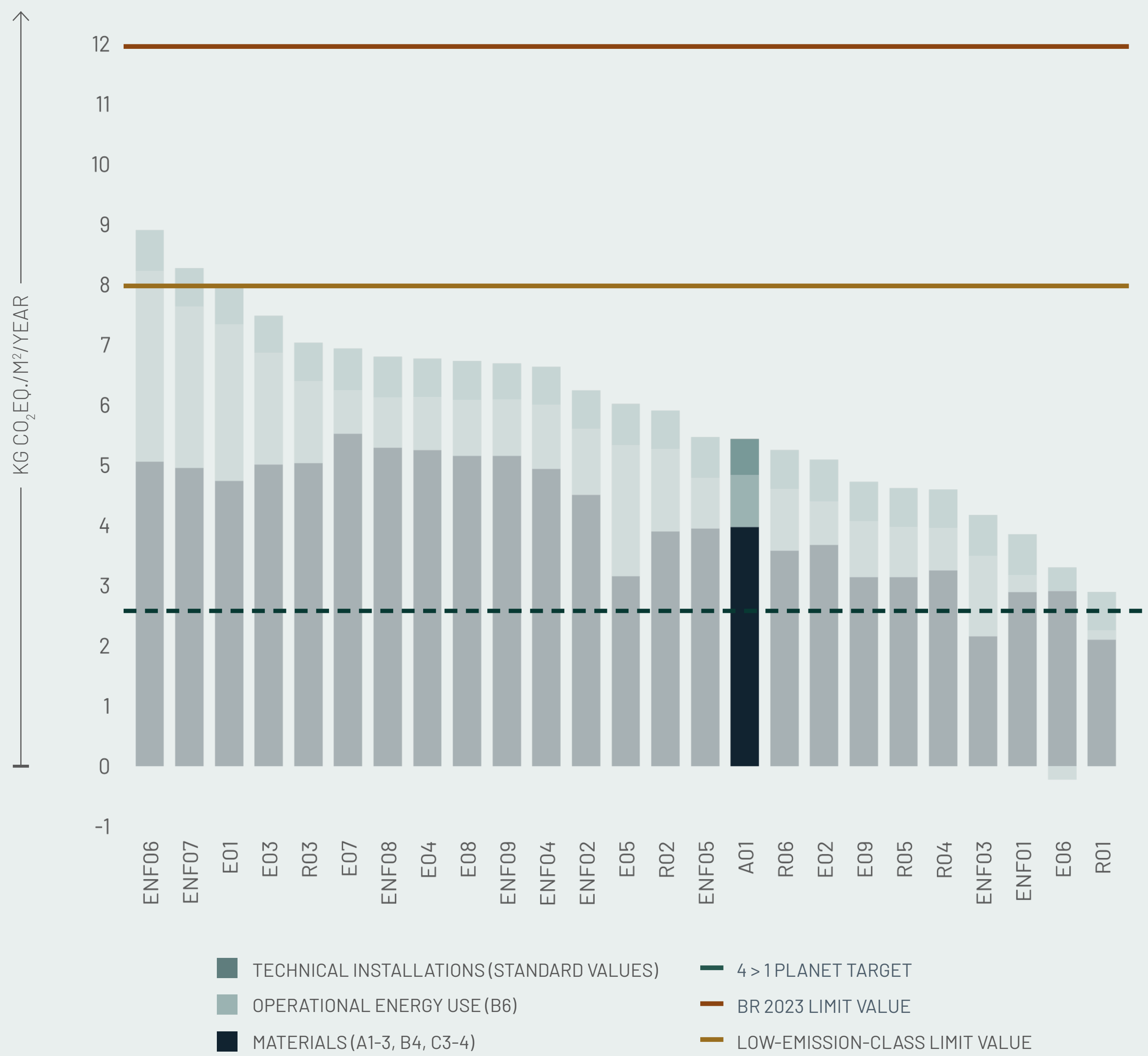



**Figure A01.5: Housing case studies**
The vertical axis shows the emission of $CO_2$eq./m²/year. The horizontal axis shows the 25 best practice cases.



A01: Aktivitetshus i Kanalbyen PIXIE CASE

## ENVIRONMENTAL IMPACT IN RELATION TO REDUCTION ROADMAP

Environmental impact is shown in $CO_2$eq./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 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 $CO_2$eq./m²/year, and the 'safe operating space'.

# FINDINGS

# KONKLUSION

## ENVIRONMENTAL IMPACT RELATIVE TO LIMIT VALUES

This report presents life-cycle assessments of 25 best practice cases. Of these, the findings of 19 of the case studies are complete whereas the findings of the 6 pixie case studies are preliminary with a high degree of detail.

Of the 25 case studies, 23 meet the limit value of 8 kg $CO_2$eq/m$^2$/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 $CO_2$eq/m$^2$/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 $CO_2$eq 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.

## KLIMAPÅVIRKNINGEN FRA BYGNINGSDELE

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 the highest 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.

As in conventional construction, the median for multi-storey housing in the case collection is closest to the overall median for the environmental impact of housing generally (Figures 17–24). 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 nine 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, with which materials to use and, not least, in which subsoil conditions multi-storey housing should be built.

# BUILDING COMPONENTS

# FOUNDATIONS

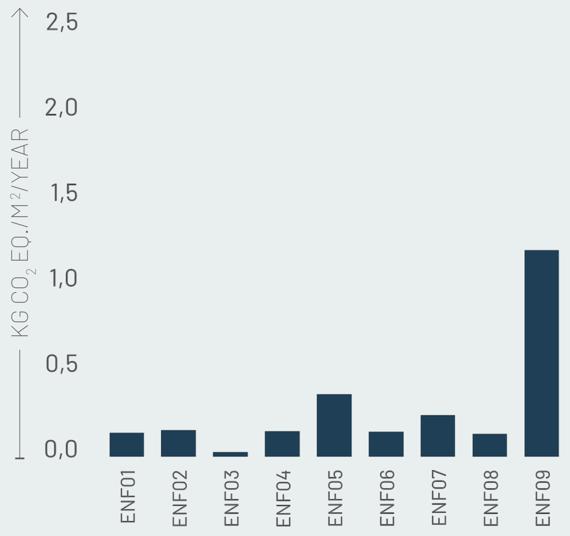
## SINGLE-FAMILY HOUSING

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

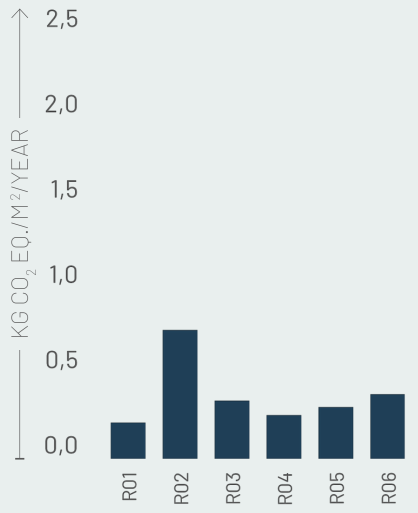
Continuous foundations in concrete with lightweight aggregate blocks (R01)

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)

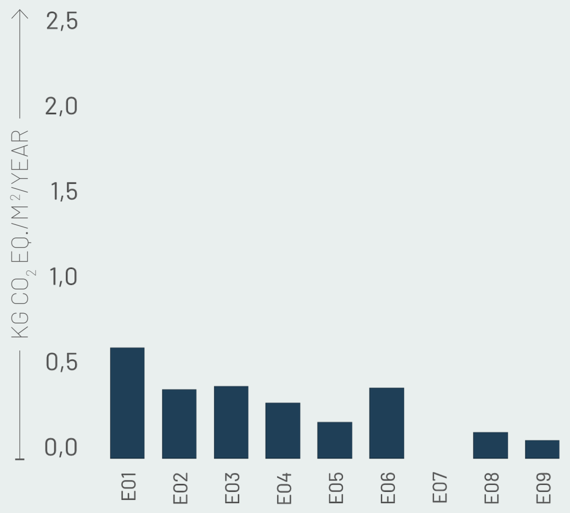
Wall and continuous foundations in concrete insulated with EPS (E03)

Continuous concrete foundations (E04)

Concrete with PIR insulation E05)

Lightweight aggregate blocks with EPS (E06)

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)

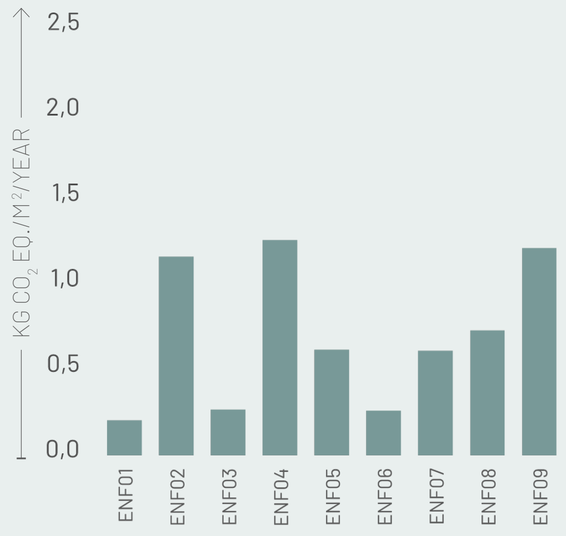
Timber cassettes insulated with wood-fibre (ENF05)

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

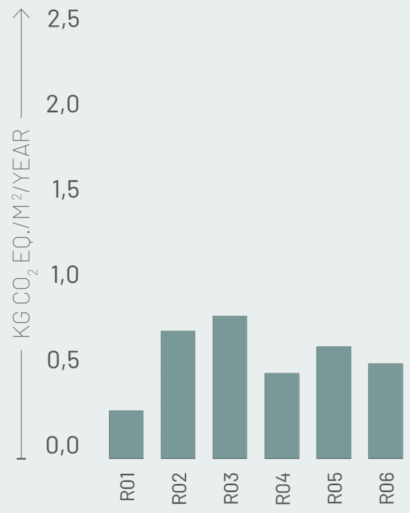
Reinforced concrete deck of low-emission cement insulated with stone wool (R01)

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)

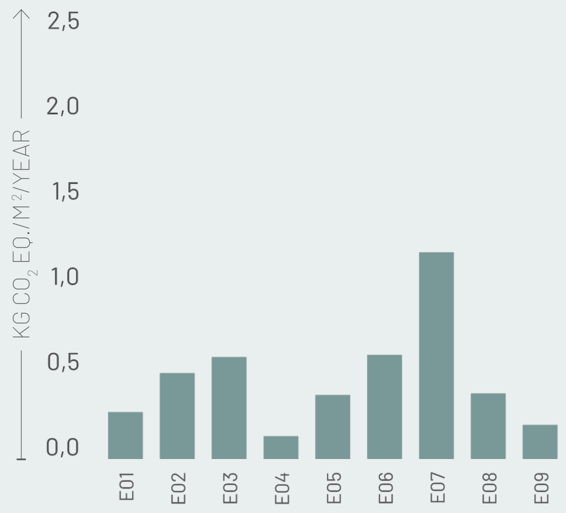
Timber structure insulated with mineral wool and EPS with fibre-cement cladding (E03)

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

Concrete and timber structure insulated with EPS (E06)

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 cellulo-se 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)

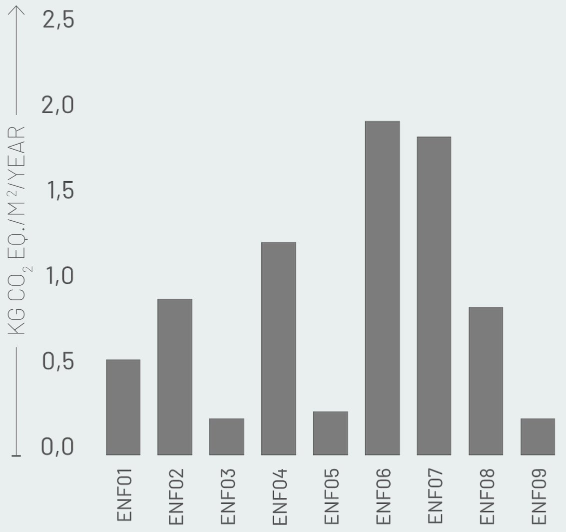
Timber and steel structure insulated with cellulose and wood-fibre, facade cladding of brick, wood, and cork (ENF06)

Frame structures in timber and reused materials from steel containers insu-lated 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 cel-lulose and mineral wool (R01)

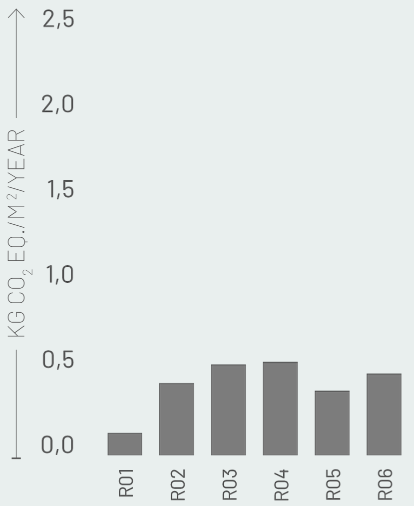
CLT timber modules insulated with glass wool (R02)

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

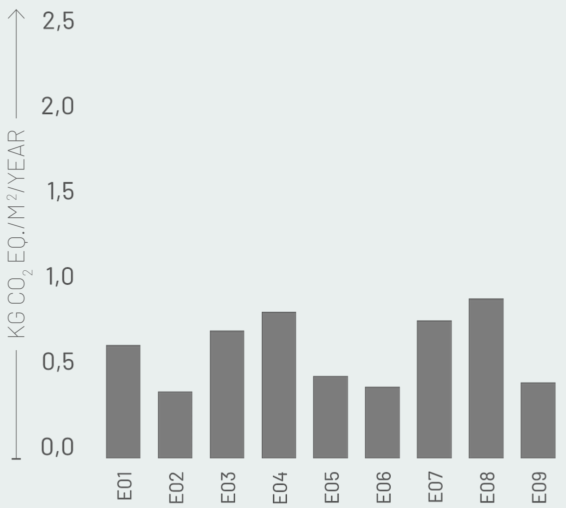
Load bearing structures in CLT, glulam, and steel, lightweight timber-frame walls insulated with wood fibre and mineral wool (E01)

Lightweight structures as supporting and lightweight exterior walls insula-ted 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) glass wool – slate and timber facing (E06)
(C) mineral wool – timber facing (E08)
(D) 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

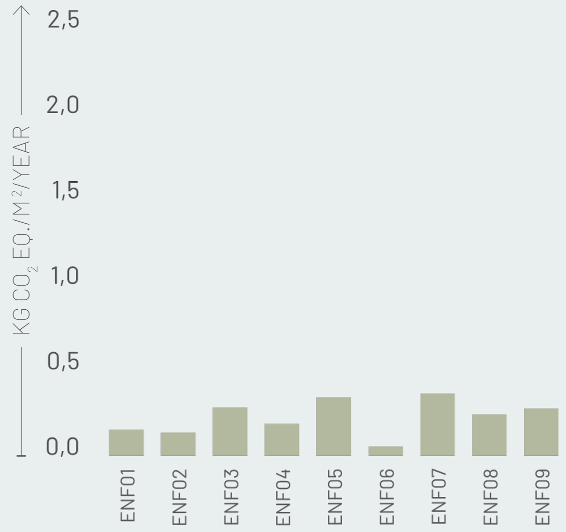
Timber-frame walls insulated with wood fibre – plywood and fibre gypsum facing (ENF:01, 09)

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)



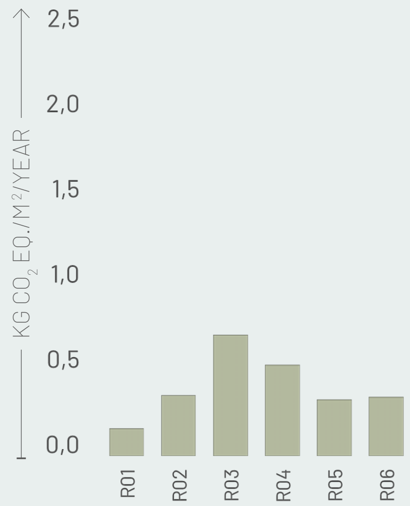

## TERRACED HOUSING

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

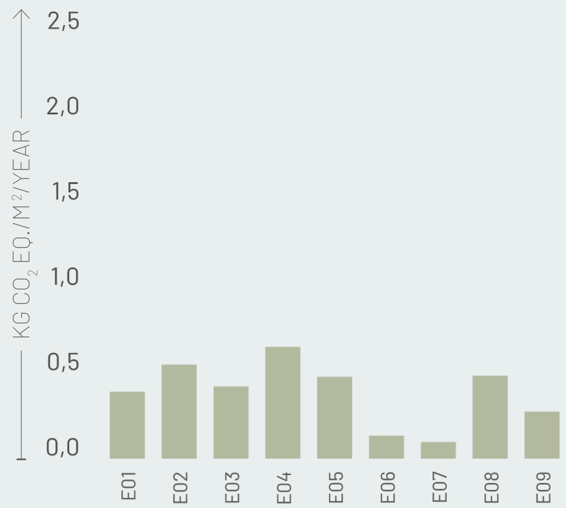
Load bearing structures in CLT, glulam and steel, lightweight tim-ber-frame walls – insulated with wood-fibre and mineral wool, fibre gypsum facing (E01)

Aerated concrete and timber-frame walls with mineral wool insulati-on – 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)

Timber-frame walls in OSB, insulated with glass wool – gypsum facing (E06)



# DECKS

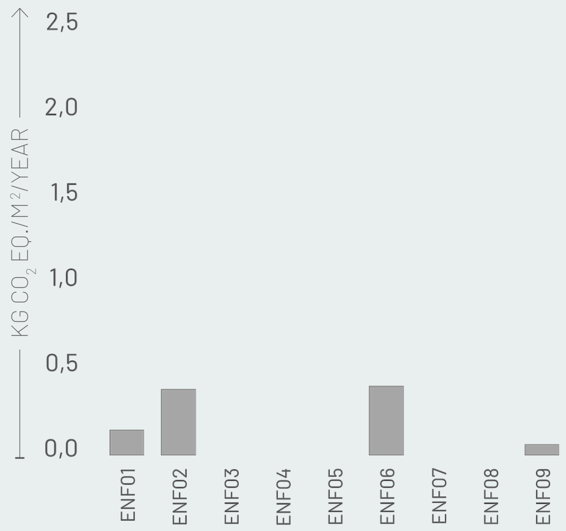
## SINGLE-FAMILY HOUSING

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

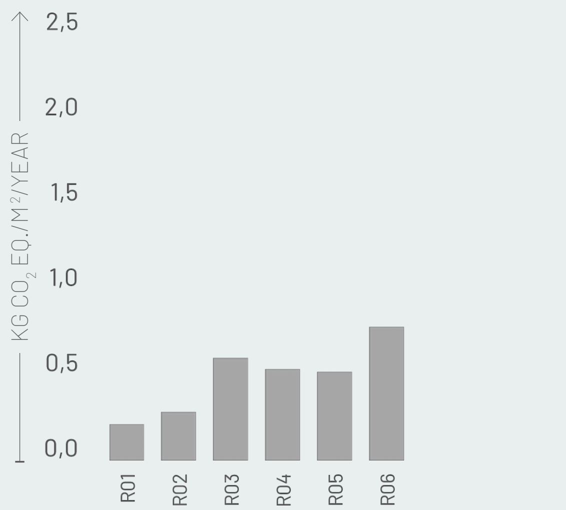
Ribbed deck construction in mass timber with footfall insulation membrane and plywood (R01)

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)

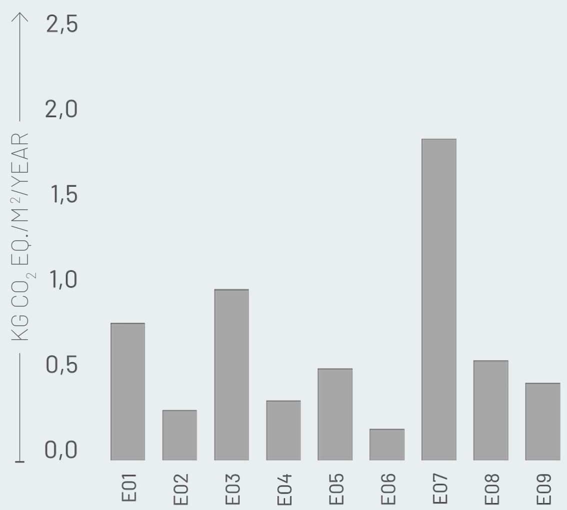
Timber-frame structure and steel and concrete structure – insulated with mineral wool, fire-rated gypsum facing (E02)

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)
(C) glass wool (E06)

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)

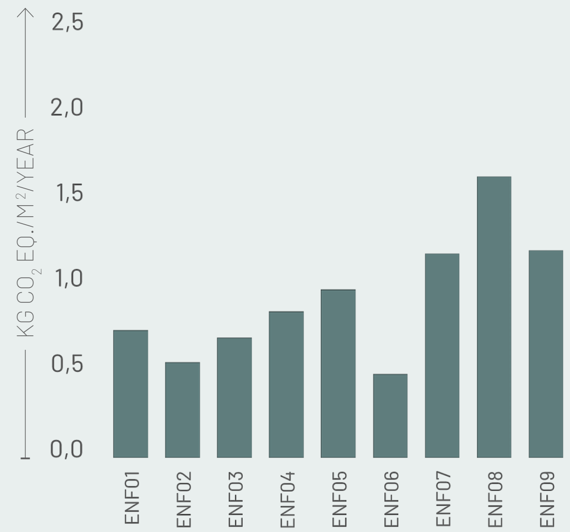
Timber-frame structure insulated with eelgrass (ENF03)

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

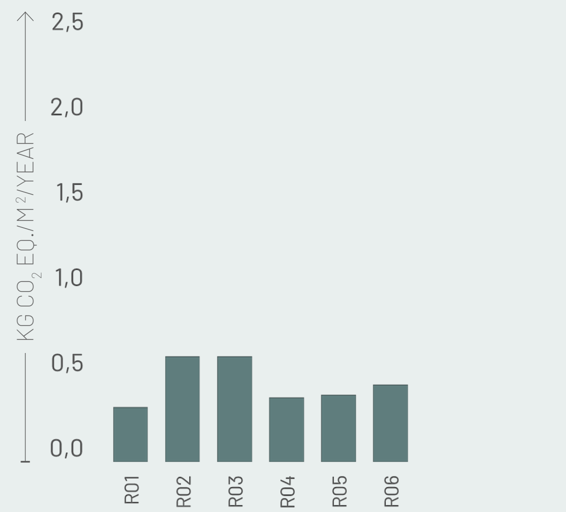
Timber cassette structure insulated with cellulose – slate and bituminous felt facing (R01)

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)

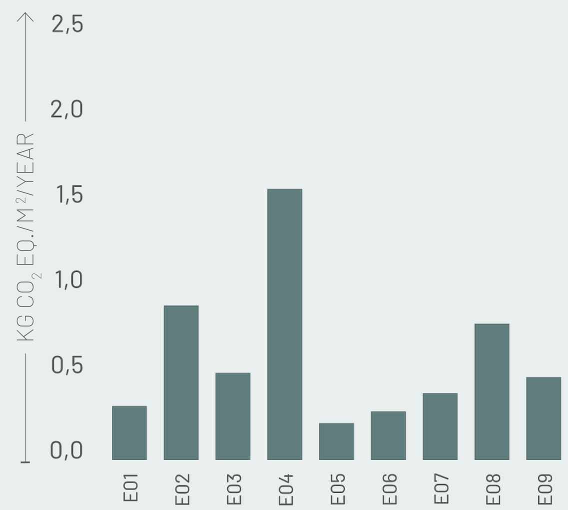
Glulam structure with vented cavity space and fire-rated gypsum – insulated with pressure-resistant mineral wool. Sedum and bituminous felt roofing (E03)

Glulam structure with a facing of clear polycarbonate (E04)

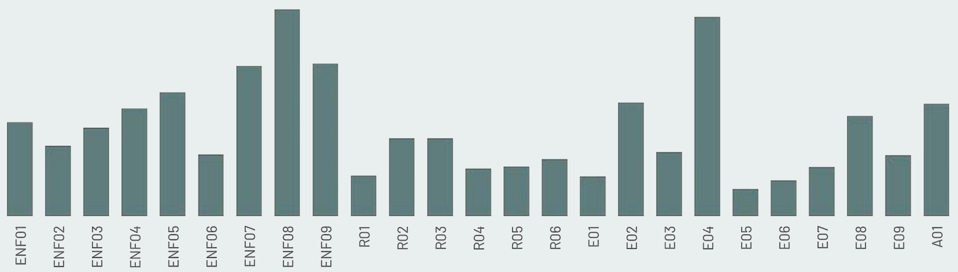
Timber cassette module insulated with:
(A) mineral wool with a facing of bituminous felt (E:04, 05)
(B) part of the roof doubling as roof terrace (E05)
(C) glass wool with a facing of bituminous felt (E06)

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

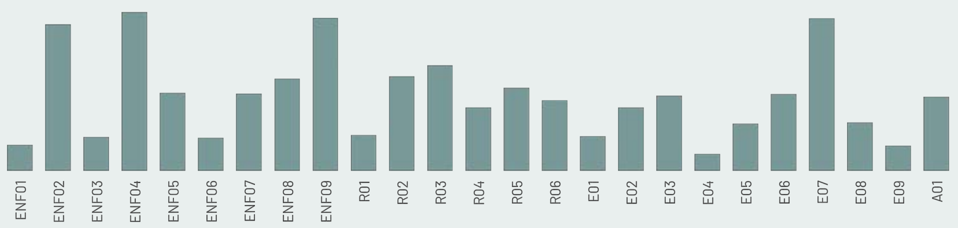



FOUNDATIONS:

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.

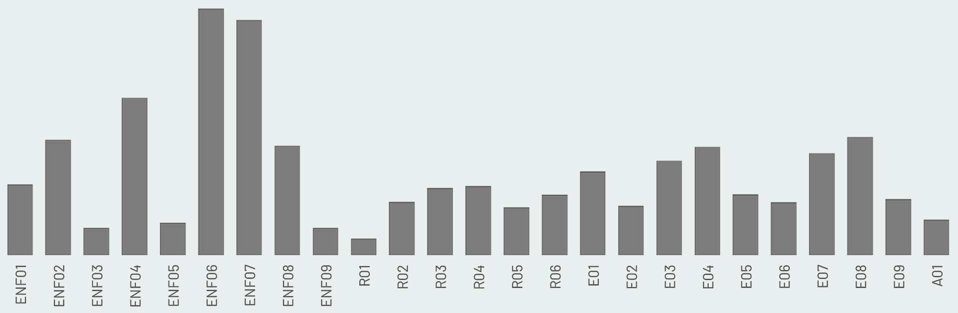
Concrete foundations and lightweight aggregate blocks are the commonest solutions for terraced and multi-storey housing.




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.

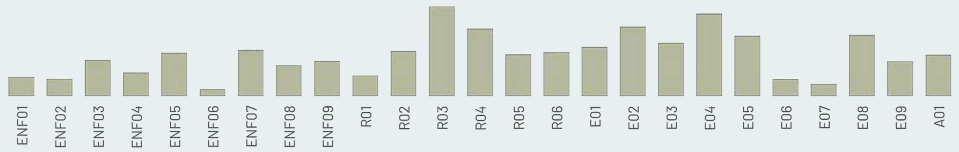
Insulation materials in timber-framed walls are often bio-based; cellulose and wood-fibre insulation being a very frequent choice.

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

Timber and slate are the preferred facing materials.



# SUMMARY

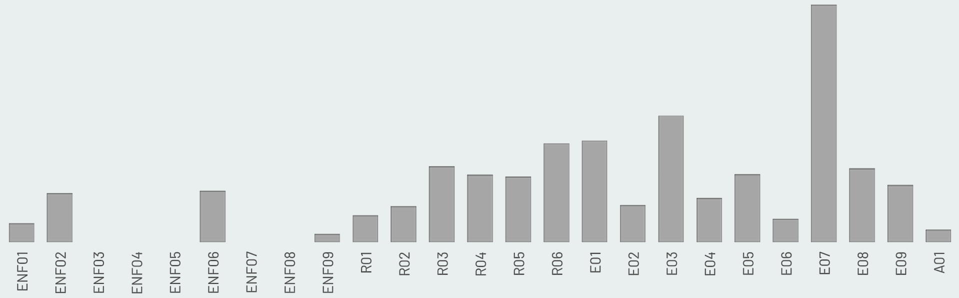



INTERIOR WALLS:

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.

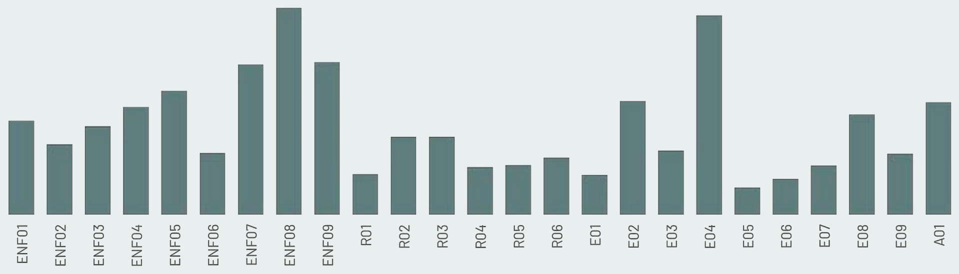



DECKS:

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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UNFCCC, The Paris Agreement, December 2015

**Global Status Report 2022**
United Nations Environment Programme, 2022 Global Status Report for Buildings and Construction: Towards a Zero emission, Efficient and Resilient Buildings and Construction Sector, 2022. Nairobi.

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2022 Edition
data.footprintnetwork.org

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**Tozan, B., et al., 2021**
Tozan, B., Brisson Jørgensen, E., & Birgisdottir, H., Klimapåvirkning fra 60 bygninger: Opdaterede værdier baseret på nyere data og danske branche EPD'er, april 2021
Institut for Byggeri, By og Miljø (BUILD), Aalborg Universitet.
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https://sbi.dk/Pages/Klimapaavirkning-fra-60-bygninger_.aspx

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URL: https://doi.org/10.48550/arXiv.2209.00118

**Figure 01: Housing construction from 4 to 1 planet**
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**DS/EN15978:2012**
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**DS/EN ISO 14040:2008**
Dansk Standard, Miljøledelse – Livscyklusvurdering – Principper og struktur, september 2008,
4. udgave

**Figure 02: Life-cycle stages and related modules**
Andersen, C. M. E., Garnow, A., Sørensen, C. G., Hoxha, E., Rasmussen, F. N. & Birgisdottir, H., Whole Life Carbon Impact from: 45 Timber Buildings 2023
Institut for Byggeri, By og Miljø (BUILD), Aalborg Universitet.
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IPCC, Synthesis report of the IPCC sixth assessment report (AR6), March 2023

**de Klerk, L., et al., 2022**
de Klerk, L., Shmurak, A., Gassan-Zade, O., Shlapak, M., Korthuis, A., Climate damage caused by Russia's war in Ukraine, 2022 Initiative on GHG accounting of war

**Figure 03: Global emission trends 2015–2021 (Global Carbon Budget, 2022)**
Global Carbon Budget, 2022
URL: https://doi.org/10.5194/essd-14-4811-2022

**Klima-, Energi- og Forsyningsministeriet, 2020**
Klima- Energi- og Forsyningsministeriet, Lov om klima,
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LOV nr 965 af 26/06/2020
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**Indenrigs- og Boligministeriet, 2021**
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URL: https://im.dk/Media/637787884257325807/National%20strategi%20for%20b%C3%A6redygtigt%20byggeri-a.pdf

**Figure 04: Time schedule for climate targets and limit values for emissions of kg $CO_2$eq./$m^2$/year**
Videncenter om bygningers klimapåvirkning, 2023
URL: https://byggeriogklima.dk/klimakrav/tidsplan/, 15-05-2023

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**Figur 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

**Figur 05b: Planetary boundaries (Sept 23, updated in 2nd edition and translation)**
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