Whole Life Carbon Impact of

45 Timber Buildings

Andersen, Camilla Marlene Ernst; Garnow, Agnes; Sørensen, Christian Grau; Wittchen, Alexandra; Stranddorf, Liv Kristensen; Hoxha, Endrit; Rasmussen, Freja Nygaard; Birgisdottir, Harpa

Publication date:
2023

Document Version
Publisher's PDF, also known as Version of record

BUILD REPORT

2023:10

Whole Life Carbon Impact of:
45 Timber Buildings

Camilla Ernst Andersen, Agnes Garnow, Christian Grau Sørensen, Alexandra Wittchen, Liv Kristensen Stranddorf, Endrit Hoxha, Freja Nygaard Rasmussen, Harpa Birgisdottir

Whole Life Carbon Impact of: 45 Timber Buildings

TITLE	Whole Life Carbon Impact of: 45 Timber Buildings
SERIES TITLE	BUILD Report 2023:10
FORMAT	Digital
EDITION	1st edition
YEAR OF PUBLICATION	2023
DIGITAL PUBLICATION	May
AUTHORS	Camilla Ernst Andersen, Agnes Garnow, Christian Grau Sørensen, Alexandra Wittchen, Liv Kristensen Stranddorf, Endrit Hoxha, Freja Nygaard Rasmussen, Harpa Birgisdóttir
PEER REVIEWER	Morten Birkved
LANGUAGE	Danish
NO. OF PAGES	187
REFERENCES	15
KEYWORDS	Life Cycle Assessment, environmental impact, timber buildings, case
ISBN	978-87-563-2112-9
ISSN	2597-3118
FRONT	Agnes Garnow
PUBLISHER	Department of the Built Environment, Aalborg University A.C. Meyers Vænge 15, 2450 Copenhagen SV, build@build.aau.dk, www.build.aau.dk This publication is covered by the Danish Copyright Act.

FAGFÆLLE-
BEDØMT

CONTENT

FOREWORD

Sustainable buildings are increasingly a key concern, especially when it comes to reducing their climate footprints. This has resulted in the 2023 Building Regulations introducing requirements for the environmental impact of buildings. Buildings of more than 1000 square metres must now comply with requirements of 12 kg CO_2 eq per square metre per year.

To reduce the impact from buildings, focus is increasingly on bio-based materials, including wood, since wood will capture CO_2 during growth and store it until end-of-life breakdown. Consequently, bio-based materials are frequently used, largely because of the potential to reduce existing environmental impact from buildings now and in the future.

This report highlights the environmental potential of using bio-based materials in the construction industry. The report investigates the environmental impact of 45 timber buildings along with the practical challenges encountered when using timber in construction. First, the report presents the findings of all 45 case studies and, second, a case collection comprising 35 of these to provide inspiration for using wood in construction.

The publication is financially supported by Realdania and the Villum foundation. Data and experience from the case studies are obtained in collaboration with architects, engineers, and architectural technologists and construction managers from Vandkunsten, Arkitema Architects, Lendager Group, Artelia (formerly MOE), Adserballe & Knudsen, Henning Larsen Architects, EcoCocon Denmark, Arken, and Mikael Skadborg & Martha Lewis.

The report is prepared by BUILD in 2022/2023 by Camilla Ernst Andersen, Agnes Garnow, Chrisitan Grau Sørensen, Alexandra Wittchen, Liv Kristensen Strand-dorf, Endrit Hoxha, Freja Nygaard Rasmussen, and Harpa Birgisdottir. Prior to publication, the report has been peer-reviewed by Professor MSO Morten Birkved from the University of Southern Denmark, whom BUILD would like to thank for his constructive work.

BUILD – Department of the Built Environment, Aalborg University Copenhagen, Division of Energy and Sustainability in Buildings.

May 2023

Tine Steen Larsen
Divisional Head

INTRODUCTION

BACKGROUND

Reducing global footprints is a key topic in today's world. The focal point in the construction sector had previously been to reduce operational energy use in buildings, but this has recently shifted to environmental impacts from materials. Bio-based materials, including wood, are particularly interesting, since they will actively help reduce impacts from buildings unlike traditional materials. This is chiefly due to wood's capacity to capture and store carbon. Knowledge about the application of bio-based materials in construction is therefore essential when discussing how to reduce emissions from materials.

This publication brings together the existing knowledge on timber buildings. Besides presenting data from several newly built Scandinavian timber buildings, the report also brings together knowledge from the following published reports:

- **Anvendelse af træ i byggeriet (Using Wood in Buildings) (Rasmussen et al., 2020) In Danish**
- **Klimapåvirkning fra 20 træbyggerier (Whole Life Carbon Assessment of 20 Timber Buildings) (Andersen et al., 2021) In Danish**
- **Erfaringer fra 20 træbyggerier (Experience from 20 Timber Construction Projects) (Wittchen & Rasmussen, 2021) In Danish**

Please consult the three BUILD reports above for a more detailed review of Danish timber buildings, their environmental impact, and the life-cycle assessment method applied.

Case collection

First, the publication presents an overview of environmental impacts from 45 timber buildings. Second, a case collection comprising 35 of these, emphasising the experiential aspects of designing and building in wood and the environmental impact produced by each building. The case collection is intended as a reference work to provide inspiration for those wishing to use timber in construction.

LIVSCYKLUSVURDERING

What is an LCA?

A life-cycle assessment (LCA) is a standardised method for assessing and evaluating the environmental impact and use of resources associated with a product or service, including construction. LCA can be used to compare environmental impacts from entire buildings but also from smaller parts such as specific building products or components. An LCA includes impacts from the life cycle of the whole building subdivided into stages. The stages comprise resource extraction and manufacture of materials, transport, construction, use, maintenance, and end-of-life treatment of materials. The subdivision into stages is shown in Figure 1 cf. EN 15978 (CEN, 2012).

Embodied and operational emissions

Results from an LCA can be subdivided into embodied and operational emissions. Embodied emissions are directly associated with building products and the construction and demolition of buildings. Accordingly, they are covered by the life-cycle stages A1–5, B1–5, and C1–4. Operational emissions are linked to the operational use of energy and is covered by the life-cycle stages B6–7. Further, there are so-called upfront emissions, integral to the embodied emissions arising from the construction process (life-cycle stages A1–5). So, these emissions occur even before the building becomes operational.

For more detailed information about LCA methodology, please consult the reports "LCA ifølge klimakravene" (LCA According to Environmental Requirements) (Videncenter om Bygningers Klimapåvirkning, 2022).

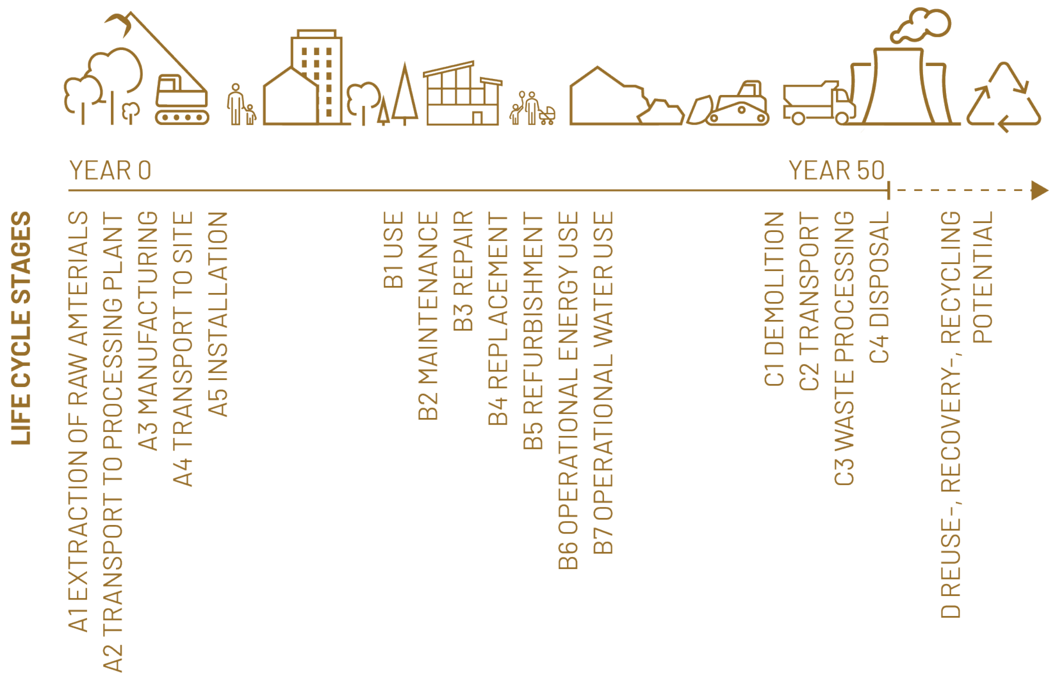


Figure 1. Life cycle stages of buildings
The overall life-cycle stages of buildings comprise: Product (A1–A3), Construction Process (A4–A5), Use (B1–B7), End of Life (C1–C4), and Beyond Life Cycle (D).

DEFINITION OF A TIMBER BUILDING

"Timber buildings are buildings in which wood or wood-based products, to some extent, are an integral part of the building materials used above grade or above the load-distributing concrete slab in the grade deck, exclusive of glazed areas." *(Rasmussen, 2020:25, p. 16)*

Skademosen Photo Adserballe & Knudsen

THE -1/+1-METHOD

The European standard EN 15804 (CEN, 2013) stipulates that biomass carbon capture is characterised as -1 kg CO_2 eq per kg CO_2 captured from the atmosphere. This is part of the Product stage (module A1) and a negative impact is therefore obtained at the Product stage when using wood. The negative impact in the Product stage is, in turn, offset at the End-of-Life stage (module C3), irrespective of disposal method. Here it is characterised as the corresponding amount of CO_2 in the biomass, so +1 kg CO_2 eq per kg CO_2. In the overall life cycle, therefore, wood will emerge as carbon neutral for the stored carbon in the biomass (CEN, 2014). Fossil emissions from the production of wood will continue to vary depending on the different life-cycle stages, as they are linked to the production methods used for the specific products. This calculation method is typically referred to as the -1/+1 method, illustrated in Figure 2. In 2020, the new European standard EN15804:2012+A2:2019 came into force (CEN, 2019). This includes several amendments relative to calculating environmental impact for wood products, however, the -1/+1 method is still in use (CEN, 2019). The standard aims to increase the transparency of the CO_2 capture and emission by trees by stipulating that fossil and biogenic emissions are declared separately.

It is important to note that the -1/+1 method does not take future disposal scenarios into account. This means that regardless of whether the wood is burnt, recycled, or reused, the biogenic CO_2 is calculated as emissions at the end-of-life stage. Differences in environmental impact between disposal scenarios will therefore only occur due to fossil emissions associated with a specific disposal scenario. This ensures that the biogenic CO_2 ranks as neutral within each life cycle, avoiding double counts.

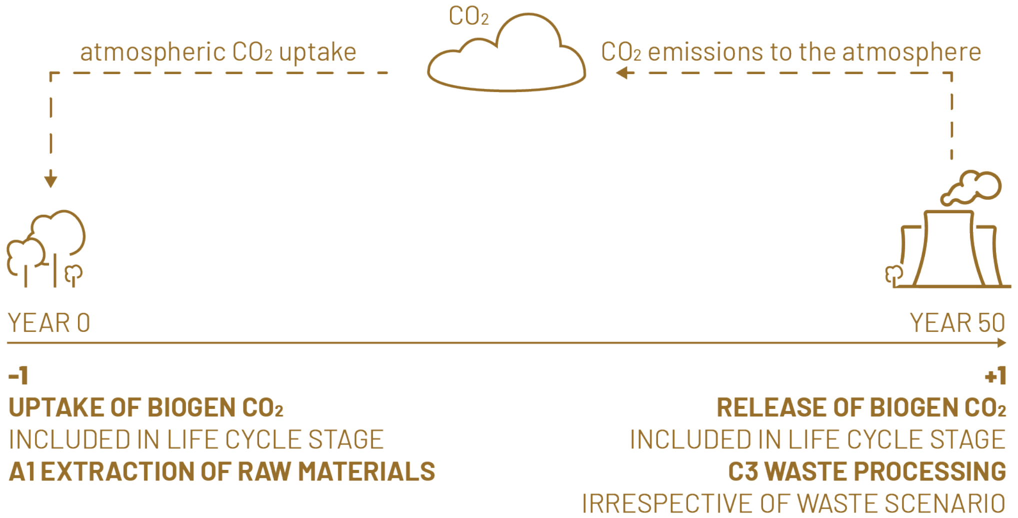


Figure 2. Method for calculating biogenic CO_2 in bio-based productS
Potential environmental impact of timber products is calculated using the -1/+1 method, which assumes that biogenic carbon is captured and stored by trees (+1) used in construction. It is emitted later at the end-of-life stage (-1).

THE INDUSTRY'S EXPERIENCE WITH TIMBER

Tips for timber construction

Several Danish companies have acquired skills in timber construction. The report "Erfaringer fra 20 Træbyggerier" (Experience from 20 Timber Construction Projects) (Wittchen & Rasmussen, 2021) outlines experience from 20 timber buildings designed by the architects' firms Lendager Group, Vandkunsten, C.F. Møller Architects, and Arkitema Architects. The report is based on interviews with architects, architectural technologists and construction managers, and engineers, who have carried out design work for timber construction projects.

Based on interviewees' experience of timber construction, the following advice can be passed on to enterprises wishing to acquire skills in timber construction:

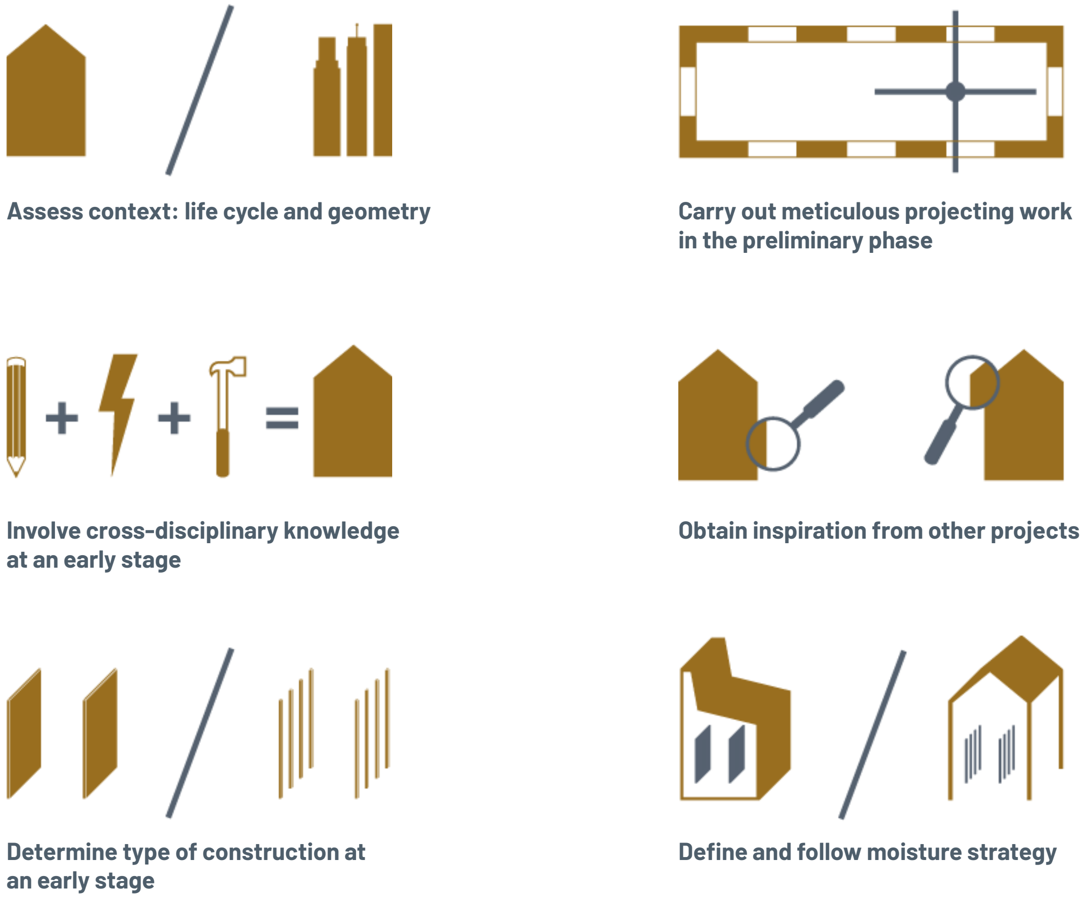


Figure 3. Tips for timber construction
Tips for timber construction are based on experience presented in the report "Erfaringer fra 20 Træbyggerier (Experience from 20 Timber Construction projects)" (Wittchen & Rasmussen, 2021).

Lisbjerg Bakke Photo Vandkunsten

USING WOOD IN THE FUTURE

Wood is often mentioned as a material that contributes to reducing the environmental impact of buildings, but although wood is a renewable resource and stores carbon, it is essential to know in which context the material is used. We therefore need to consider the following strategies when trying to reduce impact from buildings by using wood:

Reuse and recycle instead of burning
Reusing and recycling wood should be considered an end-of-life strategy to avoid it being burnt. When reusing and recycling, the carbon remains stored for longer periods, thus delaying emissions. We therefore need strategies to recycle or upcycle building components and materials which have outlasted their usefulness in the life cycle of another building.

Assess the context in which the wood will be used
Wood resources should be used where it makes sense – and we must avoid excessive use of materials. To give an example, residual products from the timber industry are often popular with the textile and furniture industries with potential buyer synergies and reuse and further exploitation of the materials.

Select a sustainable wood supply
We must ensure that the wood we use is the product of sustainable forestry, where thought is given to biodiversity, current ageing of trees, and the ensuing continuous CO_2 storage. Moreover, it is vital to take a broad view of using wood, also taking into account other environmental aspects than those affecting the climate.

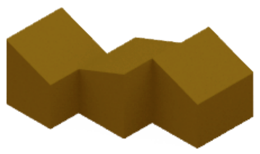
Remember: sustainable construction is holistic
Sustainable construction is not only about building in wood but just as much about optimising your building in relation to other sustainability strategies. This might include building less, building with more flexibility, exploiting every square metre, optimising use of material resources, reusing materials, renovating, and giving thought to the building's functional and cultural relevance for both users and society at large. This will help ensure that our buildings are environmentally, socially, and financially sustainable – also in the long term.

Lethal Photo Vandkunsten

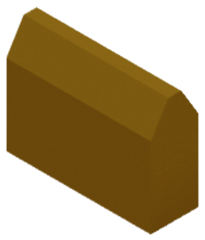
DATA TREATMENT

SUMMARY OVERVIEW OF CASES

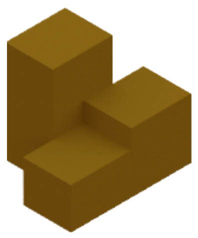
The data used were obtained in collaboration with Vandkunsten, Arkitema Architects, Lendager Group, Arken, Artelia (formerly MOE), EcoCocon Denmark, Henning Larsen Architects, and Adserballe & Knudsen in 2021–22. Data from a total of 45 building case studies are gathered, of which 35 are freely available in the collection of case studies at the back of the publication. The focal point of the data collection has been the design process, and the LCAs are thus primarily based on quantity take-off from architects' models. Other than that, the building case studies are a snapshot account of buildings already constructed. LCA was not actively used as a tool in the design phase of the projects, and the cases are therefore comparable to other timber construction projects in Denmark.



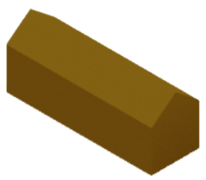
Terraced House
Denmarksgrunden Almenbolig+
Balancen
Timianhaven
Skråningen I
Skråningen II
Grøntorvet Almenbolig+
Engdraget
Skademosen
Anonymous, terraced house #1



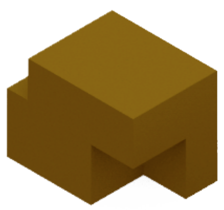
Multi-story housing
Lisbjerg Bakke
Studio[Home] Lyngby
Studio[Home] Ballerup
Knudrisrækkerne
UN17 Village Kronen
Toppen
Skousbo I
Anonymous, multi-storey #1
Anonymous, multi-storey #2
Anonymous, multi-storey #3
Anonymous, multi-storey #4



Other buildings
Uninsulated street games hall
Klub Svanen
Bakkens Hjerte
KUGA
Oksenøya Res. & Treatment Centre
Oksenøya Kindergarten
Erlev School
Lysningen
Samsø Energiakademi
Trondheim Central Station
Feldballe Friskole
Rosa Day-care institution
Karolinelund Kindergarten
Skolen for livet
Anonymous, other #1
Anonymous, other #2



Singly-familu housing & holiday homes
Skadborg
Modern Seaweed House
Straw house, Ebeltoft
Friland
Broager
Anonymous, Holiday home #1



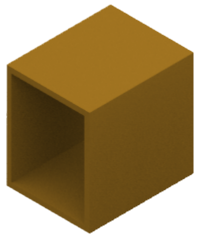
Office building
Storkens Kvarter
Anonymous, office #1
Anonymous, office #2

Figure 4.Location of timber buildings
The locations of the 45 timber-building case studies are marked on the map. The size of the circles indicates the number of cases in the area.

TYPES OF STRUCTURE

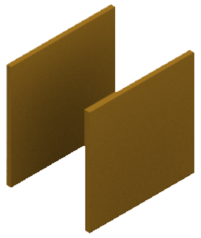
Design principles

Primarily four different design principles were used in the 45 timber building projects: cassettes, sheeting (including cross-laminated timber (CLT)), timber frames, and glulam. Other than that, hybrid denotes buildings using two or more of the structures mentioned. The types of structure are defined as follows:



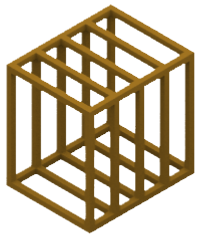
Cassette

Large prefabricated modules, such as a complete housing unit in multi-story housing



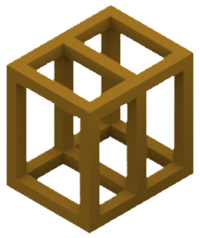
Sheeting

Small prefabricated panels, such as wall components or CLT



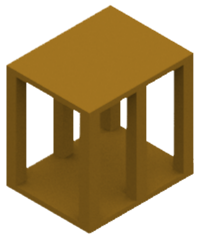
Timber frame

Timber frame construction in mass timber



Glulam

Glulam beam-column structure



Hybrid

A combination of two or more of the above-mentioned design principles

Samsø Energiakademi Photo Arkitema

DATA COLLECTION

Modelling using the LCAbyg tool
All timber buildings are modelled using the digital tool LCAbyg (2023) based on quantity take-off from architectural or engineering models. The buildings are modelled on the method described below:

Life-cycle stages
This study includes the life-cycle stages of manufacture and transport of building materials (A1–3), transport to building site and construction process (A4–5), replacement of building parts (B4), operational use of energy (B6), and end-of-life waste disposal (C3–4). Figure 5 illustrates all the modules covered by EN 15798 (CEN, 2012) and indicates the modules included in this study (Andersen et al., 2021, p.16).

Building parts
In the data collection, emphasis has been on harmonising those building parts included in the LCAs across all building case studies (Andersen et al., 2020, p. 16). The analyses include foundations, grade deck, deck, exterior walls, supporting structures, interior walls, roofs, staircases and ramps, balconies and access balconies, windows, doors and glass facades, electrical and mechanical systems, and other. Other elements, plantation and paving, channels below grade, hollows, and minor fasteners are not included.

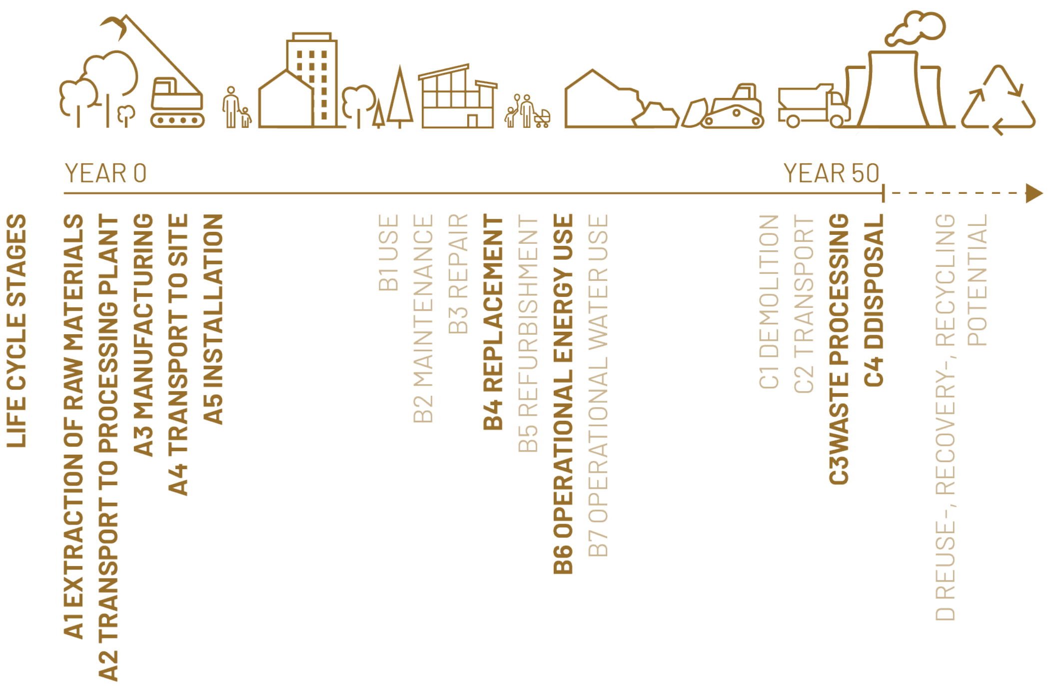


Figure 5. Life cycle stages included in the building case studies
The overall life cycle stages of buildings comprise the stages: Product (A1–A3), Construction Process (A4–A5), Use (B1–B7), End of Life (C1–C4), and Beyond Life Cycle (D), of which the marked life-cycle stages are included in the LCAs of building case studies.

Data on technical installations tend to be inadequate in most case studies. For this reason, generic data have been used for drains, and water, heating, ventilation, and cooling systems 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 site 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 group electrical and mechanical systems, since these are typically photovoltaic modules and lifts.

Assumptions
Bituminous felt
It is normal practice to install a single layer of bituminous felt or other protective layer across the upper side of cassettes supplied without factory-fitted roofing. This has therefore been added assuming that the area covered with bituminous felt is identical to the deck area of the buildings.

Paint
For plasterboard walls, a standard assumption of a layer of primer of 0.19 kg/m^2 and two layers of emulsion totalling 0.38 kg/m^2 is applied for paint unless otherwise specified.

Reuse
Building materials likely to be made from reused materials such as reused brick tiles and metal sheeting are modelled according to the cut-off method, where only impact from extra processing is included at the Manufacturing stage (modules A1–3).

Timber building products	Drains	Water	Heating, ventilation, and cooling systems
Single-family housing & holiday homes	0.02 kg CO_2 eq/m^2/year	0.06 kg CO_2 eq/m^2/year	0.60 kg CO_2 eq/m^2/year
Terraced housing	0.10 kg CO_2 eq/m^2/year	0.04 kg CO_2 eq/m^2/year	0.51 kg CO_2 eq/m^2/year
Multi-storey housing	0.12 kg CO_2 eq/m^2/year	0.06 kg CO_2 eq/m^2/year	0.51 kg CO_2 eq/m^2/year
Office building, school, and institutions	0.04 kg CO_2 eq/m^2/year	0.06 kg CO_2 eq/m^2/year	0.84 kg CO_2 eq/m^2/year
Other buildings	0.05 kg CO_2 eq/m^2/year	0.08 kg CO_2 eq/m^2/year	1.09 kg CO_2 eq/m^2/year

Figure 6. Generic values for technical installations according to type of building
The generic values for technical installations 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)

DATA MODELLING

Data base

The LCAs in this project are primarily based on environmental data from the integral LCAbyg database gen_dk. Data in gen_dk originate from the German database Ökobaudat 2020 and is not, therefore, necessarily representative of Danish practice relative to manufacture and disposal. At present, no Danish database exist that broadly covers construction materials, and Ökobaudat was therefore selected as the basis for environmental data. However, Danish trade associations are progressively publishing more EPDs, and the likelihood of using Danish trade-association and product-specific data for future LCAs is thus expected to increase. The development of EPDs can help reduce uncertainties associated with environmental data, and hence EPDs from Danish trade associations are used for concrete and timber products and product-specific EPDs for wooden facades in this project (see Table 2) (Andersen et al., 2021, p. 17). Other than that, EPDs are used for building materials such as straw bales and green roofs for which no generic data exist.

Reference study period

In accordance with the Frivillig Bæredygtighedsklasse (FBK) (Voluntary Sustainability Class) and future requirements of the Danish Building Regulations, the LCA reference study period is 50 years. This period will be standard in future requirements and in FBK to obtain comparable calculations for all projects. The reference study period specifies the number of years during which the building will be analysed and may have considerable influence on the dispersal of impact across the life-cycle stages. The longer the reference study period, the greater weight is attached to the future impact, such as during the building's operational stage, whereas less weight will be attached to the impact during the building's construction stage. Please note that the reference study period is a calculable assumption, stating the period of analysis during which impact from the building is calculated and thus not an estimation of the building's service life. The actual service life of the building is therefore likely to deviate from the reference study period and may prove both shorter or longer than the reference study period (Andersen et al., 2021, p. 18).

Environmental impact categories

With an LCA, it is possible to calculate the impact from various environmental impact categories. Examples of environmental impact categories are global warming, breakdown of the ozone layer, acidification, primary energy consumption, photochemical ozone formation. For this project, focus is on global warming potential (GWP), which is an impact indicator for the potential global rise of the Earth's surface temperature due to increased concentrations of greenhouse gases in the atmosphere. The unit designating GWP is kg CO_2 eq and includes the impact of different greenhouse gases compared to that of carbon dioxide (Andersen et al., 2021, p. 19). However, it is also essential to investigate other environmental impact categories to avoid reducing the impact in one category whilst increasing

Timber building products	
Spacer bars/lathing	MD-20004-EN
Structural timbers/lathing/jambs	MD-20002-EN
Cross-laminated timber (CLT)	MD-20007-EN
Glulam	MD-20005-EN
Plywood	MD-20008-EN
Particle board	MD-20006-EN
Untreated wood facade	MD-20002-EN
Painted/treated wood facade	MD-20002-EN
Hardwood facade	MD-20032-EN
Concrete building products	
Concrete C20/25	MD-20011-DA_rev1
Concrete C30/37	MD-20012-DA_rev1
Precast concrete slabs	MD-20015-DA_rev1
Aerated concrete wall slabs	MD-20016-DA_rev1
Hollow-core concrete deck slabs	MD-20017-DA_rev2
TT slabs/ribbed deck slabs	MD-20018-DA_rev1
Sandwich slabs/facade slabs	MD-20019-DA_rev1

Figure 7. Environmental product declarations (EPDs) applicable to wood and concrete building products
The numbers indicated for each type of material are EPD numbers, which can be retrieved from the EPD data base at EPD Denmark (EPD Denmark, n.d.)

DATA MODELLING

Wastage and transport

The life-cycle stages A4 and A5 cover wastage and transport of building materials as well as energy consumption during construction. To be specific, A4 covers transport of building materials to the building site, and it is therefore necessary to know the transport forms and distances relative to all building materials. A5 covers energy consumption on the building site and material wastage during the construction process. Both life cycles therefore require very specific data, and since it is a relatively new phenomenon to include these life-cycle stages in LCAs, such data were not available. For this reason, environmental impacts from the life-cycle stages A4 and A5 are calculated based on generic assumptions (see Table 3). Building-site energy consumption is excluded from the calculations in this study, since no data were available (Andersen et al., 2021, p. 19).

Replacing building parts

The B4 life-cycle stage covers impact from replacing building materials during the operational stage. Whether or not a building part is replaced depends on the lifetime of the specific building product and the reference study period selected. The lifetime of building products is shown in LCAbyg (Andersen et al., 2021, p. 19).

Operational energy use

Impact from operational use of energy is incorporated in the B6 life-cycle stage. Data for operational energy consumption are based on the energy framework calculations available for most of the case studies. Operational energy consumption impact calculations are based on environmental data in LCAbyg, where projected data are used to forecast energy production during the period 2020–2040 (Danish Transport, Construction, and Housing Authority & COWI, 2020). It is assumed, therefore, that the amount of renewable energy will continue to increase in both the electricity and district heating grid, and that the impact from 1 kWh or MJ of produced energy will decrease over time (Andersen et al., 2021, p. 19). The type of energy source used for the building is specified in each case study.

Data treatment and reference unit

A simple statistical analysis was made of the case study findings. The focus in the data treatment has been on identifying the differences in environmental impacts that specifically relate to the use of timber in the buildings. Findings relative to impacts will be presented as kg CO_2 eq harmonised with the area (per m2). The impact from building products (life-cycle stages A1–3, A4, A5, B4, C3, and C4) is harmonised with the gross area of the building, whereas the impact from operational use of energy (life-cycle stage B6) is harmonised with the square-metreage of the heated floor area. Finally, the findings are also harmonised with the number of years selected as the reference study period (per year) (Andersen et al., 2021, p. 20).

Building products	**A4**	**A5**
Spacer bars/lathing	600km by lorry, standard, and 170km by bulk carrier	5%
Structural timbers/lathing/jambs	600km by lorry, standard, and 170km by bulk carrier	5%
Cross-laminated timber (CLT)	1400km by lorry, standard	5%
Glulam	70km by lorry, standard	5%
Plywood	600km by lorry, standard, and 1228km by bulk carrier	5%
Particle board	200km by lorry, standard	5%
Ready-mixed concrete	50km by lorry > 26t	5%
Precast concrete slabs	150km by lorry, standard	5%
Other materials	500km by lorry, standard	10%
Soil from/to/at the building site	200km by lorry, standard	5%

Table 1. Assumptions for life-cycle stages A4 and A5
Life-cycle stage A4 concerns transport of building products to the building site and A5 concerns on-site wastage of building products. Wastage percentages indicate wastage of the quantity of materials used for the construction process (life-cycle stages A1–A3)

Uncertainties

Data in this project are mainly based on quantity take-off from architectural models, as focus was originally on the use of wood in the design phase. As no decision was typically made in the early design phase on specific details on foundations and technical installations, for example, data for these building parts are based on preliminary estimates. Studies exist, however, indicating that the level of detail for quantity take-off may result in differences in the final LCA results (Zimmermann et al., 2019). To make this plain, we have noted for each case study that the quantity take-off underlying the LCA results is based on architectural or engineering models.

EMPIRICAL RESEARCH & INTERVIEWS

A series of semi-structured interviews were conducted with actors who had played a part in designing the timber buildings presented in the case collection. These are architects, engineers, and architectural technologists and construction managers from some of the consulting firms supplying the case-specific data. The interviews were structured to include the following:

- **Visions for the project – including emphasis on the choice of wood as building material and initiatives to ensure overall sustainability**
- **Reviewing the project schedule from type of task to specific type of contract**
- **Parameters creating special potential or barriers in the project and how these were handled in practice**
- **The significance of the identified potential and barriers for the choice of materials, if any.**

Additionally, the interviews were structured to emphasise the barriers encountered when building in wood, described in the report "Anvendelse af træ i byggeriet" (Using Wood in Buildings) (Rasmussen et al., 2020). This includes the topics fire, economy, statics, moisture, aesthetics, logistics, and acoustics. The topics are illustrated in Figure 6.

A detailed description of methodology regarding the interviews is outlined in the report "Erfaringer fra 20 træbyggerier" (Experience from 20 Timber Construction Projects) (Wittchen & Rasmussen, 2021).

INTERVIEWS: SPECIAL FOCUS AREAS FOR TIMBER BUILDINGS

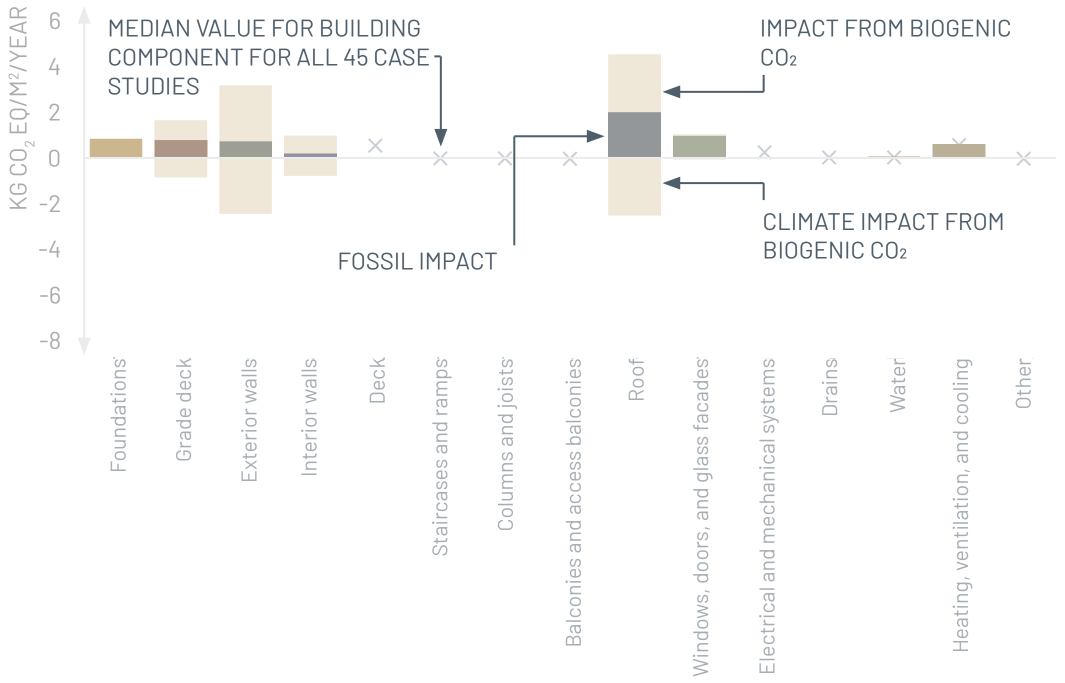
Fire (BR requirements)	Knowledge about fire safety in timber buildings
Statics (BR requirements)	Documented supporting capacity of timber building components
Acoustics (BR requirements)	Calculating and complying with sound insulation requirements
Economy	Acquiring new expertise and cross-disciplinary collaboration at an early stage
Logistics	Production and transport of timber solutions for buildings in Denmark
Aesthetics	Experiencing wood as a material
Moisture	Preventing construction moisture and moisture during use

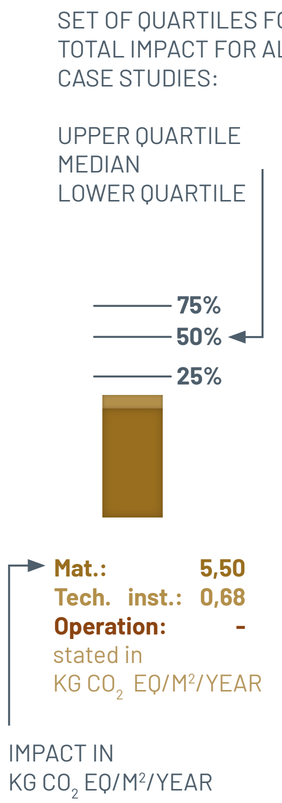
Figure 8.Special focus areas for timber buildings
Special focus areas concerning timber buildings can be subdivided into the following topics: fire, statics, acoustics, economy, logistics, and moisture. The Building Regulations (BR) specify requirements for fire, statics, and acoustics. The diagram is based on 'Figure 1: Opsummering af en række oplevede barrierer beskrevet i BUILD-rapport 2020:25 (Summary of barriers encountered, outlined in BUILD report 2020:25) (Wittchen & Rasmussen, 2021, p. 8).

HOW TO READ THE LCA RESULTS

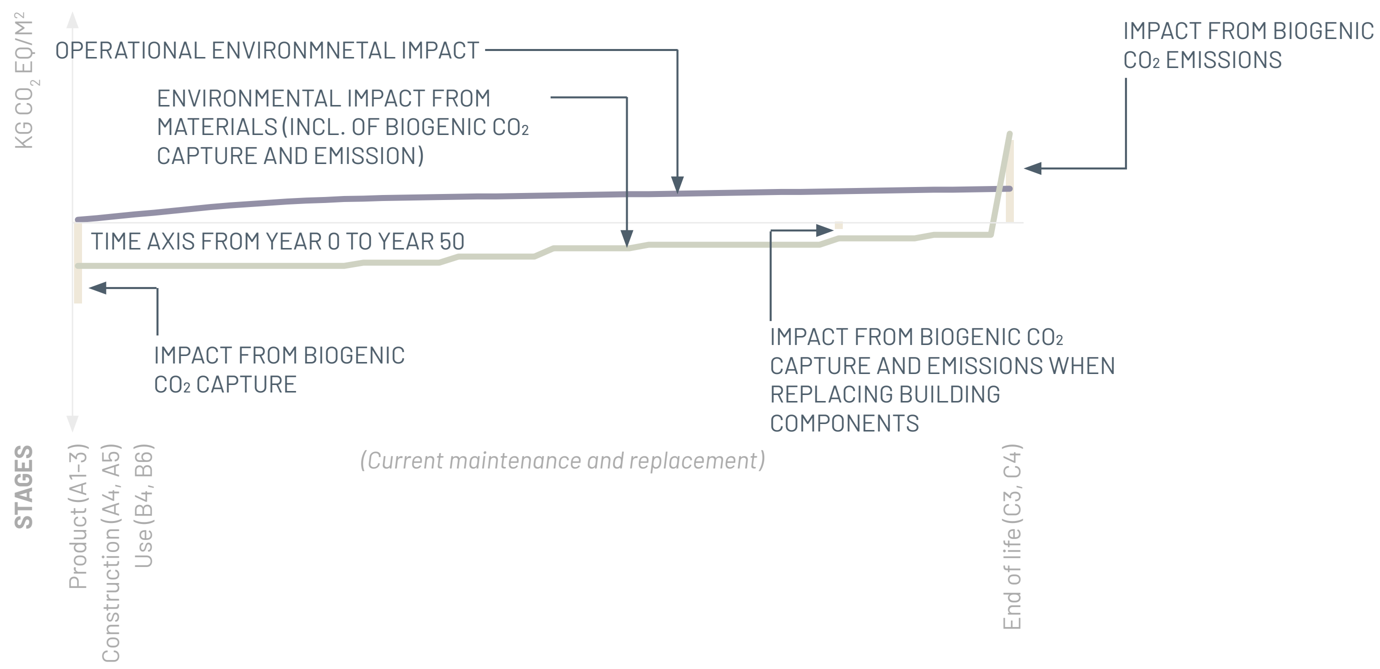
To ensure a correct reading of the LCA results, we have prepared reading guidelines for the graphs presenting the LCA results for each case study.

ENVIRONMENTAL IMPACT SHOWN AT BUILDING LEVEL OR BUILDING COMPONENT LEVEL

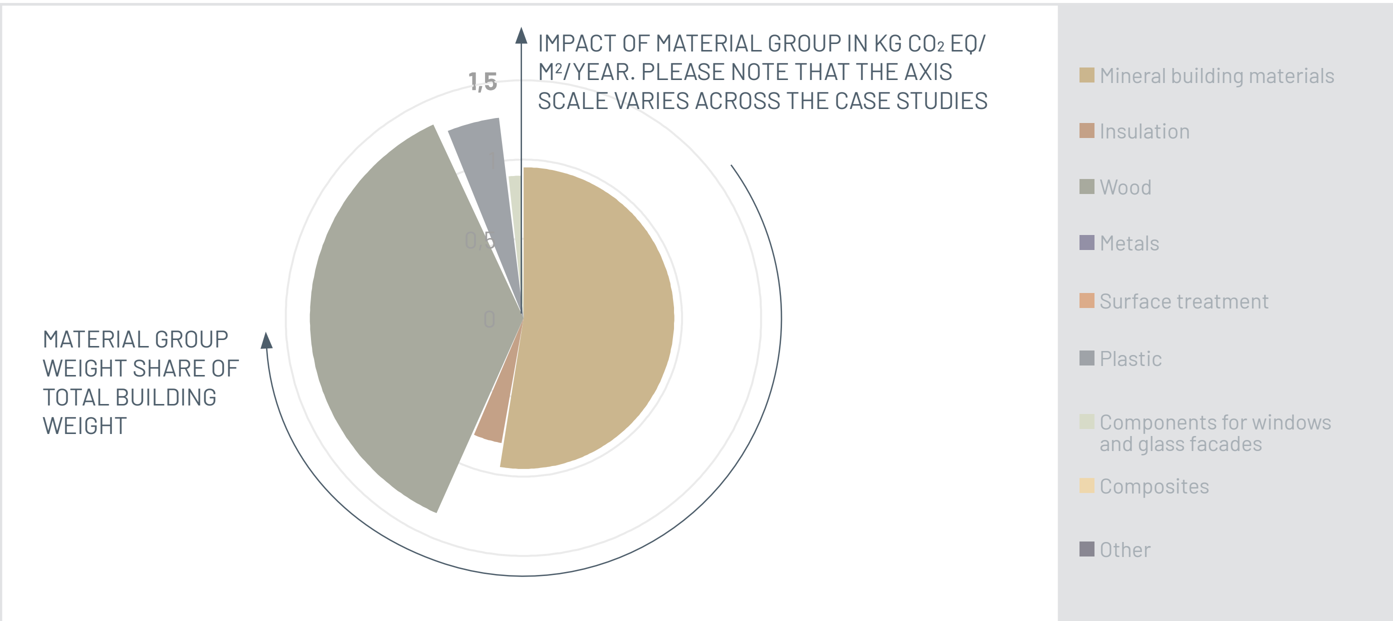




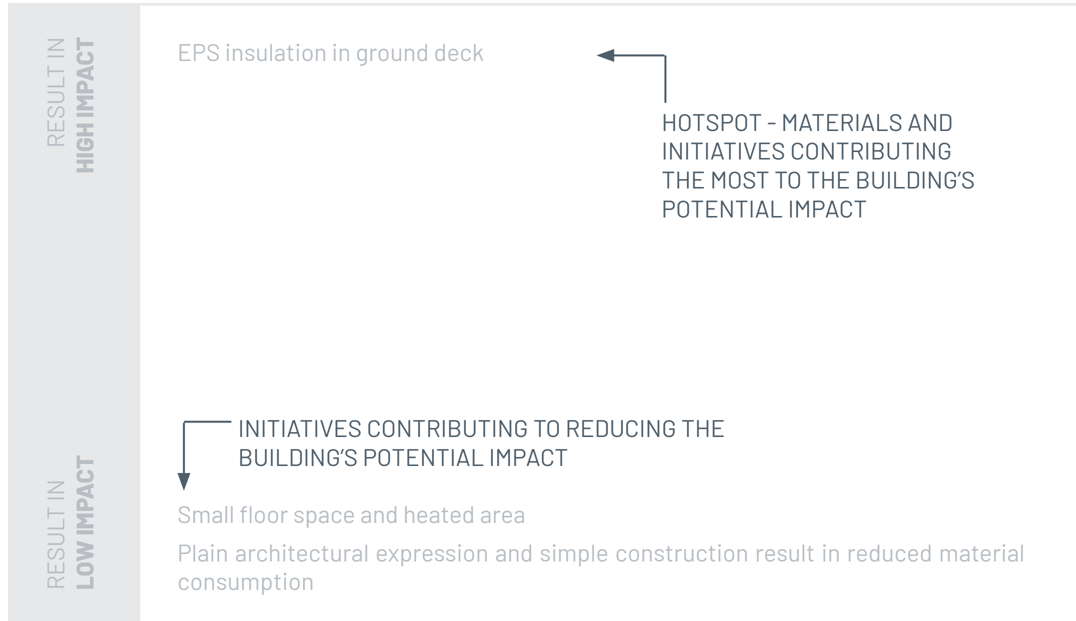
ENVIRONMENTAL IMPACT SHOWN OVER TIME



ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION



DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT



FINDINGS

45 CASE STUDIES

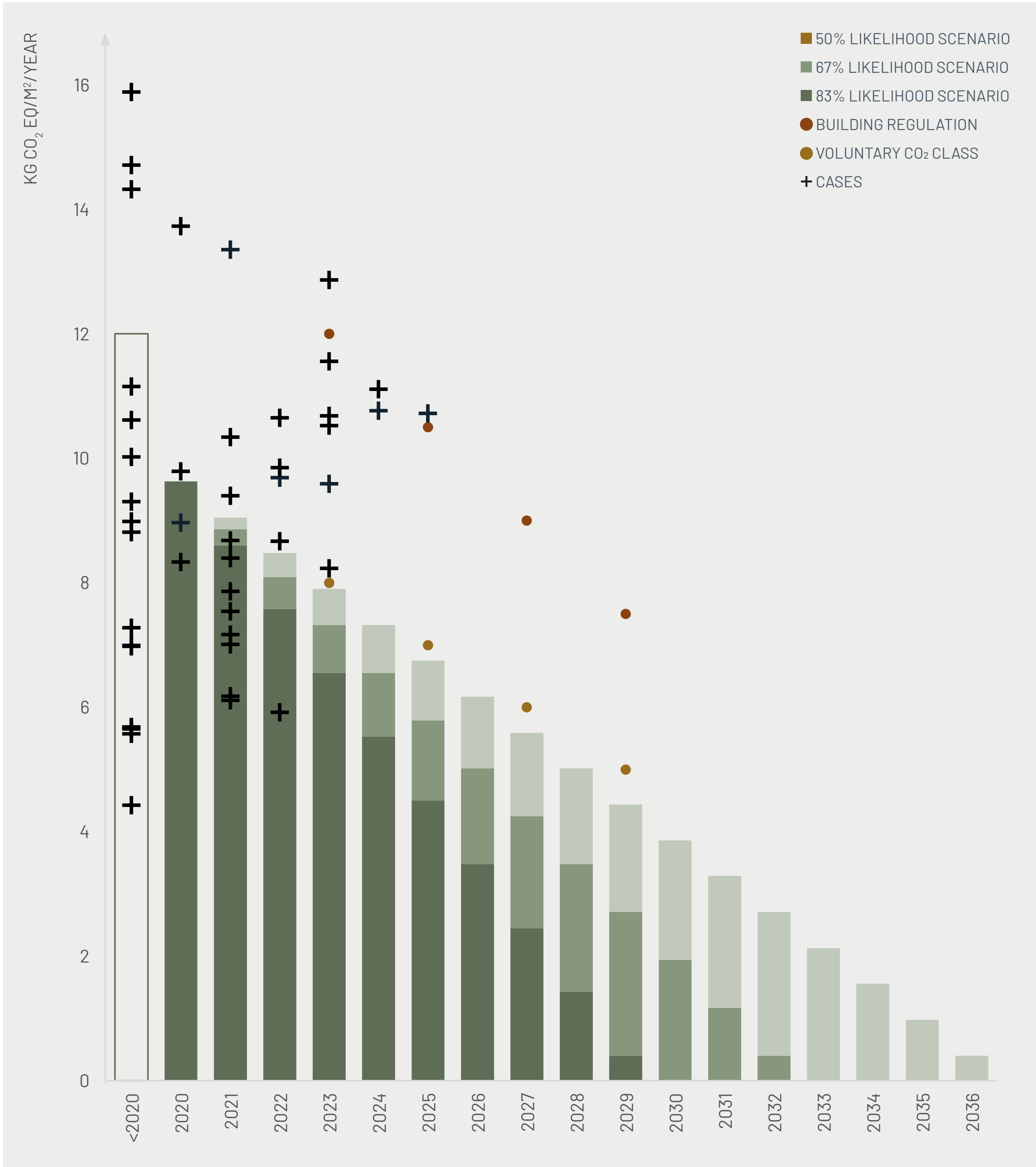
This section shows the LCA results for all 45 case studies. The results are stated in kg CO_2 eq/m²/year and several levels of detail are shown.

In the graph on the right, environmental impact from the case studies is classified in accordance with the so-called reduction roadmap (Reduction Roadmap, 2023). Reduction roadmaps are developed to show the path from an environmental impact of 9.6 kg CO_2 eq/m²/year for an average Danish house to achieve the goal of reducing impact to just 0.4 kg CO_2 eq/m²/year, which would comply with the planetary boundaries (Reduction Roadmap, 2023). Further, the reduction roadmap shows three different probability scenarios describing the likelihood of complying with the Paris Agreement's goal of limiting global temperature rises to 1.5 degrees. However, according to the latest report from the IPCC, it is impossible to meet the goal of restricting global temperature rises to 1.5 degrees unless emissions are drastically reduced immediately for all sectors (IPCC, 2022). The corollary being that the faster the building industry meets the goal of 0.4 kg CO_2 eq/m²/year, the greater the likelihood of keeping within the goal of 1.5 degrees.

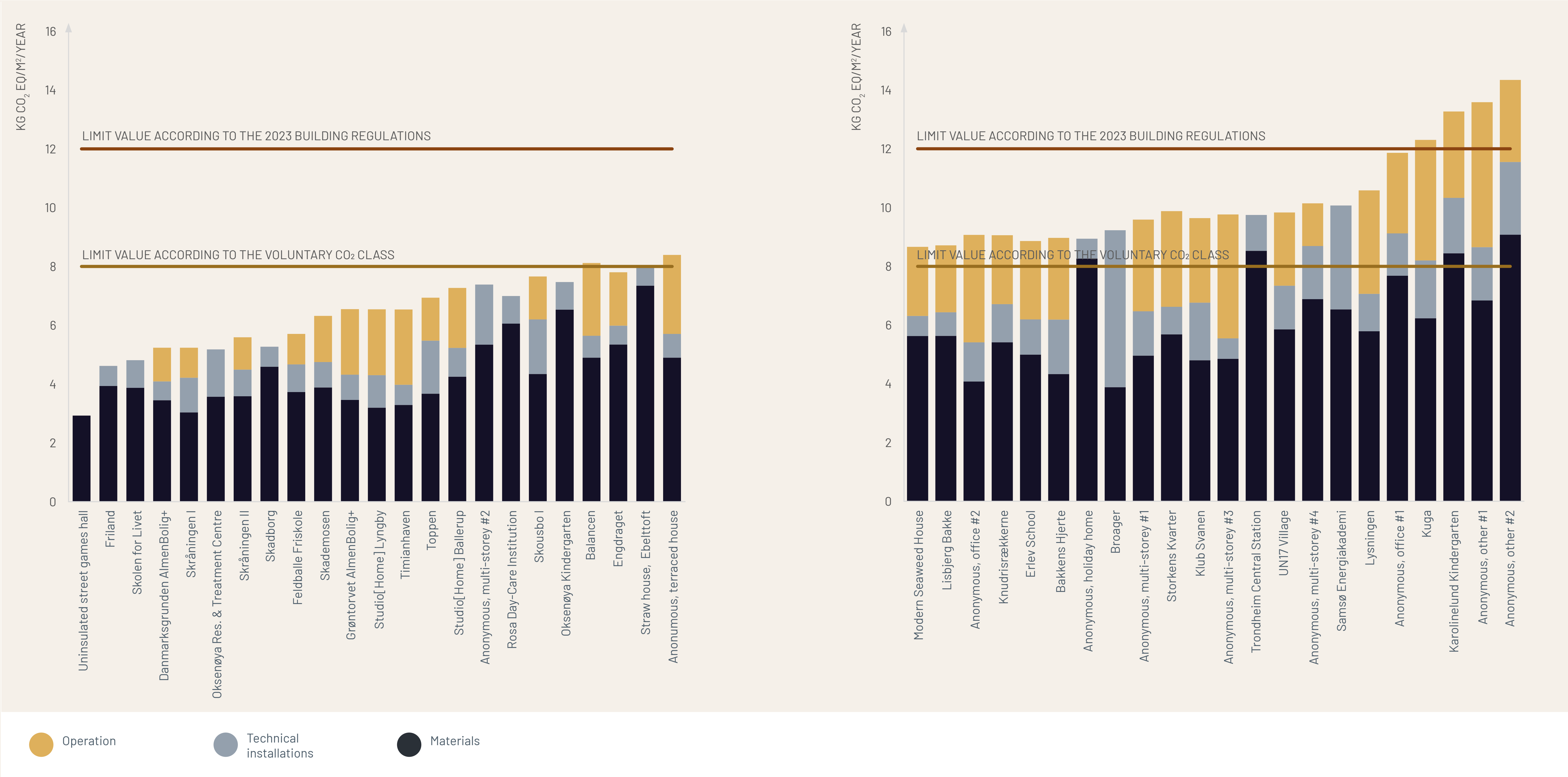
Generally, we note in the case studies that the greatest environmental impact comes from buildings constructed before 2020. Please note that the buildings in the case studies were not specifically designed to reduce environmental impact and that LCA was not used as a tool in the projects' design phase.

The following figures show that:

- **41 cases are below the CO_2 requirements of 12 kg CO_2 eq/m²/year stipulated in the Building Regulations for buildings of more than 1000 m²**
- **14 cases are below the limit value stated in the Voluntary CO_2 class of 8 kg CO_2 eq/m²/year**
- **In all cases, materials contribute more to environmental impact than operation**
- **Ground decks, exterior walls, roofs, windows, doors, and glass facades, are those building parts responsible for the highest environmental impact with more than 50% of the total impact from materials**
- **Ground decks are responsible for the highest environmental impact from materials in 14 cases with more than 22% of the total impact from materials**
- **Materials used in the cases average 684.6 kg/m² over a reference study period of 50 years**

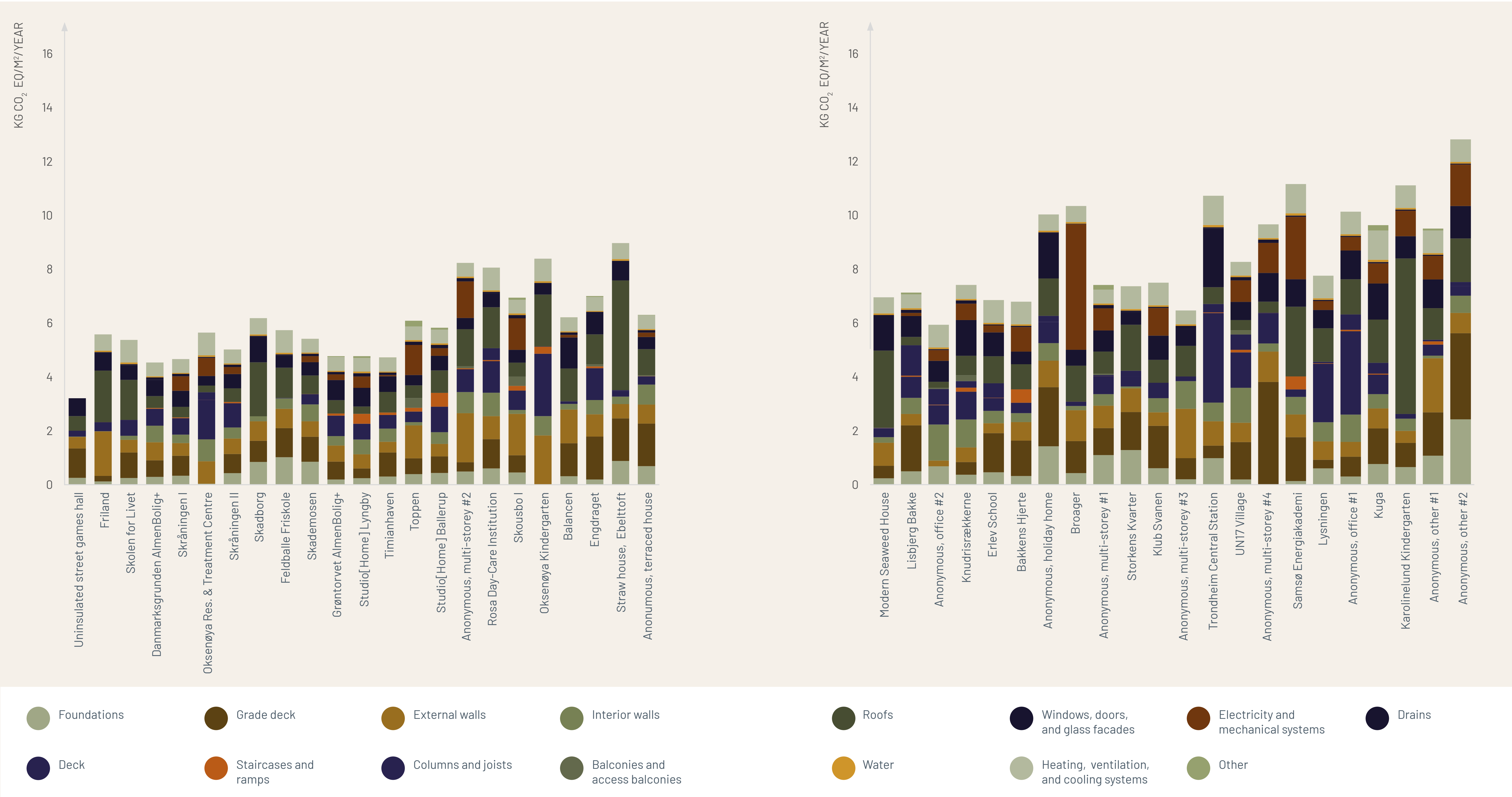


Below, the results of LCAs for all 45 case studies distributed on two graphs. Thus, the guidelines apply to both graphs. The results are specified in kg CO_2 eq/m²/year. Please note that the technical installations, drains and water, heating, ventilation, and cooling systems are based on generic values, whereas electricity and mechanical systems are based on specific values. The results are compared with the Building Regulations' LCA requirements of 12 kg CO_2 eq/m²/year and the limit value in the Voluntary CO_2 Class of 8 kg CO_2 eq/m²/year and do not, therefore, include impact from the life-cycle stages transport, energy consumption, and building-site wastage (A4 and A5).

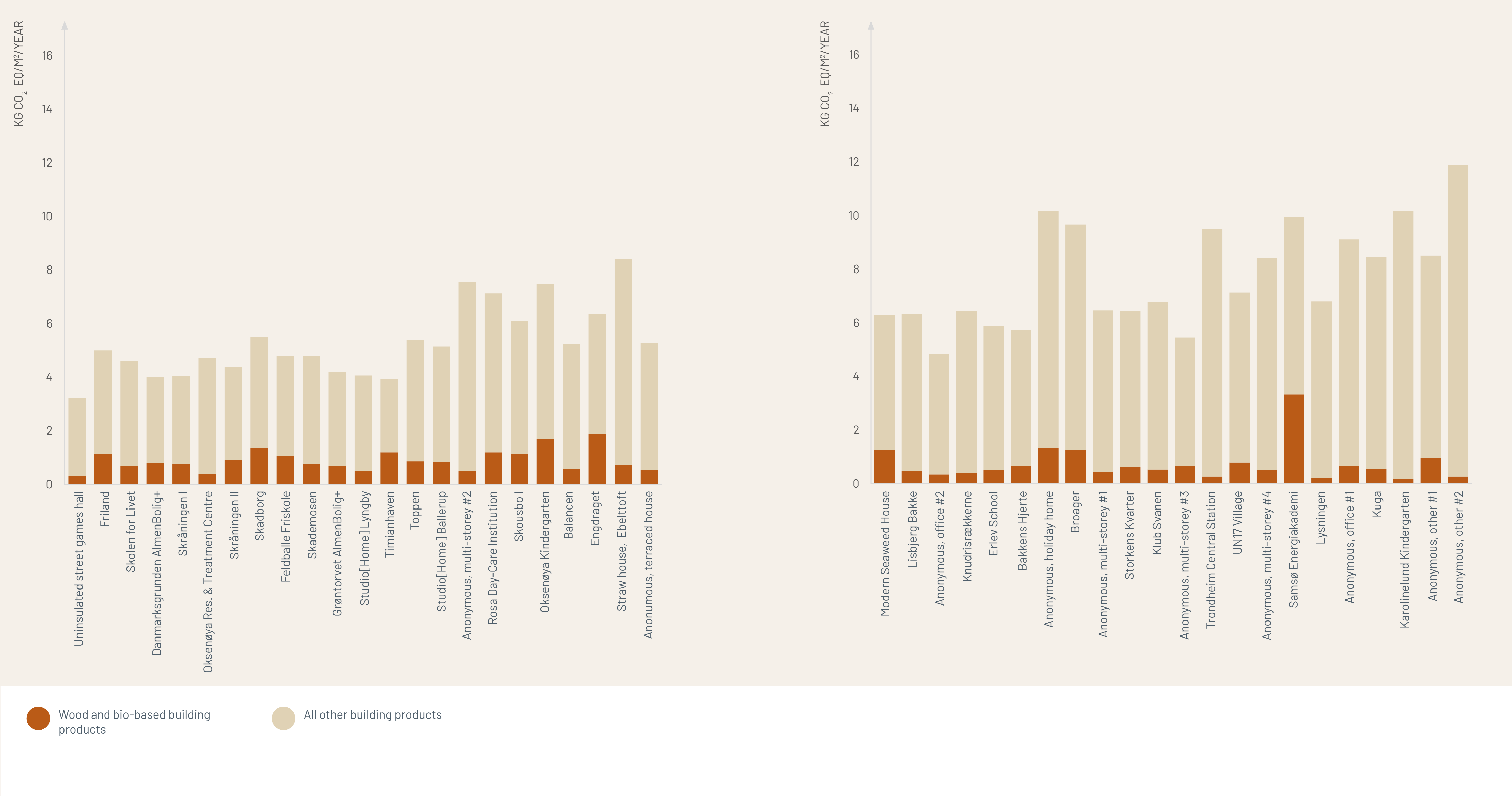


Below, the results of LCAs for all 45 case studies distributed on two graphs. Thus, the guidelines apply to both graphs. The results are specified in kg CO_2 eq/m^2/year. The results are distributed on impact from materials, technical installations, and usage as well as biogenic CO_2 capture and emission. Please note that the technical installations for drains and water, heating, ventilation, and cooling systems are based on generic values, whereas electricity and mechanical systems are specific values.

Below, the results of LCAs for all 45 case studies distributed on two graphs. Thus, the guidelines apply to both graphs. The results show the environmental impact distributed on building parts and is stated in kg CO_2 eq/m²/year. The building parts drains and water, heating, ventilation and cooling systems are based on generic values, whereas electricity and mechanical systems are specific values. Please note that the biogenic CO_2 content is not shown separately.



Below, the results of LCAs for all 45 case studies distributed on two graphs. Thus, the guidelines apply to both graphs. The figures indicate the environmental impact from bio-based building products, including mass timber, glulam, cross-laminated timber (CLT), particle board, and plywood from the total impact for the whole building stated in kg CO_2 eq/m²/year.
Please note that the biogenic CO_2 content is not shown separately.



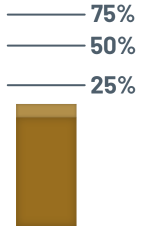
CASE COLLECTION

Photo Martha Lewis

Photo Martha Lewis

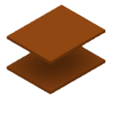
DESCRIPTION

The building is a holiday home and all supporting structures are built in CLT – floors, exterior walls, and roof. During construction, emphasis was on reusing the existing foundations, extended to accommodate a house larger than the original one. Before opting for CLT panels, the client had considered straw bales or a traditional timber-framed structure built on site. However, at the time, CLT panels turned out to be cheapest, since work to install interior cladding could be avoided. Besides, the client found that CLT panels offered a certain aesthetic ambience, as all panels are left untreated in the house

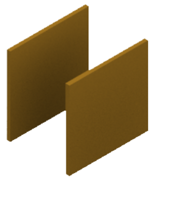


Mat.: 5,5
Tech. inst.: 0,7
Operation: -
stated in KG CO_2 EQ/M²/YEAR

Location	Zealand (NW), Denmark
Year	2021
No. of units	1
Category	Holiday home
Architect	Mikael Schmidt Skadborg & Martha Lewis
Landscape	-
Engineer	-
Client	Mikael Schmidt Skadborg & Martha Lewis
Contractor	CLT Denmark (carcase), Roskilde Tømrerfirma
Type of contract	Seperate works contract
Heated area	53 m²
Energy class	-
Total energy consumption	-
Energy source	-
Data basis for LCA	Architectural model
Certification	-
Project website	-



1 storey



Sheeting (CLT)

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Acoustics
To reduce noise, extra hemp panels were added between bathroom and bedroom and in the wall facing the bedroom.

Economy
Since interior cladding is unnecessary with this type of structure, the client decided to use CLT to save money. Further, the house was energy-optimised with small windows which keep temperatures low in summer and high in winter. Also, 40 m² of the existing concrete footings from the original house were reused, and the existing house is extended by about 20 m2 on two sides.

Logistics
At an early stage in the process, it became necessary to acquire an overview of all installations such as electricity, heating, sanitation, and drains, as these are factory cut. Detailed planning and collaboration with the supplier were required to achieve the desired result. Around 10 hours passed from the first CLT panel had been installed until a water-repellent membrane was fitted to the carcase.

Aesthetics
The aesthetics of wood had been an important design parameter. To retain the brightness of the CLT, walls and ceilings were treated with a mix of linseed oil and water. Finally, the clay floor in the bathroom gives the room a warm appearance.

Construction moisture
The client consulted Træinformation publications (traeinfo.dk) and CLT Denmarks' online information on moisture, fire, statics, and acoustics. Emphasis had been on closing off the carcase as quickly as possible to avoid construction moisture.

Moisture during use
The bathroom is placed in the corner, hence CLT was not used as flooring there. To mitigate moisture in the usage phase, the walls were given a coating of clay plaster.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

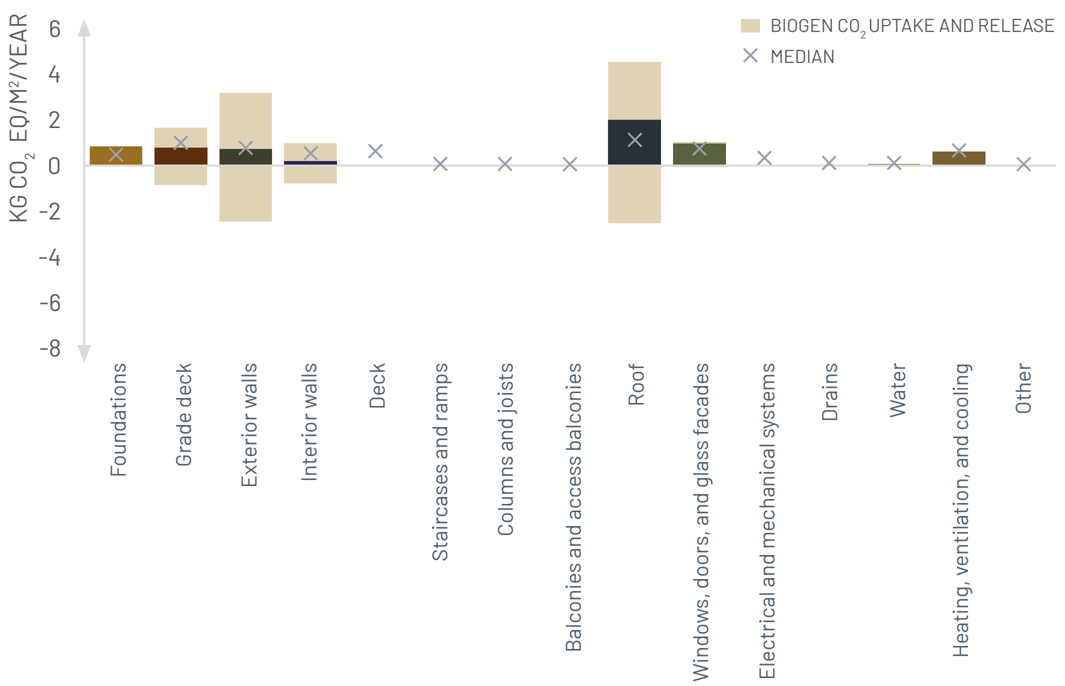


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

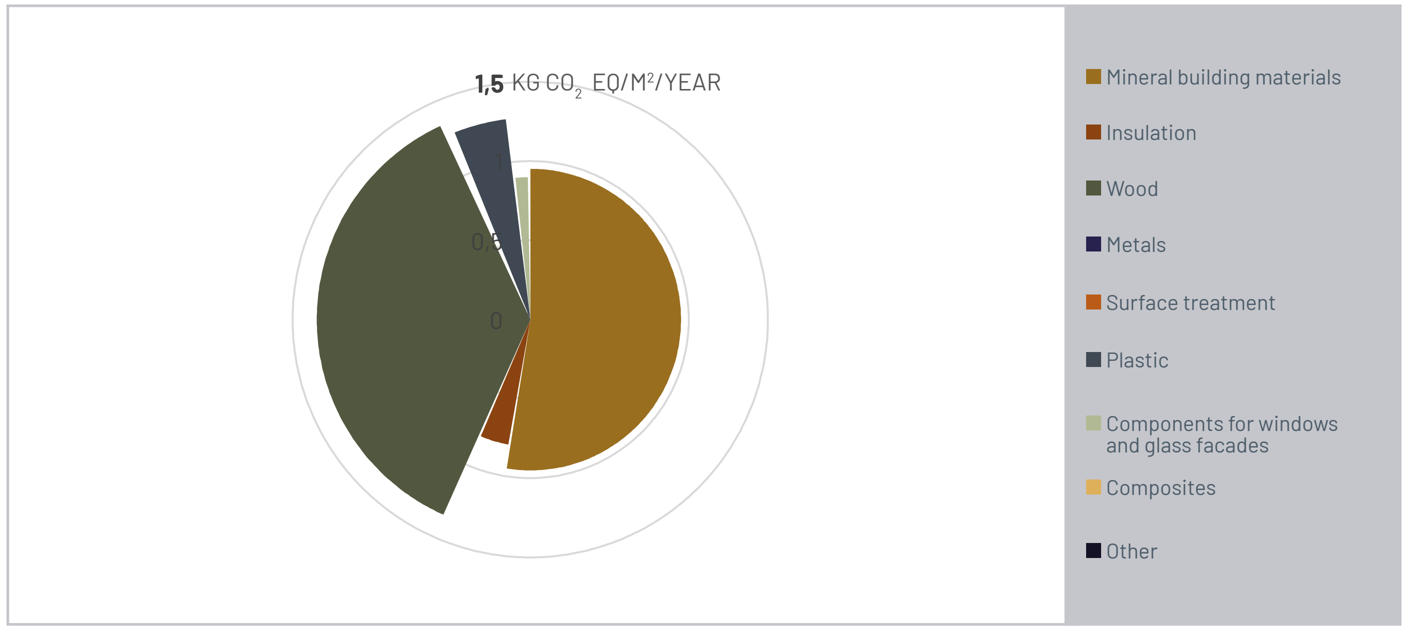


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

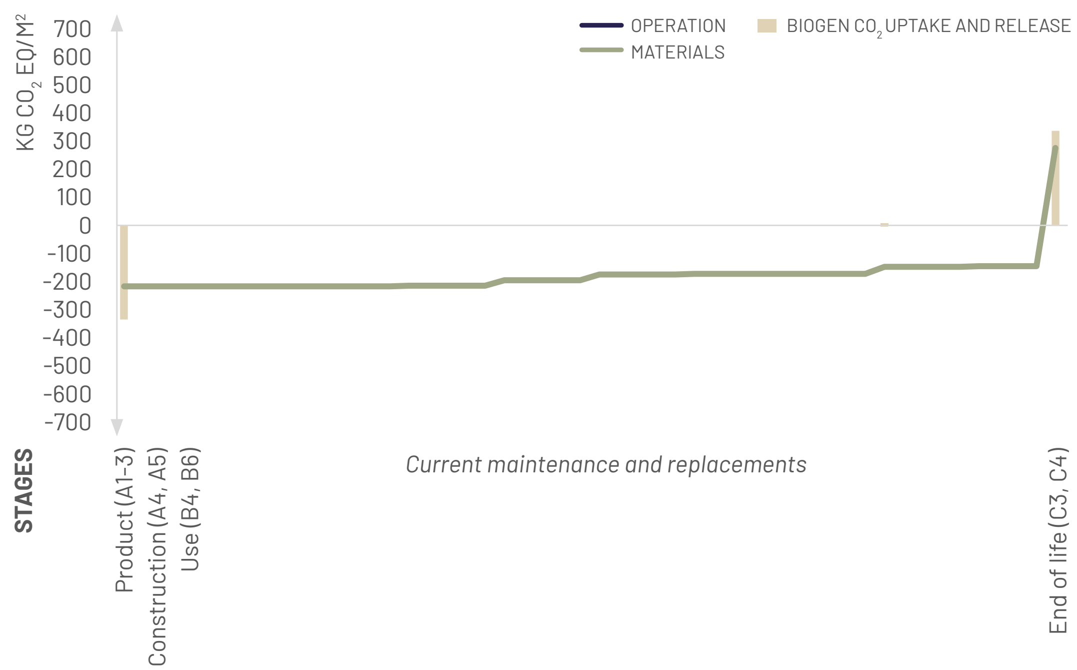


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

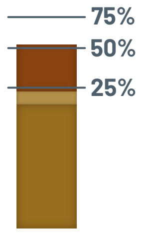
RESULT IN **HIGH IMPACT**	Slated bituminous felt roofing
RESULT IN **LOW IMPACT**	Material consumption of 570.3 kg/m² is below average (average being 684.6 kg/m²) Small floor space and heated area Plain architectural expression and simple constructions reduce the use of materials

MODERN SEAWEED HOUSE

Photo Vandkunsten

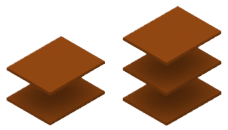
DESCRIPTION

The modern seaweed house is a contemporary interpretation of the traditional use of eelgrass for seaweed roofs commonly found on the island of Læsø, where the house is located. The building was constructed in close collaboration with local workmen and functions as a holiday home. The insulation properties of eelgrass are almost equal to those of mineral wool; a fact exploited in the modern seaweed house by placing seaweed between the floor, facade, and roofing structures. Besides, eelgrass is a fire-retardant and enhances the acoustics in the home.

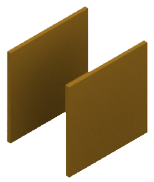


Mat.: 6,3
Tech. inst.: 0,7
Operation: 2,4
stated in KG CO_2 EQ/M²/YEAR

Location	Læsø, Denmark
Year	2012-2013
No. of units	1
Category	Single-family housing
Architect	Vandkunsten
Landscape	Vandkunsten
Engineer	Artelia (fomerly MOE)
Client	Realdania Byg
Contractor	Greenhouse
Type of contract	Turnkey contract
Heated area	87 m^2
Energy class	Building class 2020
Total energy consumption	24,7 kWh/m²/year
Energy source	Projected electricity mix
Data basis for LCA	Architectural model
Certification	-
Project website	See link



1,5 storeys



Sheeting

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Aesthetics
Eelgrass was used as insulation material and facade cladding in response to the project's main focus area. Further, wood was used as the supporting structure in cassettes, as interior and exterior cladding, and for staircases.

Construction moisture
Eelgrass was twisted and compressed in long 'knitted' tubes in wall and roof cassettes. After construction, problems with roof leakage and moisture intrusion occurred. Consequently, the present owner decided to remove the eelgrass on the roof surface and replace it with alternative materials.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

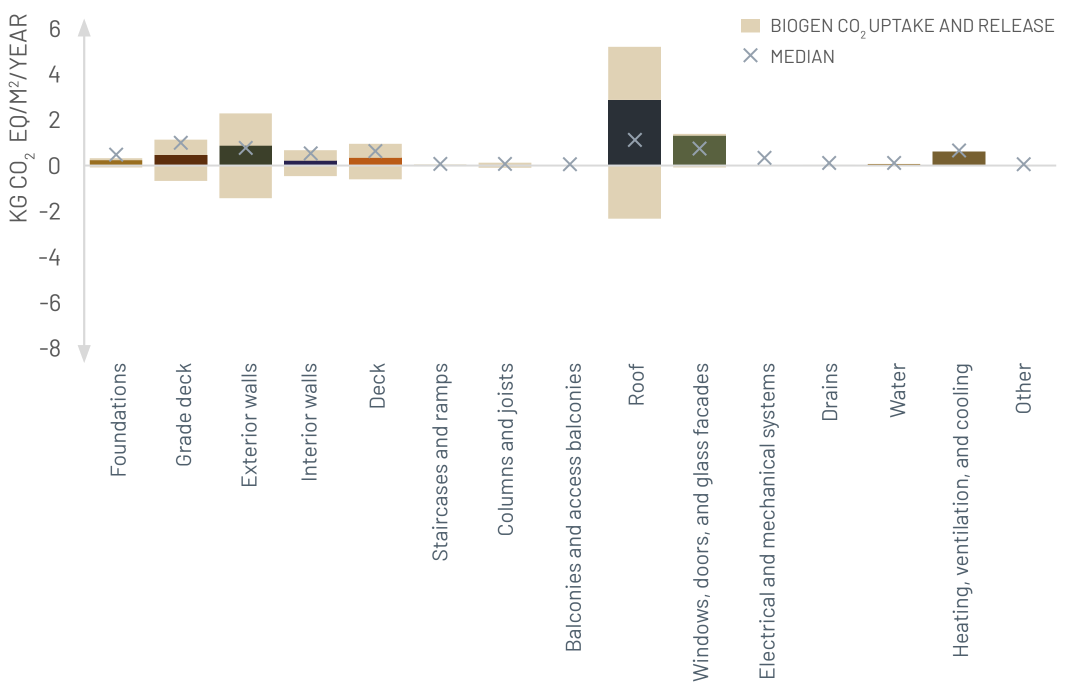


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m^2/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

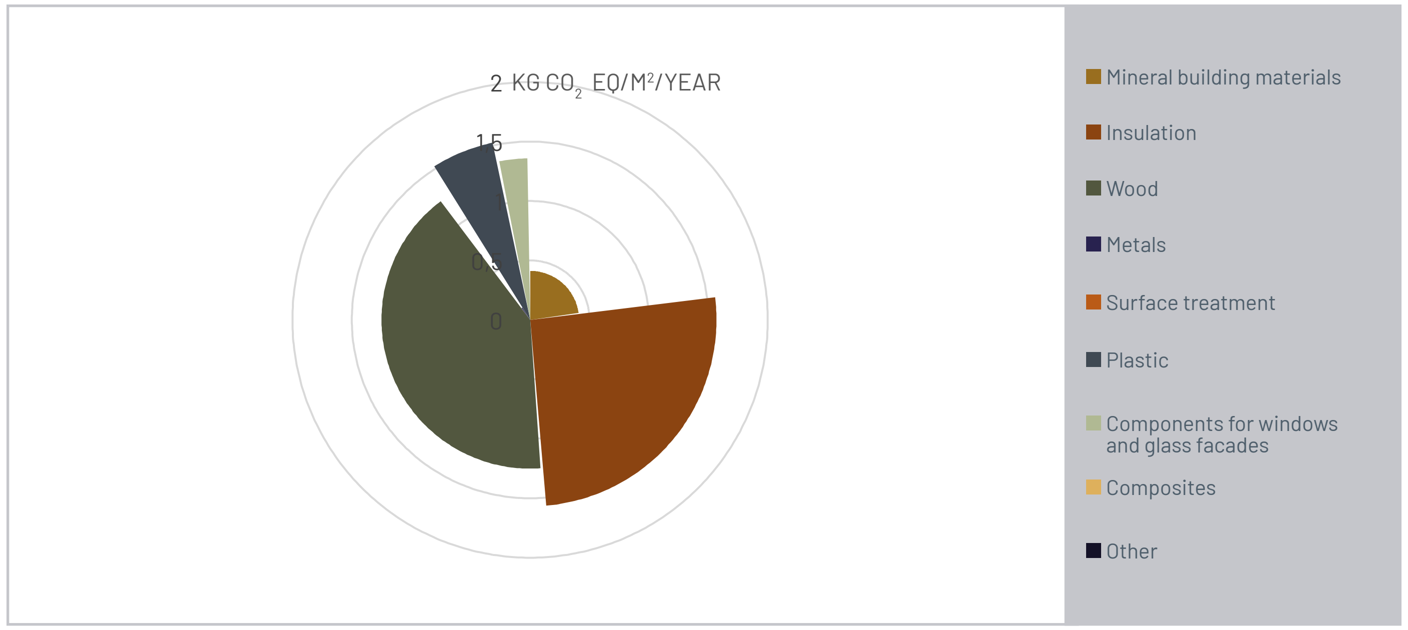


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

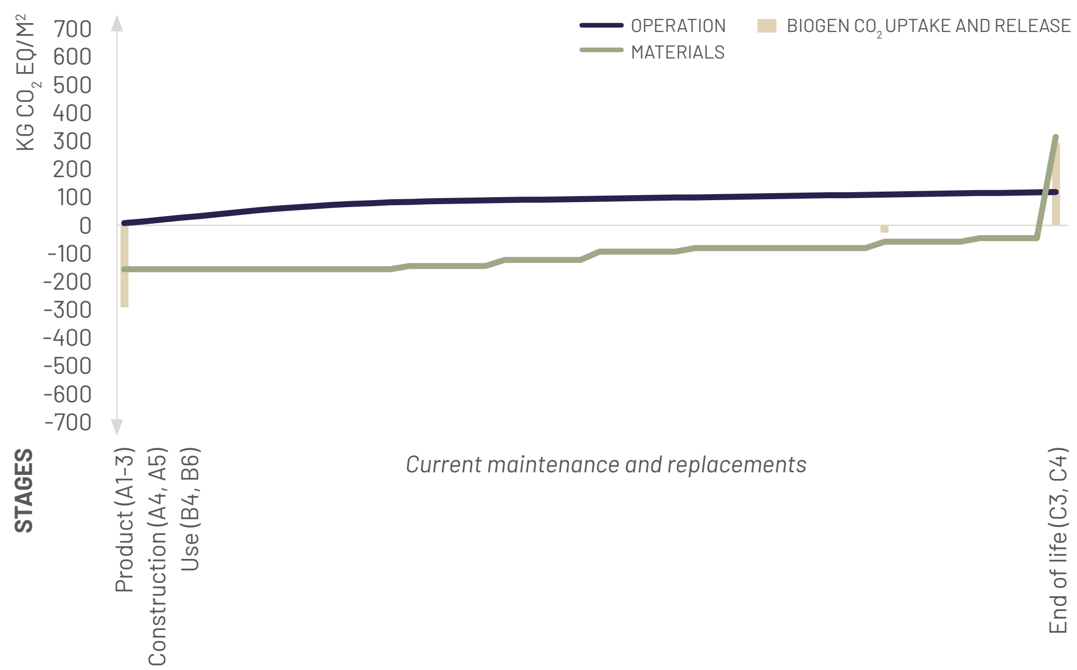


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m^2 distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

RESULT IN **HIGH IMPACT**	Double-glazing in climate envelope Bituminous felt roofing membrane substrate Eelgrass roof
RESULT IN **LOW IMPACT**	Material consumption of 460.8 kg/m² is below average (average being 684.6 kg/m²) Plain architectural expression and simple constructions reduce the use of materials

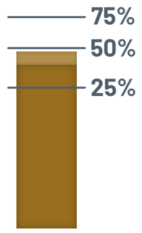
STRAW HOUSE, EBELTOFT


Photo Sophia Lydolph / EcoCocon Denmark

DESCRIPTION

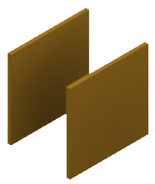
The straw-bale house in Ebeltoft was motivated by a desire to construct a sustainable building. Consequently, straw bales were used for the supporting structures and a green sedum roof was added

Location	Ebeltoft, Denmark
Year	2020
No. of units	1
Category	Single-family housing
Architect	-
Landscape	-
Engineer	Thoudal Rådgivende Ingeniørfirma
Client	-
Contractor	Self-build
Type of contract	-
Heated area	-
Energy class	147 m^2
Total energy consumption	-
Energy source	-
Data basis for LCA	Architectural model
Certification	-
Project website	-



Mat.: 8,3
Tech. inst.: 0,7
Operation: -
stated in KG CO_2 EQ/M²/YEAR


1 storey


Sheeting

USE OF WOOD: KEY ACTORS' EXPERIENCE

No interview conducted on this building, and hence no experience was shared.


Photo Sophia Lydolf / EcoCocon Denmark

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

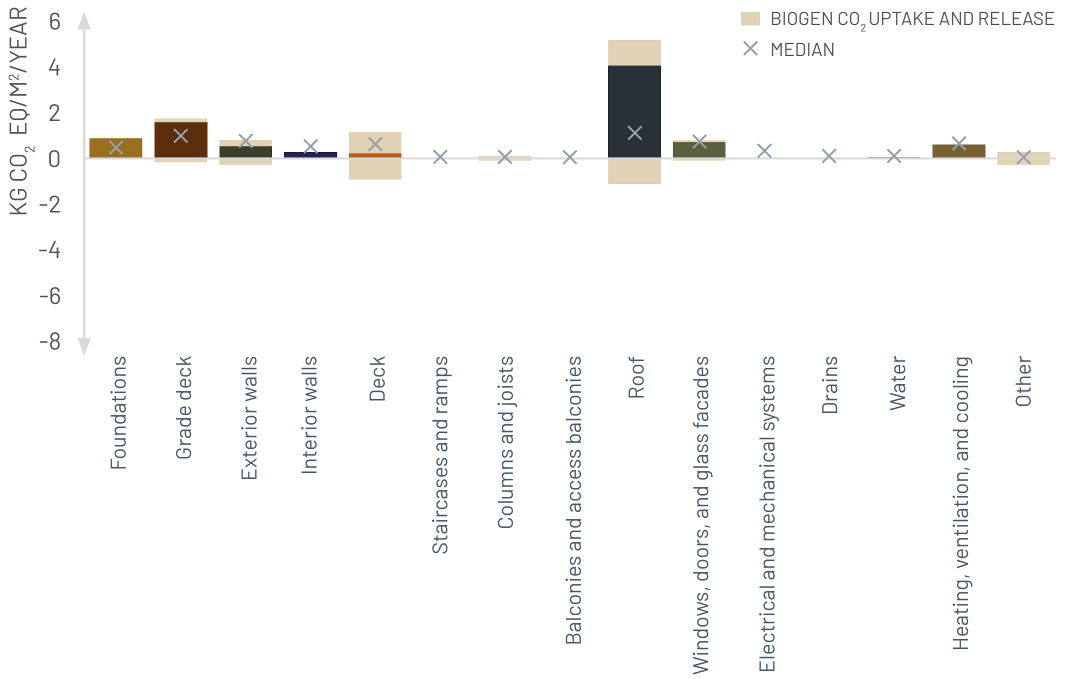


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

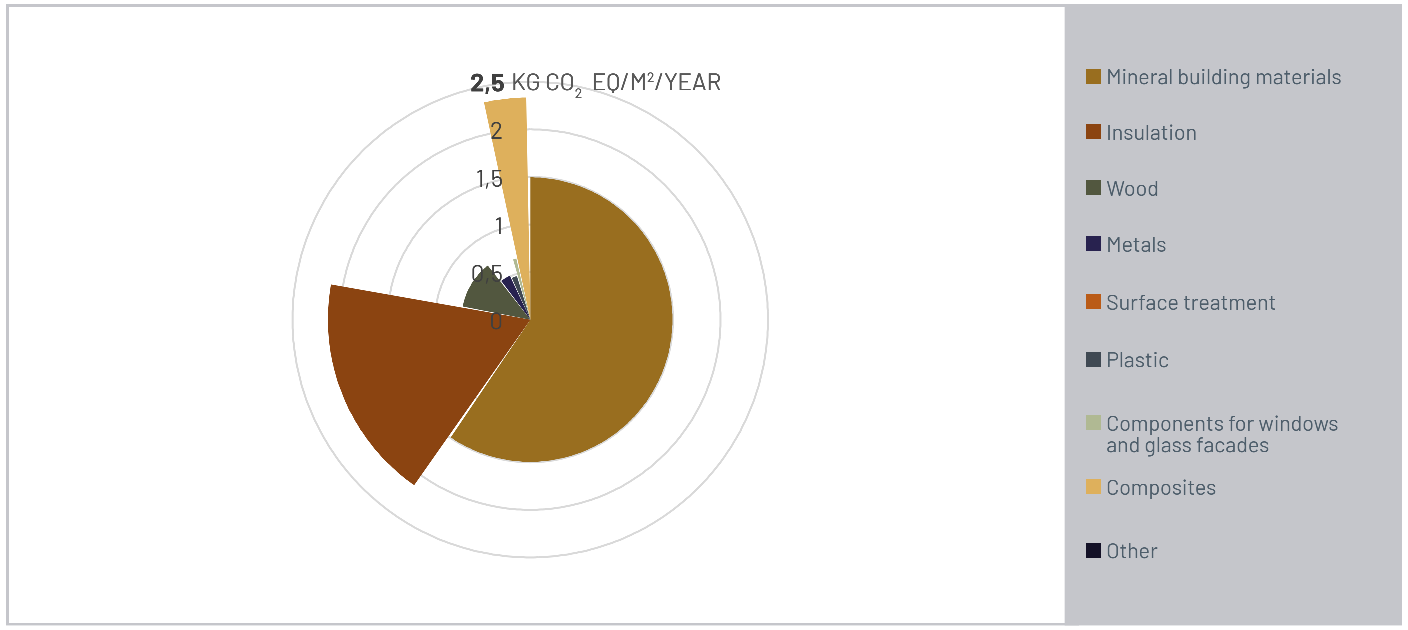


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

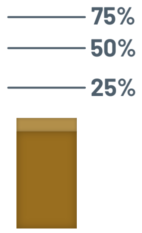
DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

RESULT IN **HIGH IMPACT**	Sedum roof results in increased use of materials in the roof structure Reinforcement mesh incorporated in grade concrete deck EPS insulation in grade deck
RESULT IN **LOW IMPACT**	

Photo Lars Keller / EcoCocon Denmark

DESCRIPTION

Friland is a private home located on the Friland estate on the Djursland peninsula. The client wanted to use bio-based materials to obtain a low climate footprint. Consequently, straw bales were chosen, as they are easy to install and can potentially be reused after the end-of-life stage. The client built the house himself assisted by friends and local workmen.



Mat.: 4,9
Tech. inst.: 0,7
Operation: -
stated in KG CO_2 EQ/M²/YEAR

Location	Rønde, Denmark
Year	2015
No. of units	1
Category	Single-family housing
Architect	-
Landscape	-
Engineer	Private acquaintance, EcoCocon
Client	Kent Olsen
Contractor	-
Type of contract	Self-build
Heated area	143 m²
Energy class	-
Total energy consumption	-
Energy source	-
Data basis for LCA	Architectural model
Certification	-
Project website	-

1,5 storeys

Sheeting

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Acoustics
Clay-plastered walls and a gypsum fibreboard ceiling with a coating of clay plaster was used to enhance the acoustics in the house. Further, wood wool filler was placed in the storey partition to avoid footfall transmission.

Logistics
The straw-bale panels were regular, facilitating the instalment work during the construction phase. Three days after the first element was delivered, the carcase was completed.

Construction moisture
The client took care not to incorporate moisture into the building. The elements were covered with tarps during construction. Further, a waterproof and vapour-permeable wind barrier was installed on the elements after delivery.

Moisture during use
A wind barrier was clipped on to the straw-bale elements. Following that, the elements were given a coating of clay plaster inside and out.

FRILAND

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

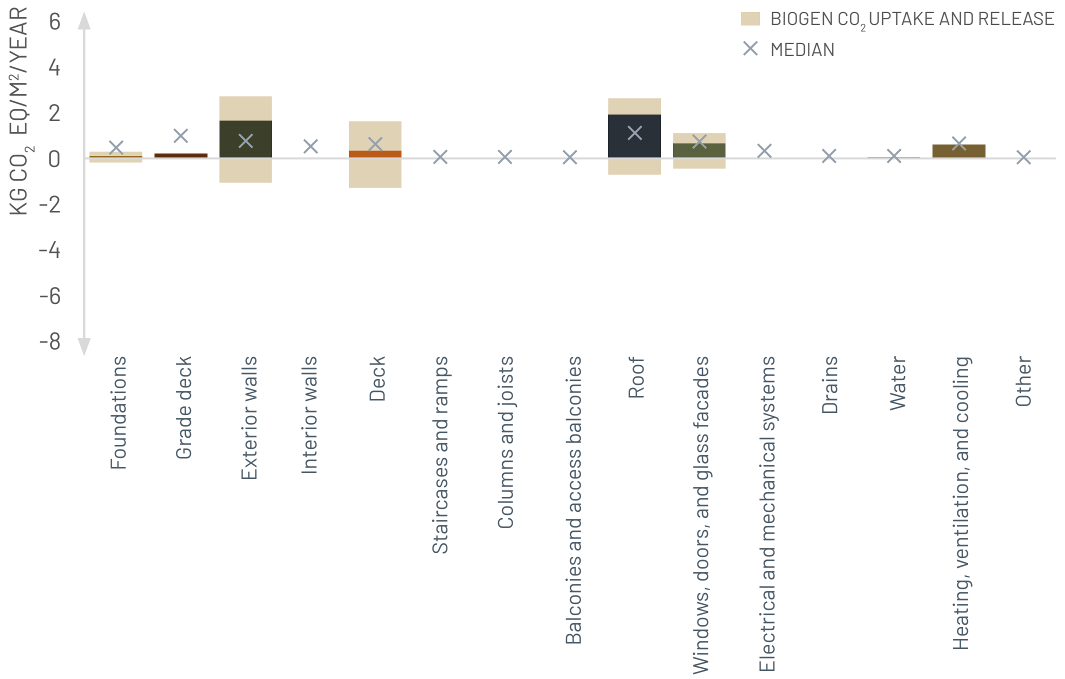


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

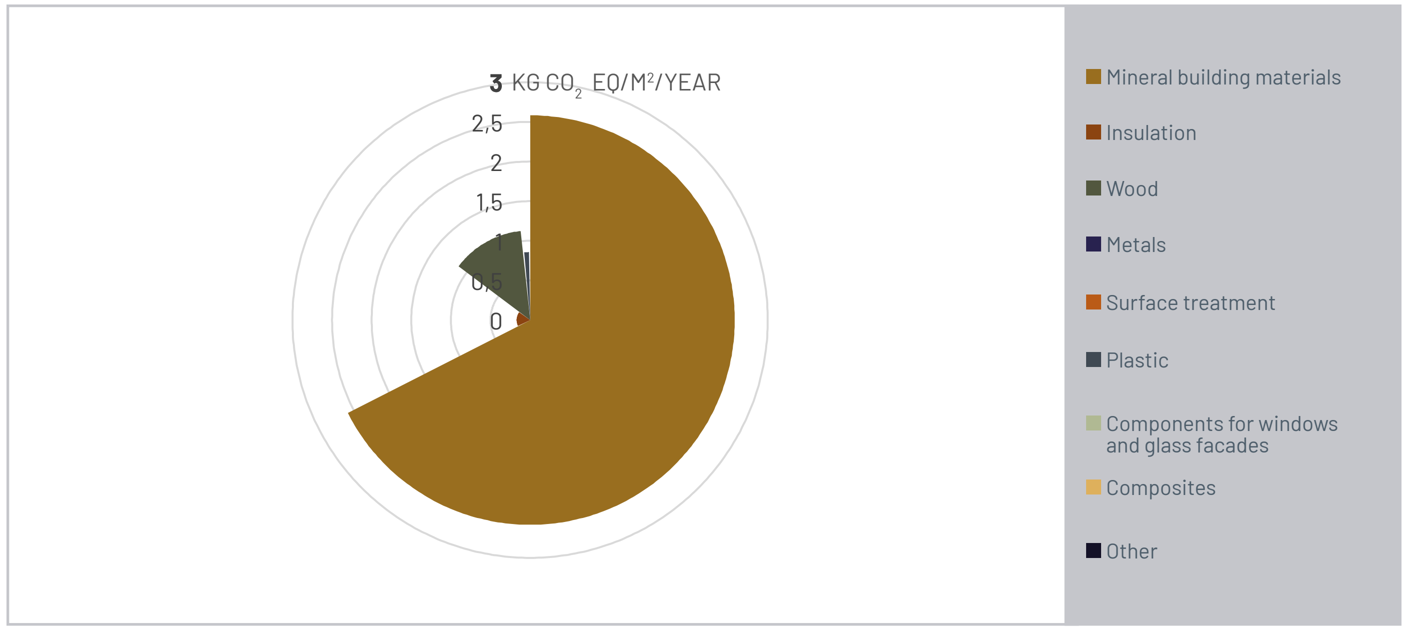


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

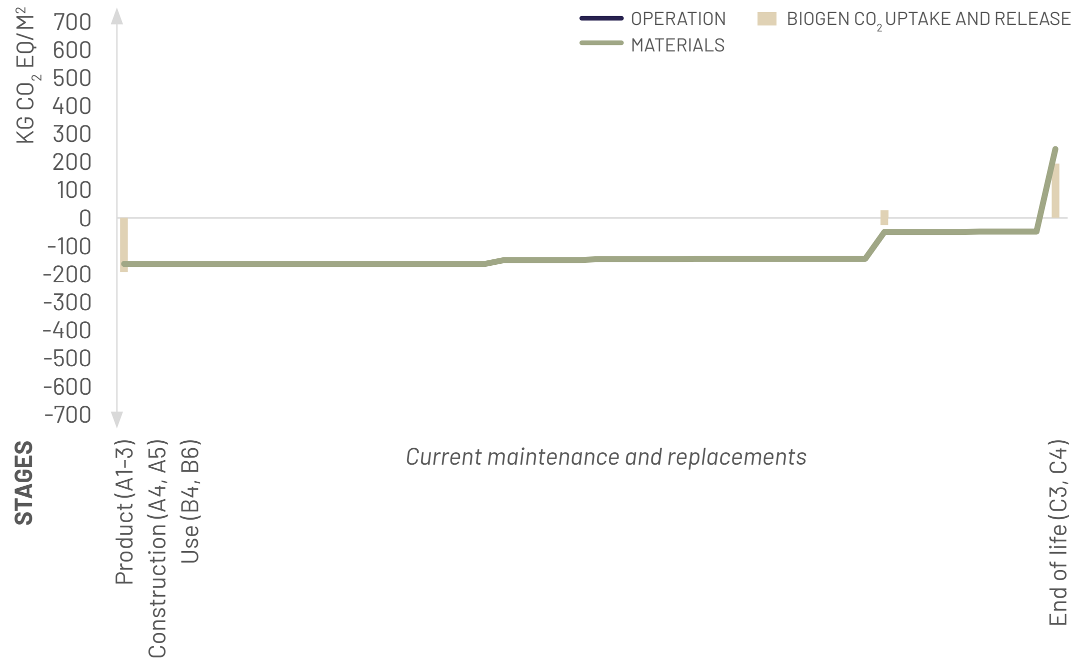


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

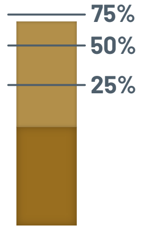
DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

RESULT IN **HIGH IMPACT**	High-pitch roof with large overhang results in an increased use of material resources for the structure Wood-fibre roof insulation
RESULT IN **LOW IMPACT**	


Photo Charlotte Maanstaedt

DESCRIPTION

Wood was selected as construction material in this single-family dwelling, as the client wanted the building to be as climate-friendly as possible. The house was constructed with straw bales in all walls, and the roof was a classic timber structure. The client wanted the walls to be screw-resistant, so gypsum fibreboard was mounted to the interior side of the straw bales and then given a coat of plaster.



Mat.: 5,0
Tech. inst.: 5,3
Operation: -
stated in KG CO_2 EQ/M²/YEAR

Location	Stevns, Denmark
Year	2021
No. of units	1
Category	Single-family housing
Architect	Charlotte Maanstaedt
Landscape	-
Engineer	Nick Kalmer
Client	Charlotte Maanstaedt
Contractor	-
Type of contract	Separate
Heated area	91 m²
Energy class	Building class 2020
Total energy consumption	-
Energy source	-
Data basis for LCA	Architectural model
Certification	-
Project website	-

1,5 storeys

Sheeting

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
The straw-bale panels carry a fire certificate

Acoustics
The client wanted the walls to be screw-resistant, so gypsum fibreboard was installed on all interior walls. The walls were given a coat of clay plaster and cement-bonded wood wool was installed on all ceilings.

Economy
It proved difficult to get a loan to build this house, as several insurance companies refuse to insure buildings constructed with untraditional building materials. This notably affected insurance against fire and fungus attack.

Aesthetics
The local plan applicable to the area stipulated that building facades must be either exposed brickwork or plastered. Consequently, the straw-bale panels were plastered on the outside.

Logistics & Construction moisture
Tarps were used to protect panels and decks during construction phase from May to August. The panels arrived in August and were installed, except for the roof, in three days by an experienced team (four carpenters, two clients, and a crane operator). Following that, the carcase was protected with tarps and the exterior walls with a wind barrier. The roof structure was then built over a period of 2–4 weeks. The client recommends working with a covered building site for similar projects in the future.

The client had contracted an engineer to advise on the handling of various issues concerning fire, moisture, and statics. Moreover, the client acted as co-builder, which ensured optimised planning throughout the project.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

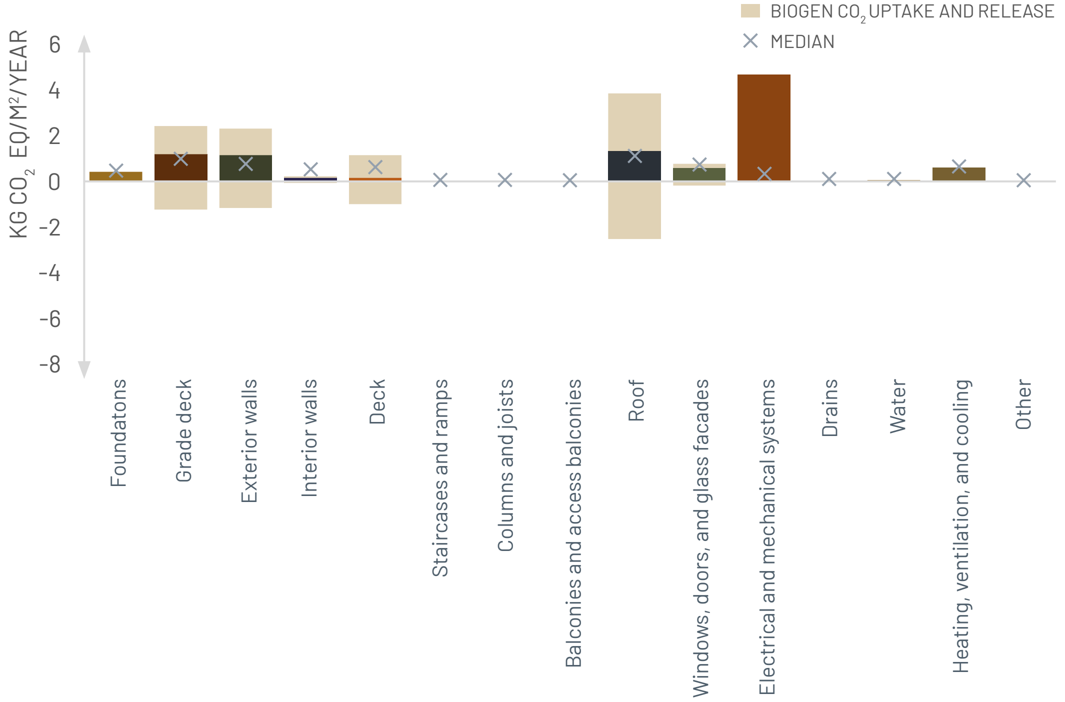


Figure 9. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc. Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

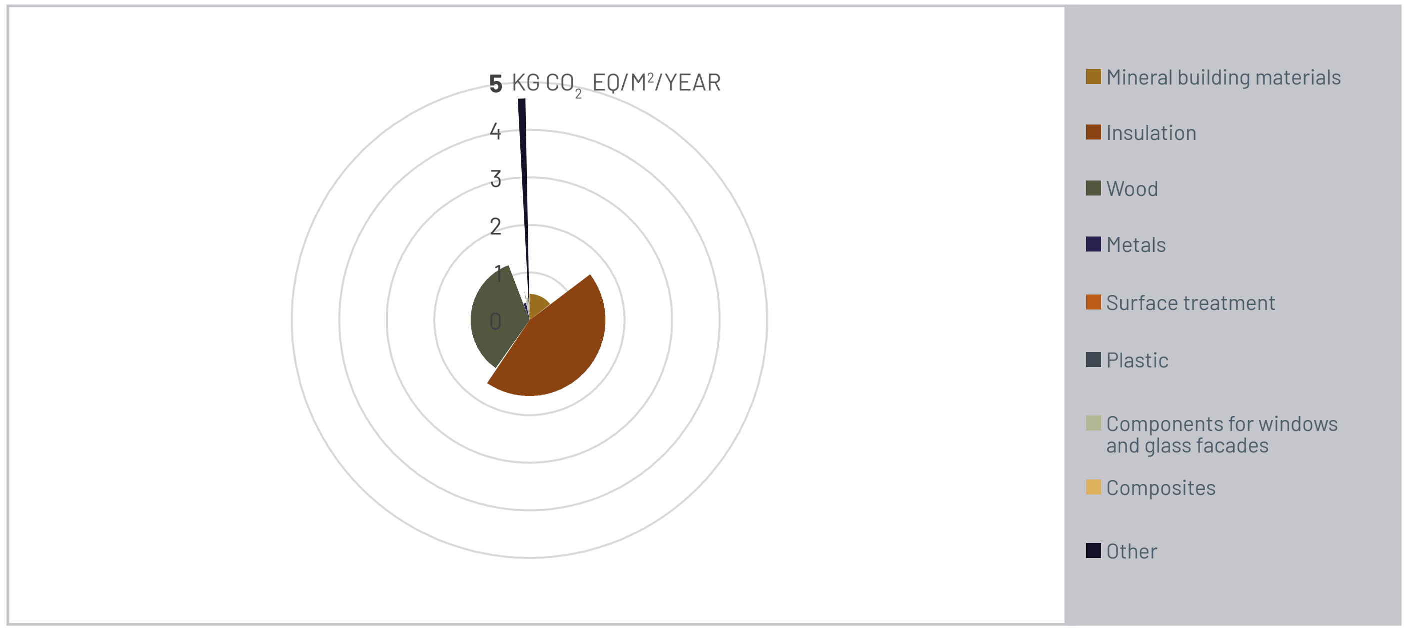


Figure 10. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

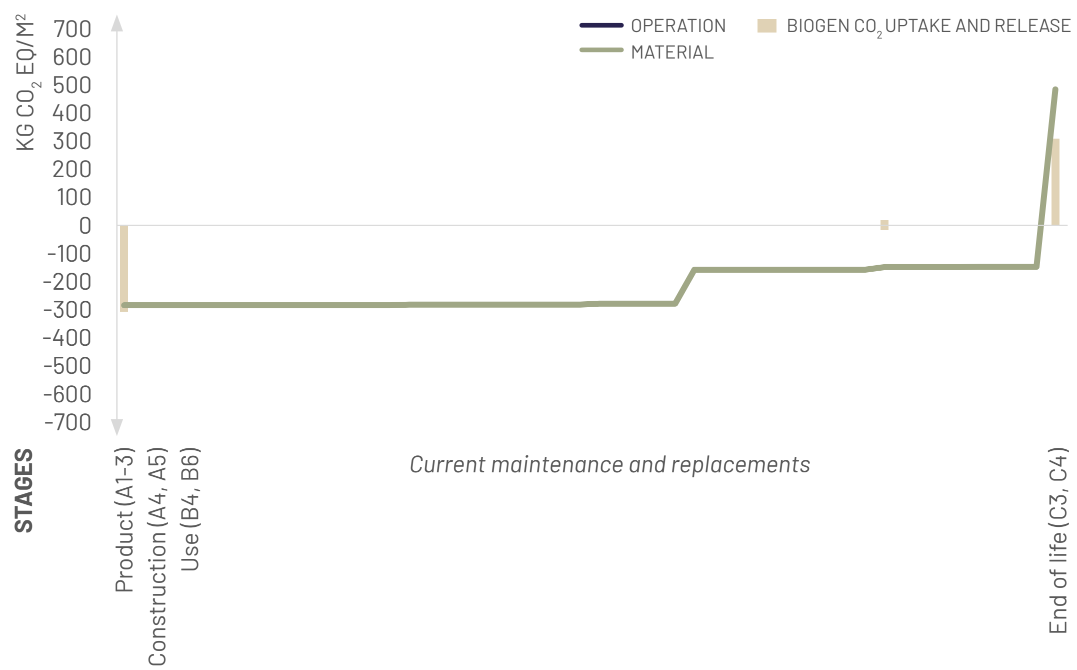


Figure 11. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

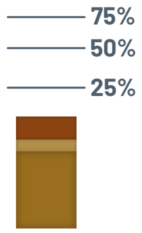
DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

RESULT IN **HIGH IMPACT**	Photovoltaic modules on roof Wood-fibre insulation in roof and grade deck
RESULT IN **LOW IMPACT**	Plain architecture without large glazed areas Material consumption of 590.1 kg/m² is below average (average being 684.6 kg/m²)


Photo Vandkunsten

DESCRIPTION

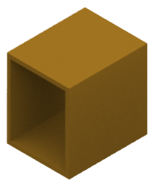
The terraced housing on Danmarksgrunden was designed for the housing association KAB. The terraced housing is part of the concept of AlmenBolig+, a concept focusing on affordable good quality homes. It is a requirements that rents are kept low. In AlmenBolig+ housing, the average rent is approx. 23% lower than in other comparable housing schemes. In this project, for example, the saving was achieved via energy-optimisation and prefabrication. The building design specified cassettes, which helped reduce costs and resources. Further, long-lasting materials were used to ensure low maintenance and a minimum of replacements.



Mat.: 3,9
Tech. inst.: 0,6
Operation: 1,1
stated in KG CO_2 EQ/M²/YEAR

Location	Rødovre, Denmark
Year	2010-2014
No. of units	72 housing units
Category	Housing scheme
Architect	Vandkunsten
Landscape	Vandkunsten
Engineer	Dansk Energimanagement and Esbensen
Client	Boligselskabet AKB, ved KAB
Contractor	GVL Entreprise & BM Tag
Type of contract	Turnkey contract
Heated area	8.370 m²
Energy class	Low-energy class BR2018
Total energy consumption	35,3 kWh/m²/year
Energy source	Projected electricity mix
Data basis for LCA	Architectural model
Certification	-
Project website	See link

2-3 storeys


Cassette

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
Three layers of gypsum or two of gypsum fibreboard were added on both sides of the fire section between housing units to protect the supporting timber structures against fire.

Economy
The goal was to obtain the best quality within the given price constraints, for example, resulting in low-maintenance facade materials being selected. This helps keep costs down for both the client and tenants during use.

Logistics & Aesthetics
The sketch plan was projected with a cassette construction, as the idea was to create quality cheap homes and attract architectural interest in using cassettes.

Construction moisture
The cassettes were delivered wrapped and protected. The facade was installed on site to ensure that the seams between the cassettes were finished correctly.

Moisture during use
The prefabricated cassettes were raised 40 cm above grade and trenches were dug around the foundations to avoid moisture intrusion.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

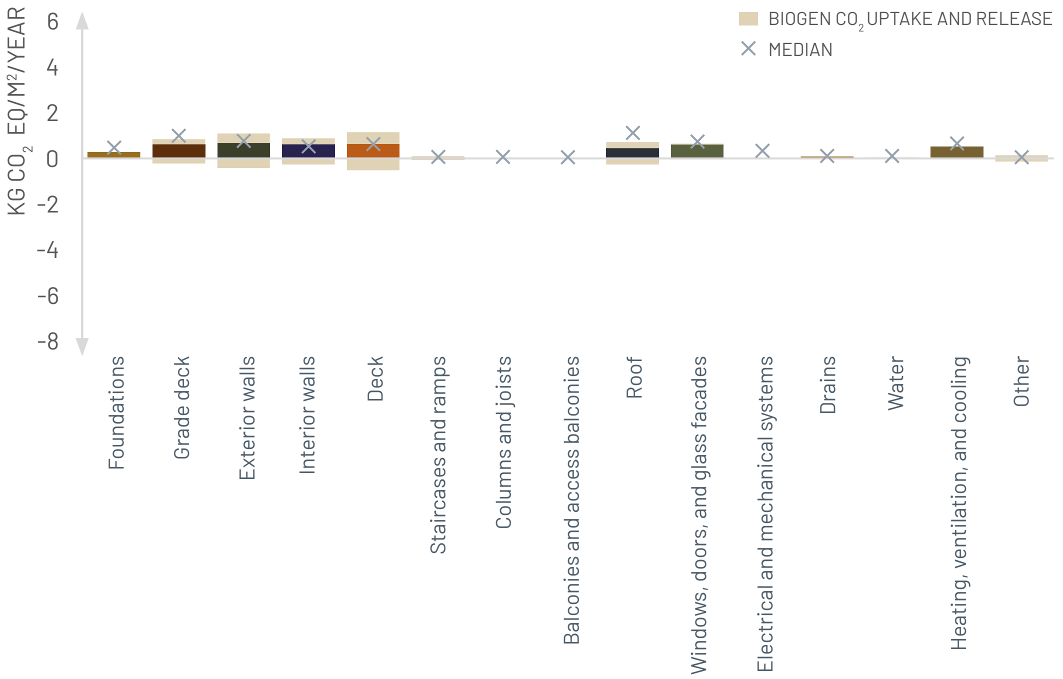


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

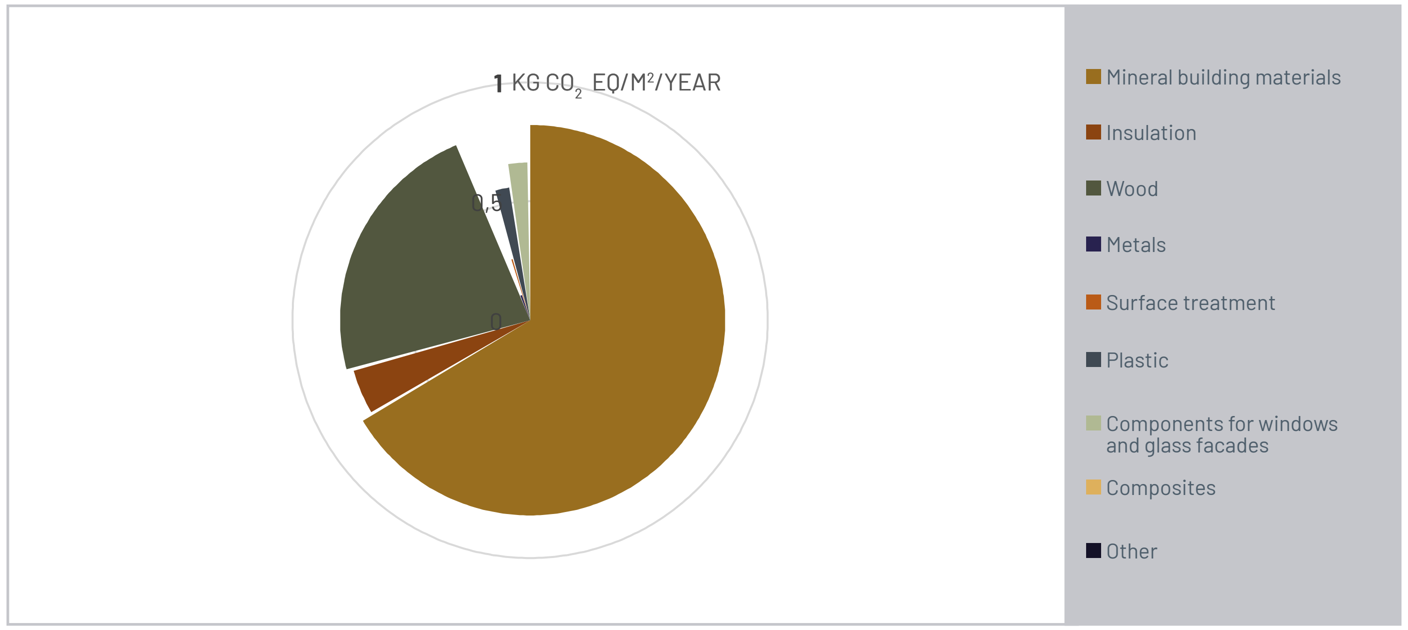


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

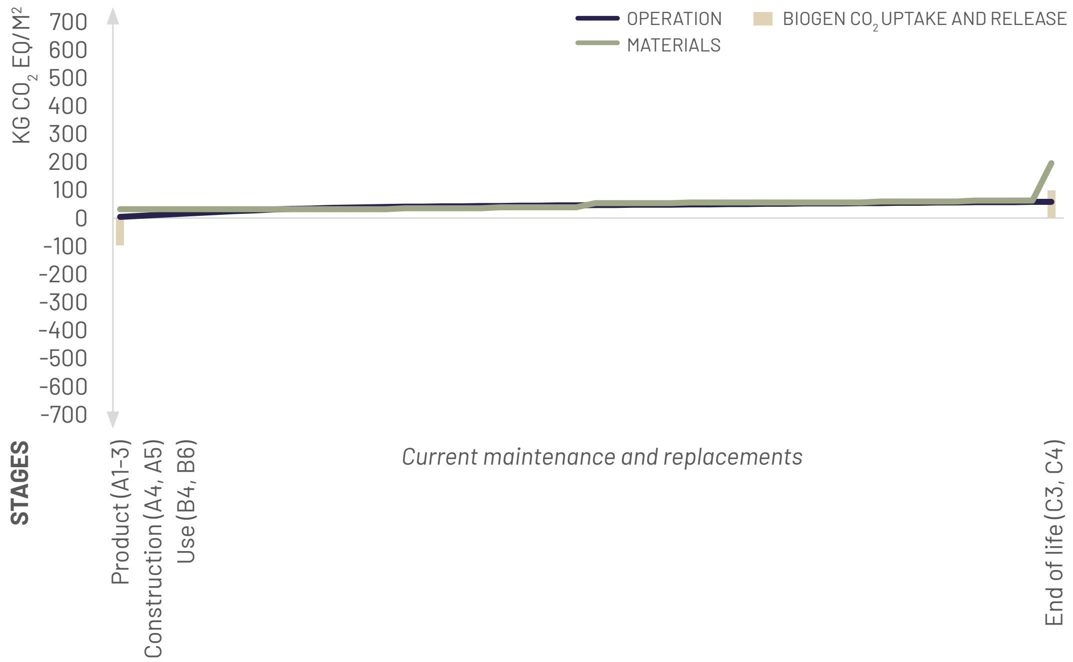


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

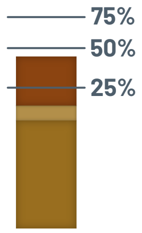
RESULT IN **HIGH IMPACT**	Triple glazing in climate envelope Cement-bonded particle board and fibre-cement sheets in exterior walls EPS insulation in ground deck
RESULT IN **LOW IMPACT**	Material consumption of 319.3 kg/m² is below average (average being 684.6 kg/m²). Compact architecture and several storeys optimise use of materials.

BALANCEN

Photo Vandkunsten

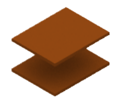
DESCRIPTION

The housing project comprises 33 homes in three different types of semi-detached houses and a communal building. The project was originally designed as a cassette construction at the sketch plan phase, but because of the geometry, sheeting was used instead. The building of this housing project is the result of a value-based programme co-developed by Pension Danmark, Realdania, and Vandkunsten. The written set of values acted as a reference point for the project throughout the construction phases and ensured close dialogue with all parties concerned. The contractor was brought in at an early stage and was in close dialogue with both the architects and the client. Other than that, the buildings were designed in accordance with requirements in the 2018 Building Regulations for low-energy construction relative to Pension Danmark's stringent sustainability requirements.

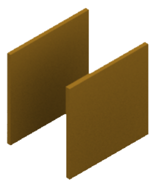


Mat.: 5,5
Tech. inst.: 0,7
Operation: 2,5
stated in KG CO_2 EQ/M²/YEAR

Location	Ry, Denmark
Year	2018-2021
No. of units	33 dwellings, communal building
Category	Cohousing, dwellings
Architect	Vandkunsten
Landscape	Vandkunsten
Engineer	Viggo Møller
Client	Pension Denmark
Contractor	LPH Byg
Type of contract	Turnkey contract
Heated area	2.942 m^2
Energy class	Low-energy class BR2018
Total energy consumption	38,7 kWh/m^2/year
Energy source	Projected electricity mix
Data basis for LCA	Architectural model
Certification	DGNB Gold
Project website	See link



1 storey



Sheeting

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
Building regulation requirements for spaces between buildings with wooden facades posed the greatest challenge to fire safety. Consequently, some sheds had an extra concrete slab fitted underneath the timber cladding to comply with the distance spacing requirements.

Acoustics
To comply with building regulation requirements on acoustics, gypsum boards were fitted to interior walls with cavities in all walls separating houses.

Economy
The idea was to stay within the financial framework, while at the same time meeting the basic values set out in the value programme and the needs and wishes of the tenants. Hence traditional materials were used to keep costs down (including gypsum walls and mineral wool insulation).

Moisture during use
To protect the facade against moisture, the wooden structure was covered with bricks at the bottom and wood at the top. Further, an external wooden sill was installed to drain off water and protect the bricks.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

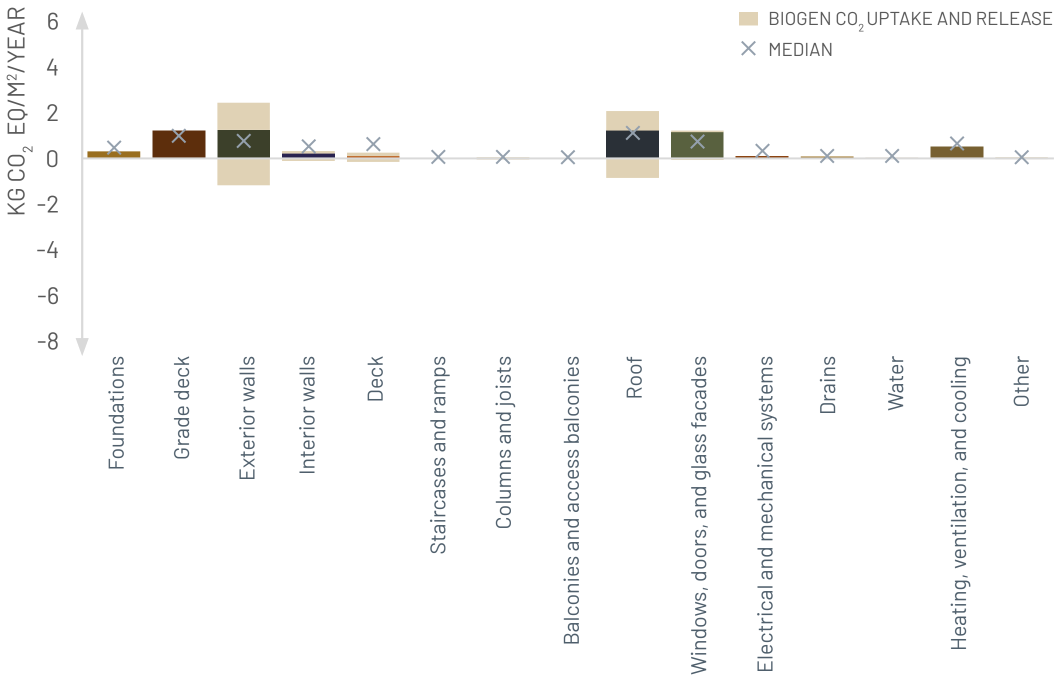


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

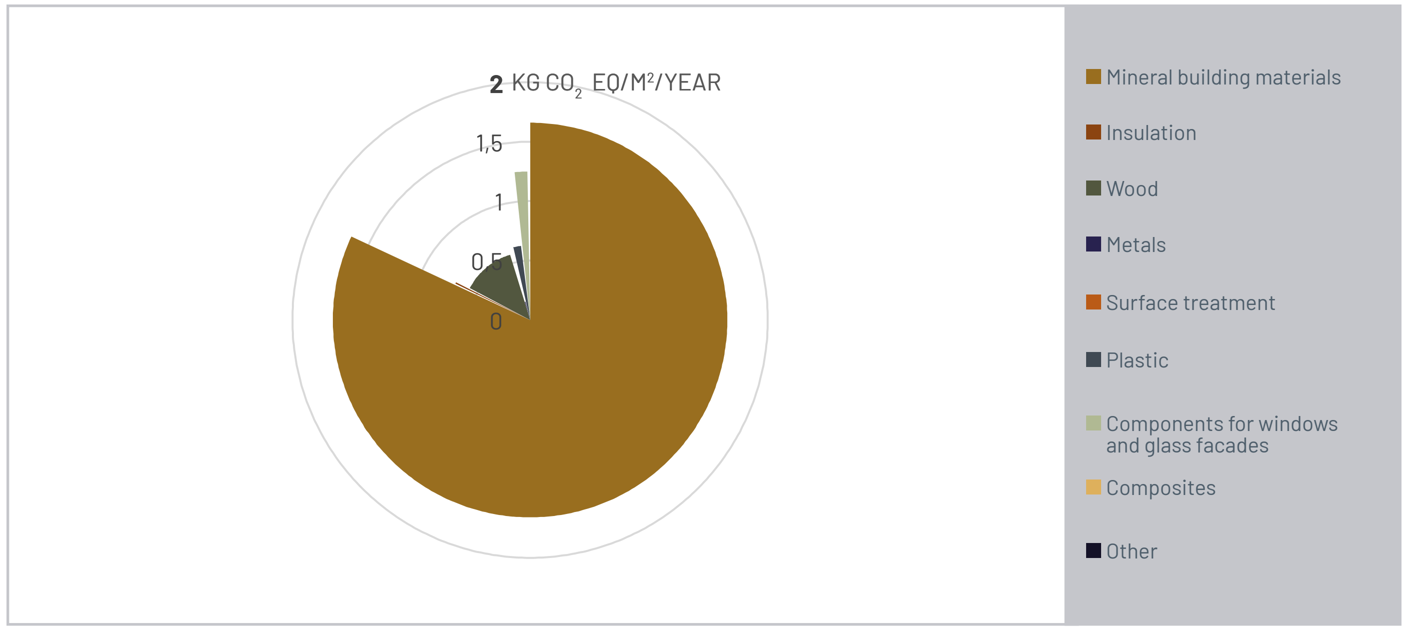


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

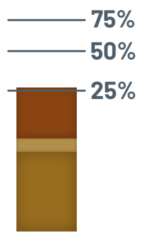
RESULT IN **HIGH IMPACT**	EPS insulation in ground deck Triple glazing in climate envelope Concrete in grade deck Bituminous felt roofing
RESULT IN **LOW IMPACT**	Material consumption of 631.4 kg/m² is below average (average being 684.6 kg/m²)

TIMIANHAVEN


Photo Vandkunsten

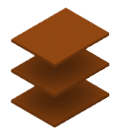
DESCRIPTION

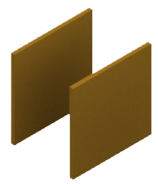
Vandkunsten originally designed an invitation to tender for a cassette project proposal based on the client's wish for geometry. However, no cassette manufacturers tendered for the project. Adserballe & Knudsen wanted to acquire new expertise and proposed a project using CLT. The project was therefore constructed with prefabricated CLT panels. Another reason for selecting CLT was the possibility of ensuring a fast and efficient building process and easy dismantling at the end-of-life phase. To ensure ample daylight, roof lights were installed, and the buildings were clad with tile shingles and larch wood.



Mat.: 4,0
Tech. inst.: 0,7
Operation: 2,6
stated in KG CO_2 EQ/M²/YEAR

Location	Havdrup, Solrød, Denmark
Year	2017-2018
No. of units	44 dwellings, communal building
Category	Housing scheme
Architect	Vandkunsten
Landscape	Vandkunsten
Engineer	Dominia
Client	Domea Solrød
Contractor	Adserballe & Knudsen A/S
Type of contract	Turnkey contract
Heated area	3.720 m²
Energy class	Building class 2020
Total energy consumption	32,7 kWh/m²/year
Energy source	Projected electricity mix & district heating
Data basis for LCA	Architectural model
Certification	-
Project website	See link


2 storeys


Sheeting (CLT)

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
CLT has fire-retardant properties and it was unnecessary, therefore, to install additional interior wall materials to optimise fire safety. However, in the attic on the first floor, the CLT panels were covered with gypsum on the outside to comply with fire requirements for interior surfaces. Further, 95 mm non-combustible insulation was installed between the housing units.

Statics & acoustics
A 50 mm layer of concrete tiles was added to stop sound transmission between housing units and to solve the issue of statics.

Economy
Based on arguments in favour of a long service life and low maintenance, materials for the project were selected by the building council. In an attempt at keeping costs low, choices were made which later turned out to be decisive for the ultimate quality and robustness of the project. A few solutions, such as edge-glued seams, incurred extra costs, presenting problems at the usage phase.

Aesthetics
Studies were made of patination with physical CLT samples to acquire knowledge about the maintenance of interior wood cladding and test ideas for exterior wood protection. Dominia had not originally wanted timber facades because of the increased maintenance required but were persuaded to do parts of the facades in wood in light of Vandkunsten's experience in constructive wood protection. The interior CLT was treated with wood lye, but the lack of standards governing wood-lye treatment meant that the walls had to be treated differently and, consequently, their appearance vary.

Fugt
The construction had no vapour barrier fitted, since this function is performed by the CLT. Inappropriate treatment of, for example, the edge-glued seams later caused cracks to appear, in turn increasing problems of leakage and moisture intrusion.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

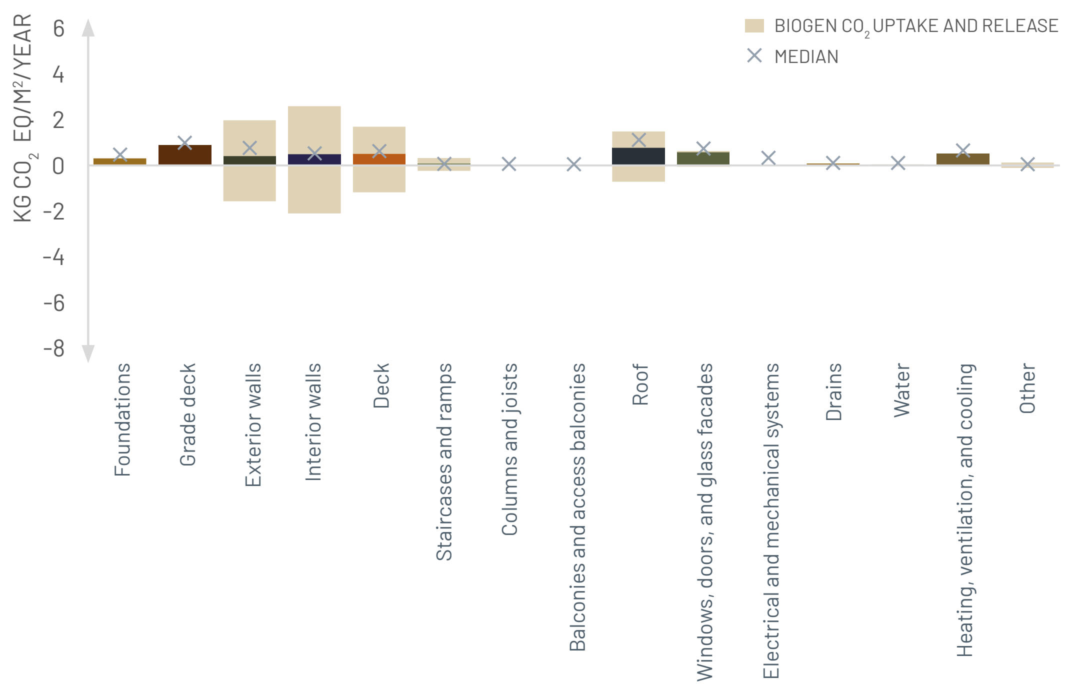


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

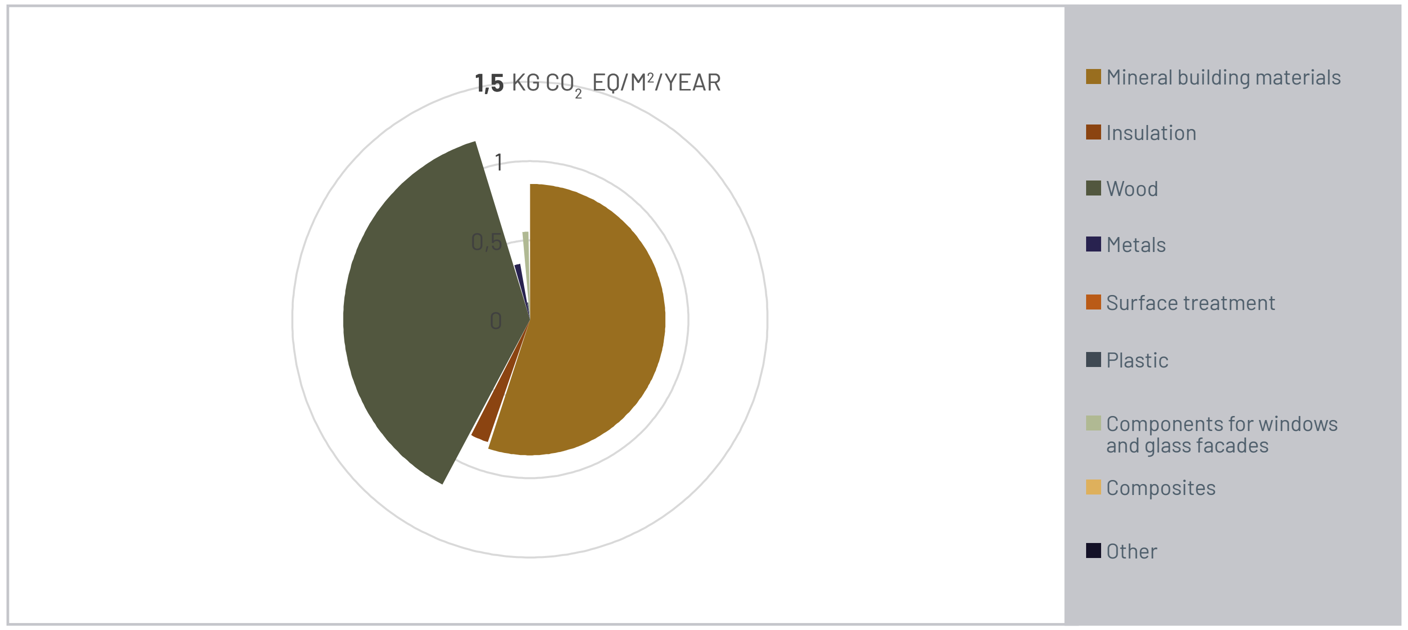


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

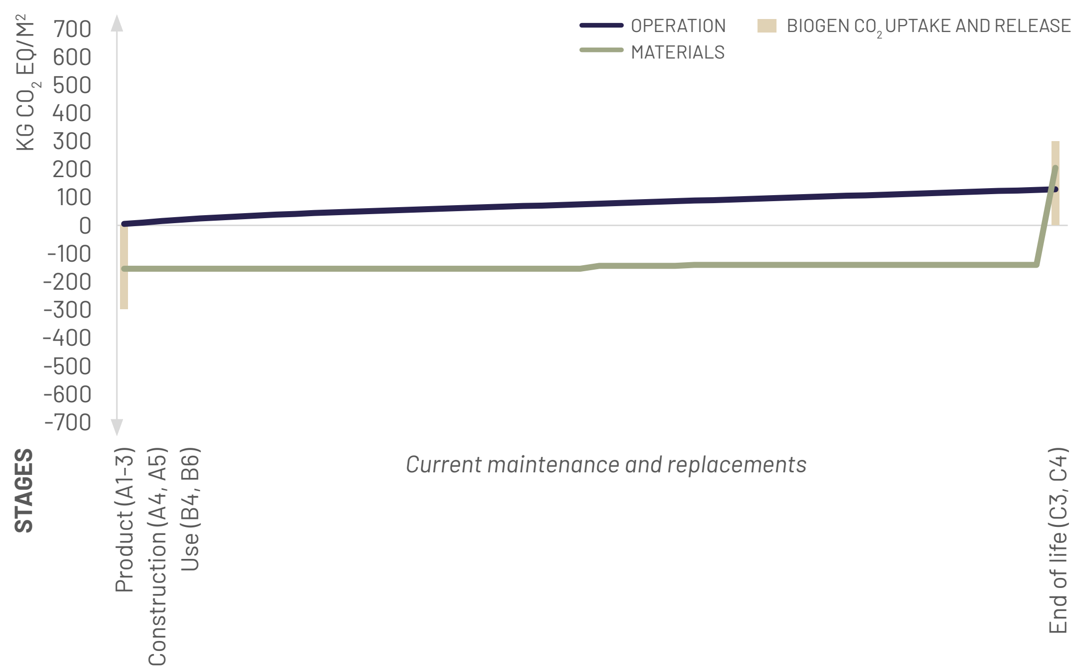


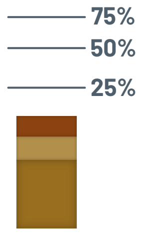
Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

RESULT IN **HIGH IMPACT**	High-pitch roof increase the use of material use EPS insulation in grade deck Triple glazing in climate envelope Concrete in grade deck Roof surface of steel sheets
RESULT IN **LOW IMPACT**	Material consumption of 506.2 kg/m² is below average (average being 684.6 kg/m²)

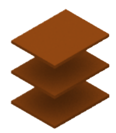
DESCRIPTION

Skråningen was built as a result of an approach from EcoVillage, who knew of Vandkunsten's experience with cohousing schemes. A building project was developed to provide for both functionality and communal living within strict financial constraints. The project emphasised the narrative of EcoVillage as a sustainable cohousing scheme, and Swan Ecolabelled timber was therefore used for the facade. The housing units were designed using a basic module, and extra modules cater for various other needs and add interest. Further, the insulation material was mainly wood-based cellulose. The common areas, such as buildings and several small common facilities make up 12% of the overall built area.

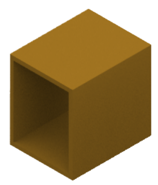


Mat.: 3,5
Tech. inst.: 1,2
Operation: 1,0
stated in KG CO_2 EQ/M²/YEAR

Location	Lejre, Denmark
Year	2015-2019
No. of units	46 dwellings, communal building
Category	Cohousing scheme
Architect	Vandkunsten
Landscape	Vandkunsten
Engineer	Scandibyg
Client	Ecovillage and CASA
Contractor	Scandibyg
Type of contract	Turnkey contract
Heated area	4.788 m^2
Energy class	Building class 2020
Total energy consumption	33,7 kWh/m^2/year
Energy source	Projected electricity mix
Data basis for LCA	Architectural model
Certification	Swan label
Project website	See link



2 storeys



Cassette

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
The facade wood was fire-impregnated.

Acoustics
From their experience with testing cassettes, Scandibyg had the expertise required to incorporate acoustic solutions in the buildings. The insulation in the cassettes made it possible to comply with requirements for timber buildings despite the horizontal boundaries between housing units.

Logistics
Transportable dimensions determined the cassette design. Proven experience in logistics meant that Scandibyg was able to organise this. Moreover, they had previous experience of designing customised solutions involving non-standard dimensions for communal facilities.

Construction moisture
Cassette structures was thought to be less prone to moisture than other types of timber structure, as the cassettes are protected during transport and installation. Scandibyg had the know-how required to avoid moisture problems.

Moisture during use
No constructive wood protection in the form of overhang was used as, since using roofing modules from another manufacturer would increase cost. Instead, the wood facade was treated with wood preserver.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

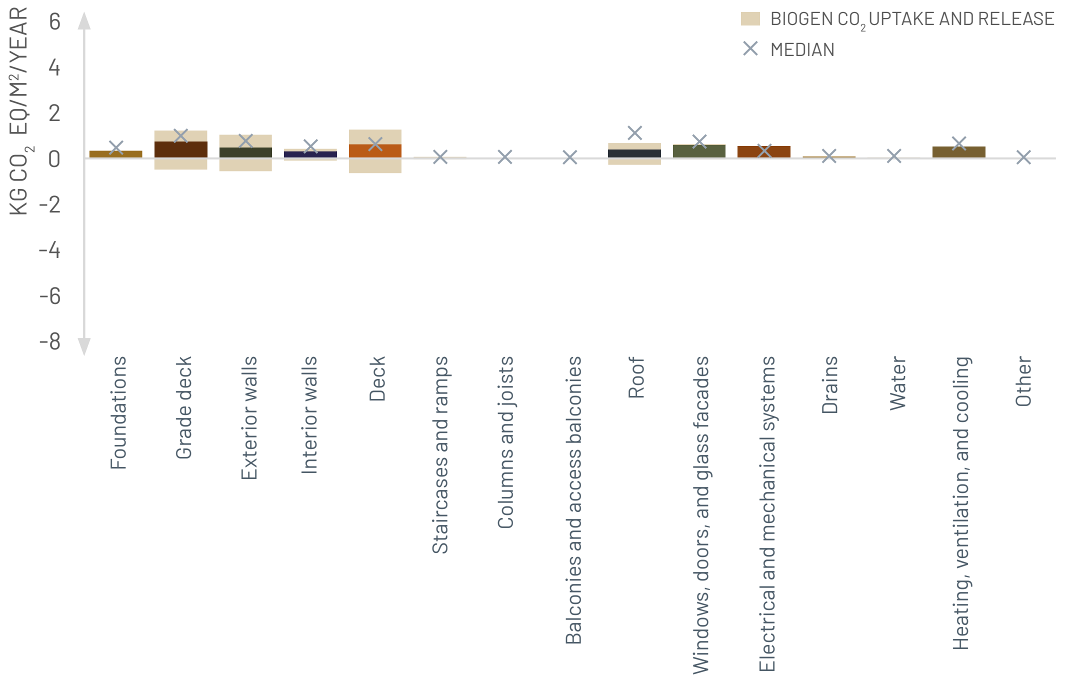


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

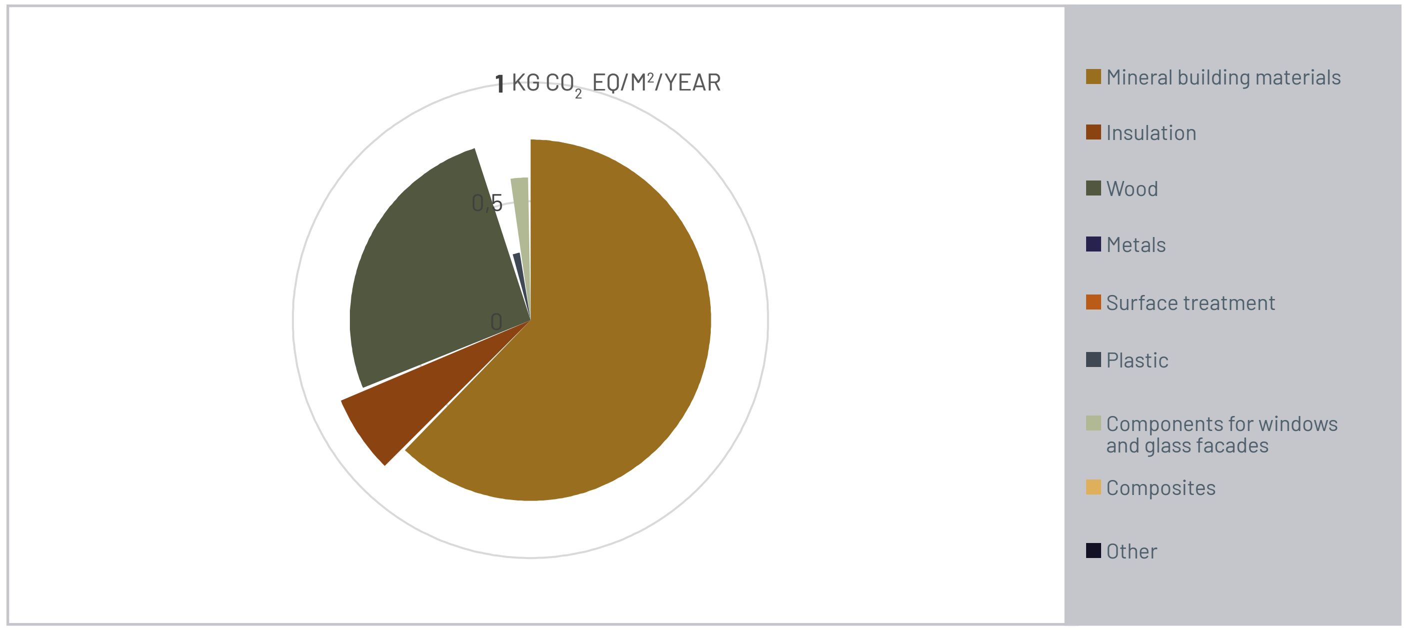


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

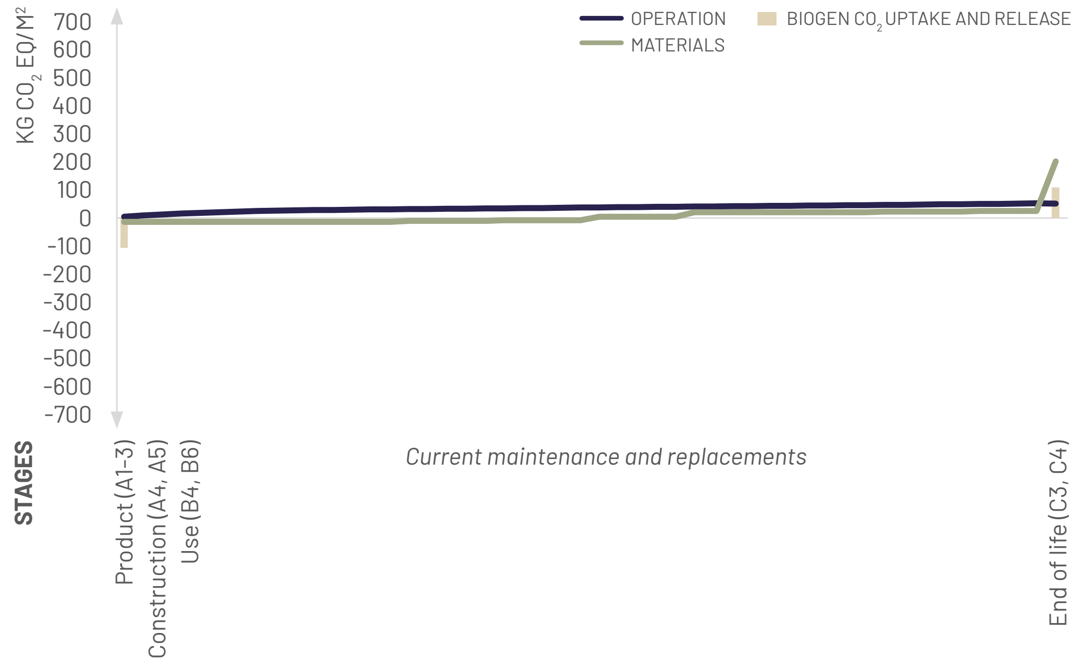


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

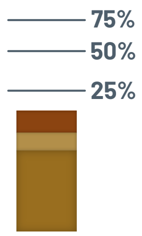
RESULT IN **HIGH IMPACT**	Photovoltaic modules on roof Triple glazing in climate envelope EPS insulation in grade deck Cement-bonded particle board in grade deck and exterior walls Large glazed areas in the housing units
RESULT IN **LOW IMPACT**	Material consumption of 295.8 kg/m² is below average (average being 684.6 kg/m²)

SKRÅNINGEN II

Photo Vandkunsten

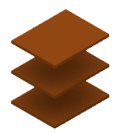
DESCRIPTION

Vandkunsten continued their collaboration with EcoVillage after the Skråningen Phase I. All housing units in Phase II have private exits, as this is what the residents wanted. Similarly, it was decided not to continue making horizontal boundaries between housing-unit, as these proved unsaleable. The project continues to emphasise the narrative of EcoVillage as a sustainable cohousing scheme, and timber carrying the Swan Ecolabel was therefore selected as facade material.

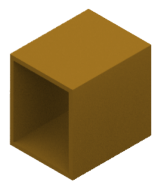


Mat.: 4,1
Tech. inst.: 0,9
Operation: 1,1
stated in KG CO_2 EQ/M²/YEAR

Location	Lejre, Denmark
Year	2020-2021
No. of units	53 dwellings, communal buildings
Category	Cohousing scheme
Architect	Vandkunsten
Landscape	Vandkunsten
Engineer	Scandibyg
Client	Ecovillage and CASA
Contractor	Scandibyg
Type of contract	Turnkey contract
Heated area	5.700 m^2
Energy class	Building class 2015
Total energy consumption	18,4 kWh/m^2/year
Energy source	Projected electricity mix
Data basis for LCA	Architectural model
Certification	Swan label
Project website	See link



2 storeys



Cassette

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
Experience from Phase I meant that the authorities were aware of the fire solutions used for that phase. This resulted in a more efficient fire-approval procedure.

Economy & Aesthetics
The architects wanted to differentiate Skråningen Phase II from Phase I by, for example, painting the facade black. The client, on the other hand, wanted to focus specifically on reducing maintenance, and therefore thermo-treated facade timber carrying the Swan Ecolabel was selected. Further, a different timber profiling was selected than the one used in Phase I. No horizontal housing-unit boundaries were built, since these had proved unsaleable in Phase I.

Logistics
Originally, the multi-purpose hall was abandoned due to transport difficulties. However, the project has been revived in response to residents' wishes. To facilitate transport, glulam was used for the multi-purpose hall instead of one single module. The multi-purpose hall corresponds to three cassettes in a space twice the height.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

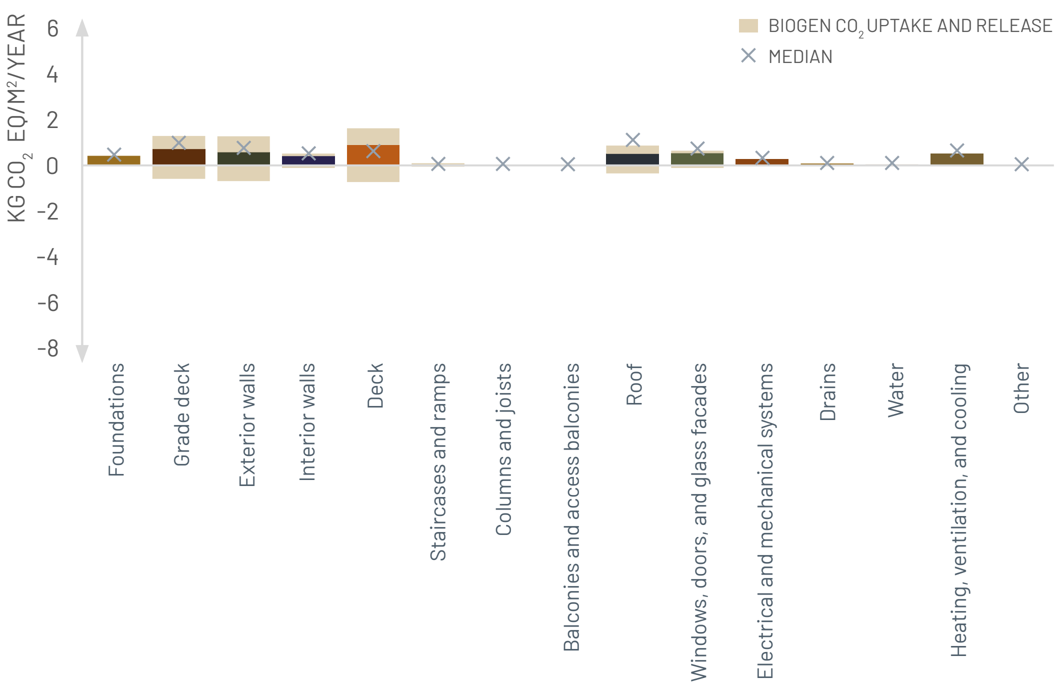


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

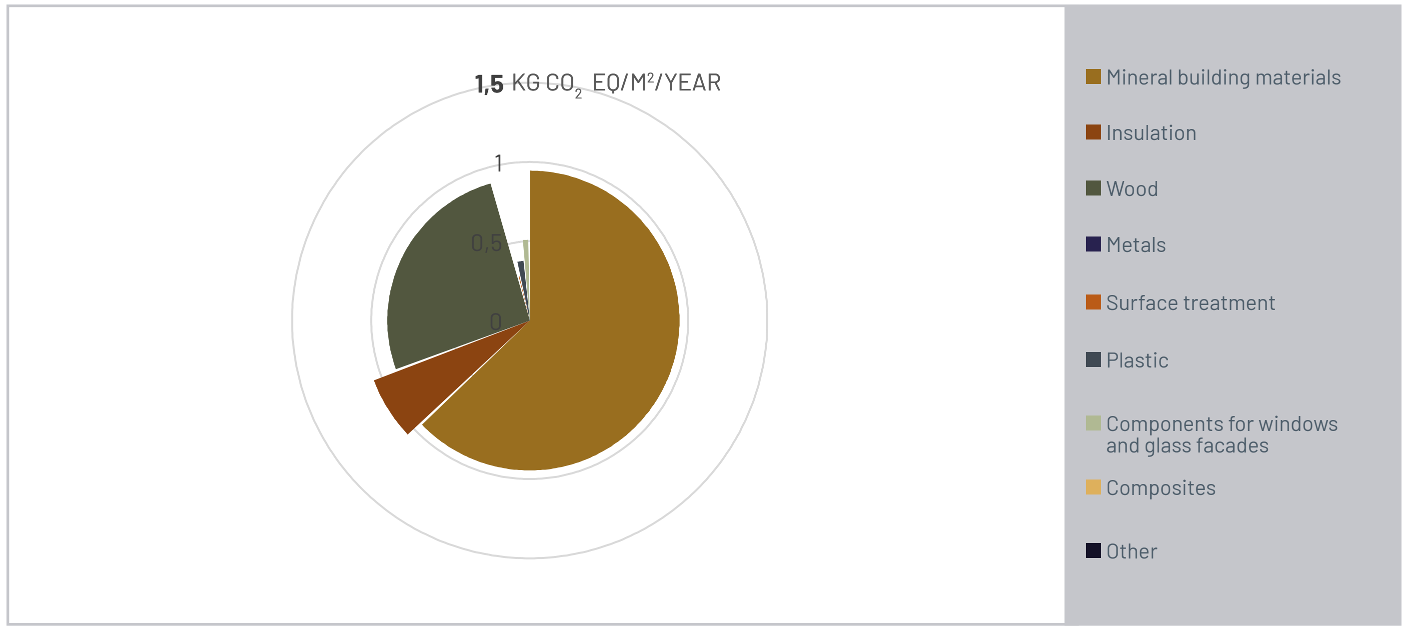


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

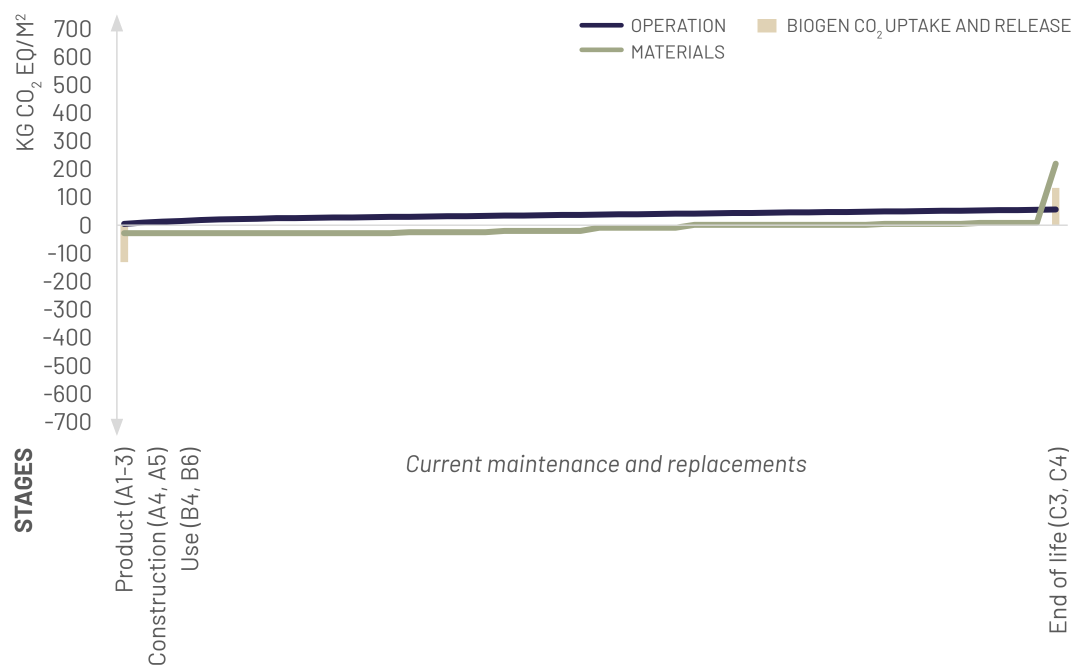


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

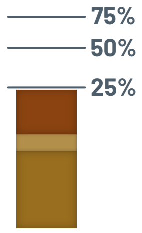
DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

RESULT IN **HIGH IMPACT**	PU foam sheets in deck EPS insulation in grade deck Cement-bonded particle board in exterior walls Triple glazing in climate envelope due to large window areas in the housing units
RESULT IN **LOW IMPACT**	Material consumption of 362.2 kg/m² is below average (average being 684.6 kg/m²)

Photo Vandkunsten

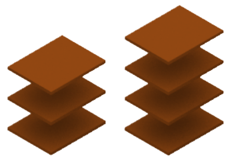
DESCRIPTION

Grøntorvet in Valby, Copenhagen, is part of the Almenbolig+ scheme, framework 5. Requirements dictated that the buildings were constructed in timber and the framework amount dictated using prefabricated cassettes, as this was an opportunity to get high quality within the given price constraints. An expert monitoring group elected among experienced people from the housing associations were consulted about selection of material for surfaces and interiors. However, the local plan stipulated the use of tiled surfaces combined with wood. The framework for the housing scheme and the involvement of the expert monitoring group resulted in a sound choice of material with a positive effect on the overall economy as well as being low-maintenance and needing few replacements.

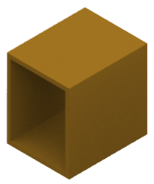


Mat.: 3,9
Tech. inst.: 0,9
Operation: 2,2
stated in KG CO_2 EQ/M²/YEAR

Location	Valby, Denmark
Year	2016-2019
No. of units	49 lejligheder
Category	Housing scheme rental
Architect	Vandkunsten
Landscape	Vandkunsten
Engineer	DEM and Týrens
Client	SAB & AKB for KAB
Contractor	BM Byggeindustri
Type of contract	Turnkey contract
Heated area	5.367 m^2
Energy class	Building class 2020
Total energy consumption	32,9 kWh/m^2/year
Energy source	Projected electricity mix
Data basis for LCA	Architectural model
Certification	-
Project website	See link



2-3 storeys



Cassette

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire	Fire requirements were easily complied with in areas less than two storeys. In three-storey housing units, fire doors were fitted in the living spaces on one storey. Open staircases were installed in each unit.
Acoustics	To improve acoustics, neoprene blocks were placed between the cassettes.
Economy	The economic framework was a decisive factor when choosing prefabricated cassettes. Moreover, the economic framework dictated a different choice of materials due to the construction and operational costs involved.
Logistics	Cassette dimensions were limited by transport conditions. As a direct consequence, the architects developed expertise in delivering design within modular dimensions.
Aesthetics	There was a wish to select materials within the framework amount which would also meet with residents' approval. In response to this, the architects compiled a materials catalogue and organised monitoring group meetings with the residents.
Fugt	The cassettes were delivered to the building site ready sealed where they could stay for up to 6 months without sustaining damage.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

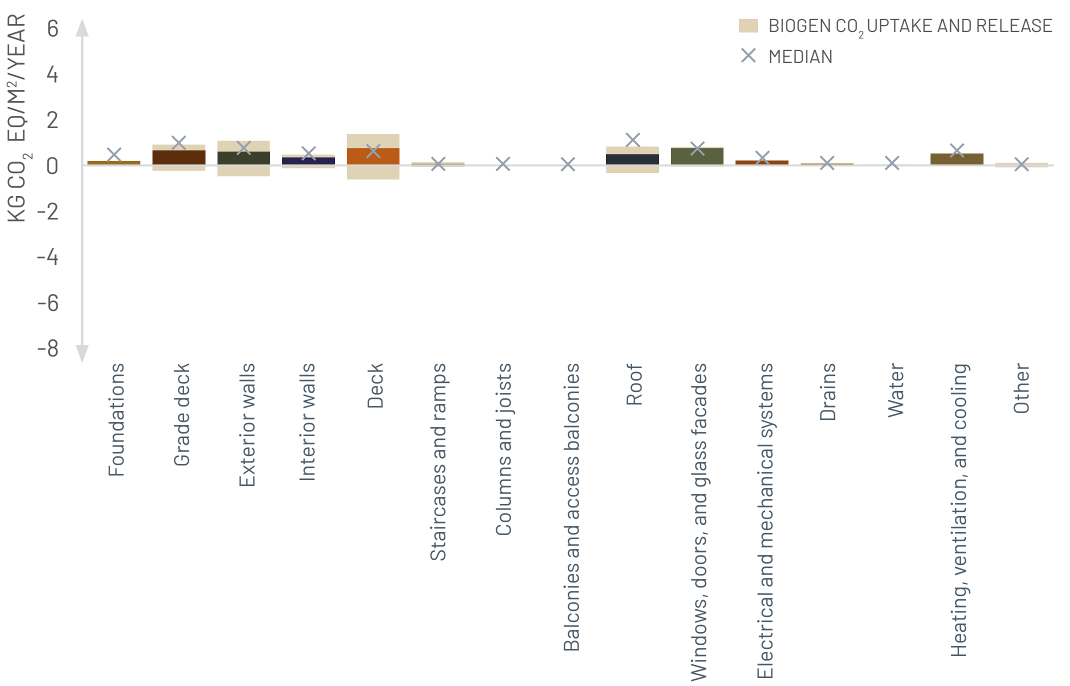


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

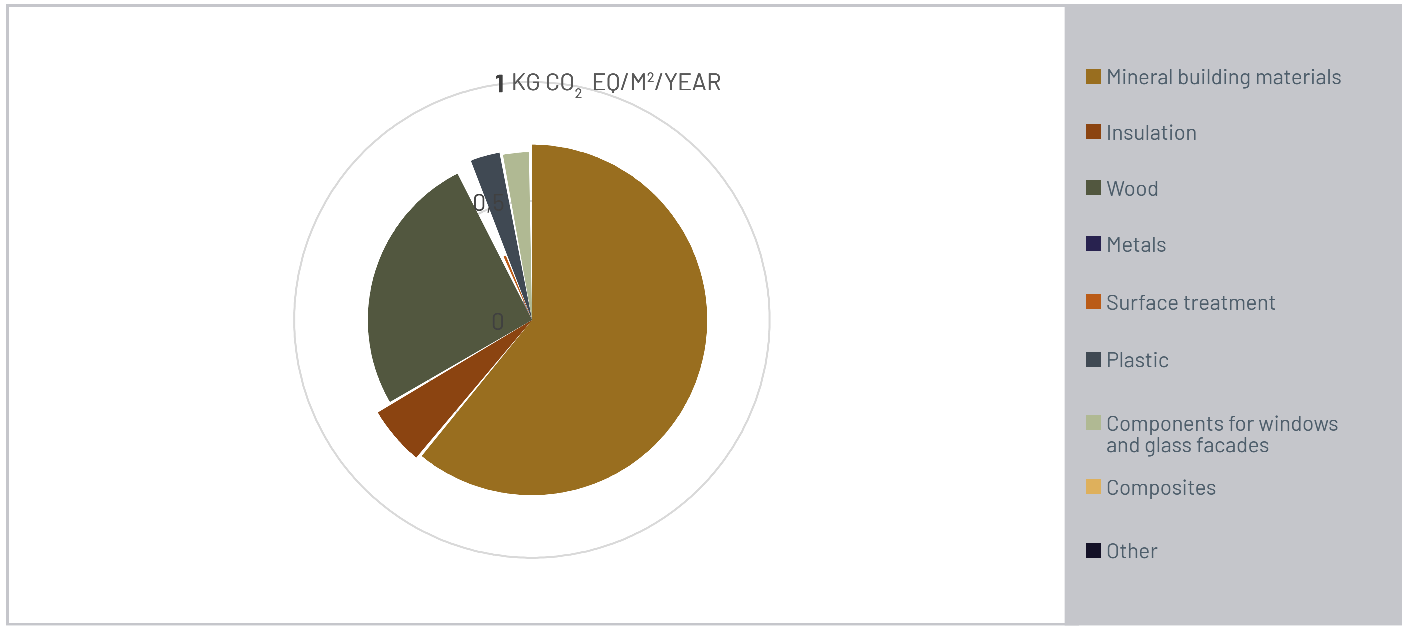


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

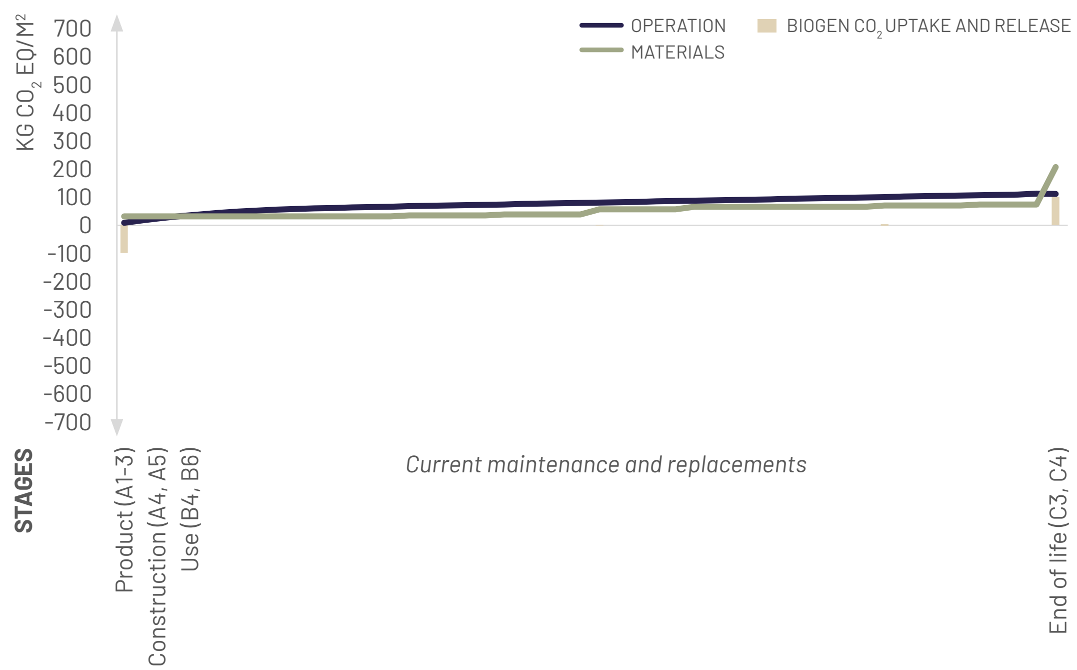


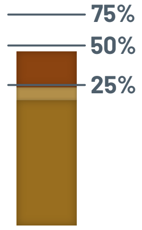
Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

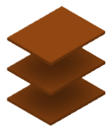
RESULT IN **HIGH IMPACT**	Photovoltaic modules on roof Triple glazing in climate envelope Cement-bonded particle board in exterior walls EPS insulation in grade deck
RESULT IN **LOW IMPACT**	Small, compact housing units mean reduced use of materials Material consumption of 278.4 kg/m² is below average (average being 684.6 kg/m²)

DESCRIPTION

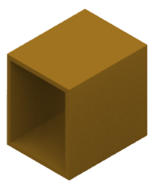
Engdraget is part of the local plan for Tidselbjerget, an approx. 60-hectare area outside Slagelse. When developing Engdraget, a sustainability memo was prepared – an outcome of the involvement of neighbours, future tenants, housing association officers, and others. This memo contained a list of requests to be incorporated in building project regarding environmental, social, and financial sustainability.



Mat.: 6,4
Tech. inst.: 0,6
Operation: 1,8
stated in KG CO_2 EQ/M²/YEAR



2 storeys



Cassette

Location	Slagelse, Denmark
Year	2018
No. of units	126 housing units, communal buildings
Category	Housing scheme rental
Architect	Arkitema
Landscape	Arkitema
Engineer	Fjerring
Client	Slagelse boligselskab
Contractor	Scandibyg
Type of contract	Turnkey contract
Heated area	13.292 m^2
Energy class	Low-energy class 2020
Total energy consumption	25,0 kWh/m²/year
Energy source	Projected electricity mix & district heating
Data basis for LCA	Architectural model
Certification	-
Project website	See link

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
There was no need for extra fire-dimensioning, since the buildings only occupy two storeys. Accordingly, fire-dimensioning expertise was left to Scandibyg.

Economy
Cassettes from Scandibyg were selected, as this was a well-known solution, thus minimising the risk of faulty construction. Moreover, it resulted in an efficient construction process of only 13 months and enhanced Scandibyg's expertise within acoustics, moisture, and statics.

Aesthetics
All solutions were chosen based a standard offer from Scandibyg. The architects had a say in the choice of surface materials.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

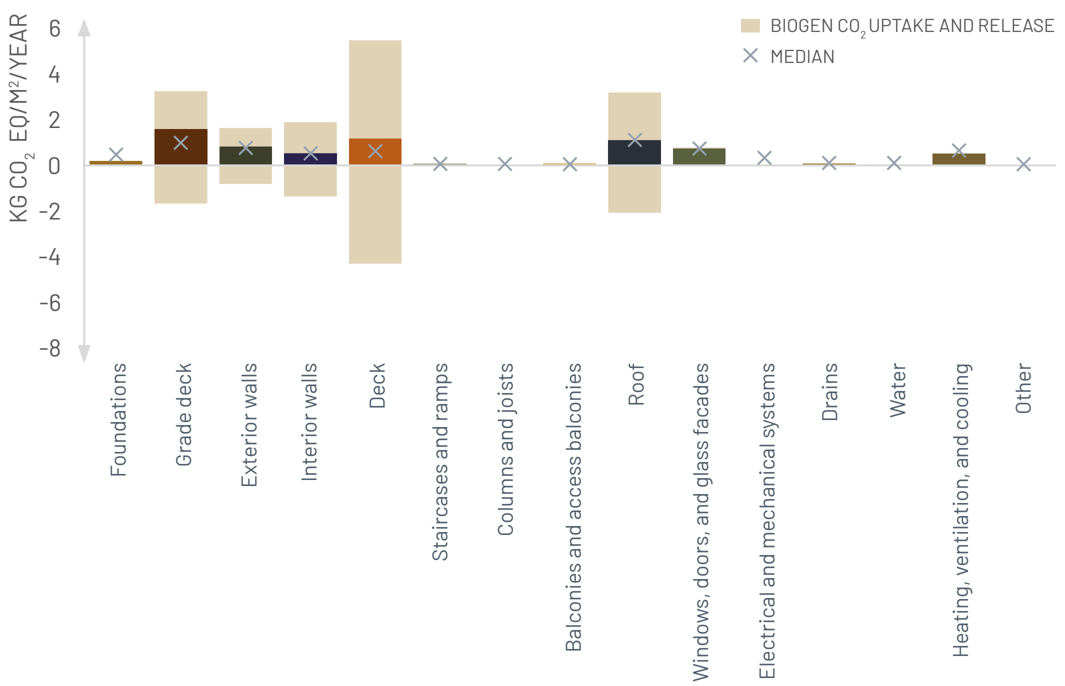


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

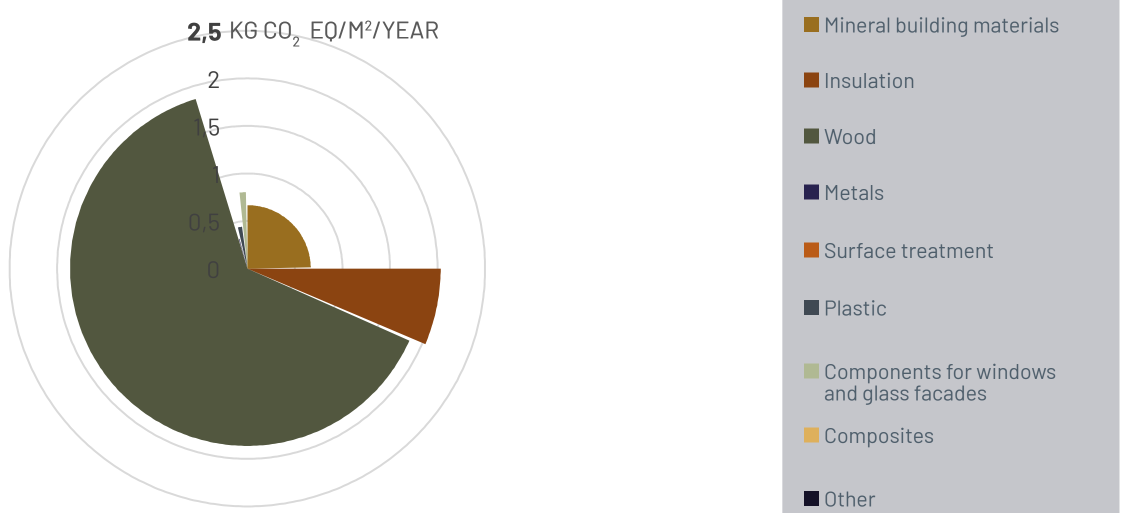


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

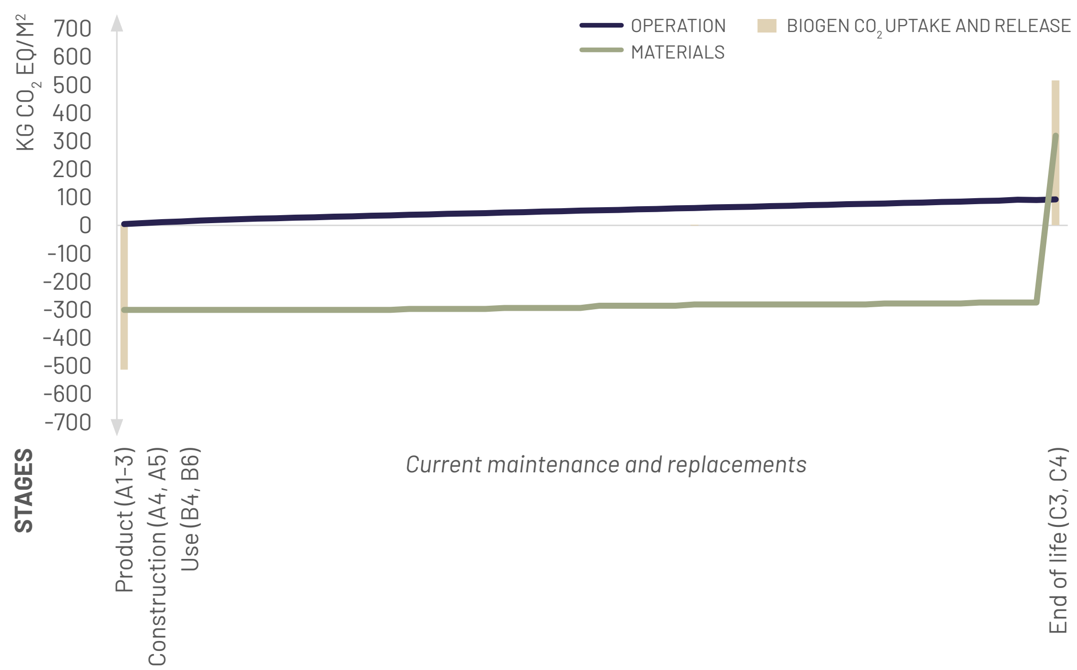


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

RESULT IN **HIGH IMPACT**	EPS insulation in ground deck Pressure-resistant mineral-wool roof insulation
RESULT IN **LOW IMPACT**	Material consumption of 532.0 kg/m² is below average (average being 684.6 kg/m²)

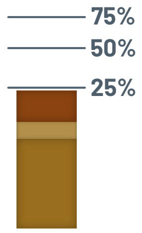
SKADEMOSEN


Photo Adserballe & Knudsen

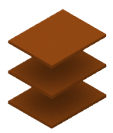
DESCRIPTION

The idea of this project was to build cheap and climate-friendly housing. The project is part of the same framework agreement as Toppen and Skousbo I, for which the construction system BoligTræ was developed. The system was developed with a view to reducing climate footprints and streamlining the project in the production and construction phases. Also, focus was on designing all buildings in digital models, facilitating ongoing optimisation across the projects in the framework agreement. Skademosen comprises 44 housing units between 30–115 m^2. The units are fully equipped but have a limited number of partition walls, providing a high level of flexibility.

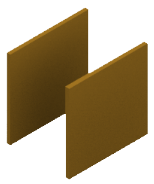
Location	Trekroner, Denmark
Year	2018-2019
No. of units	44 dwellings
Category	Housing scheme rentals
Architect	Vilhelm Lauritzen Arkitekter
Landscape	Thing Firet Landskab
Engineer	Fjerring Holmsgaard A/S
Client	Slagelse boligselskab Boligselskabet Sjælland
Contractor	Adserballe & Knudsen A/S
Type of contract	Turnkey contract
Heated area	4.146 m^2
Energy class	Low-energy class 2020
Total energy consumption	24,5 kWh/m^2/year
Energy source	Projected electricity mix & district heating
Data basis for LCA	Architectural model
Certification	-
Project website	See link



Mat.: 4,6
Tech. inst.: 0,9
Operation: 1,6
stated in KG CO_2 EQ/M^2/YEAR



2 storeys



Sheeting (CLT)

USE OF WOOD: KEY ACTORS' EXPERIENCE

No interview conducted on this building, and hence no experience was shared.

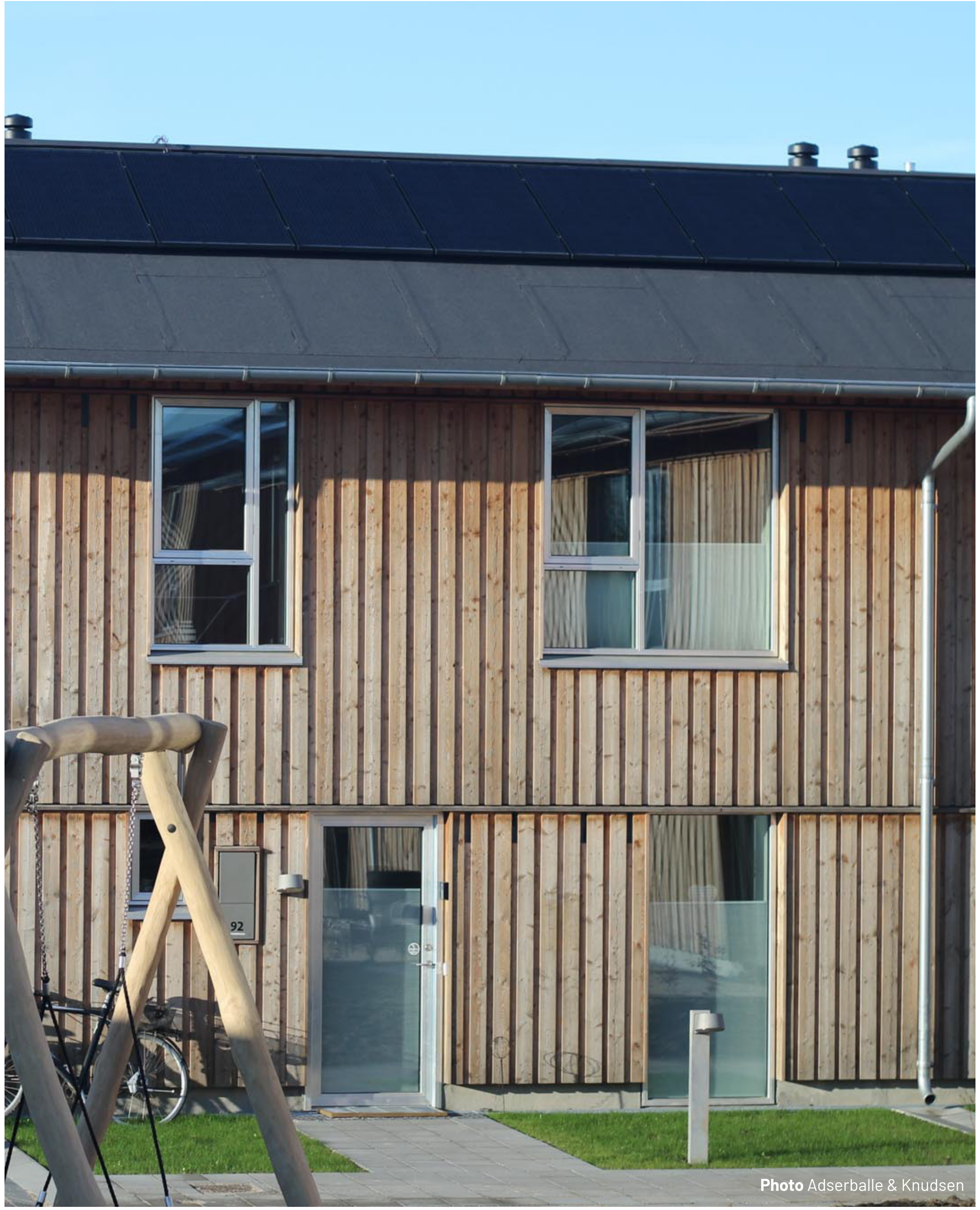


Photo Adserballe & Knudsen

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

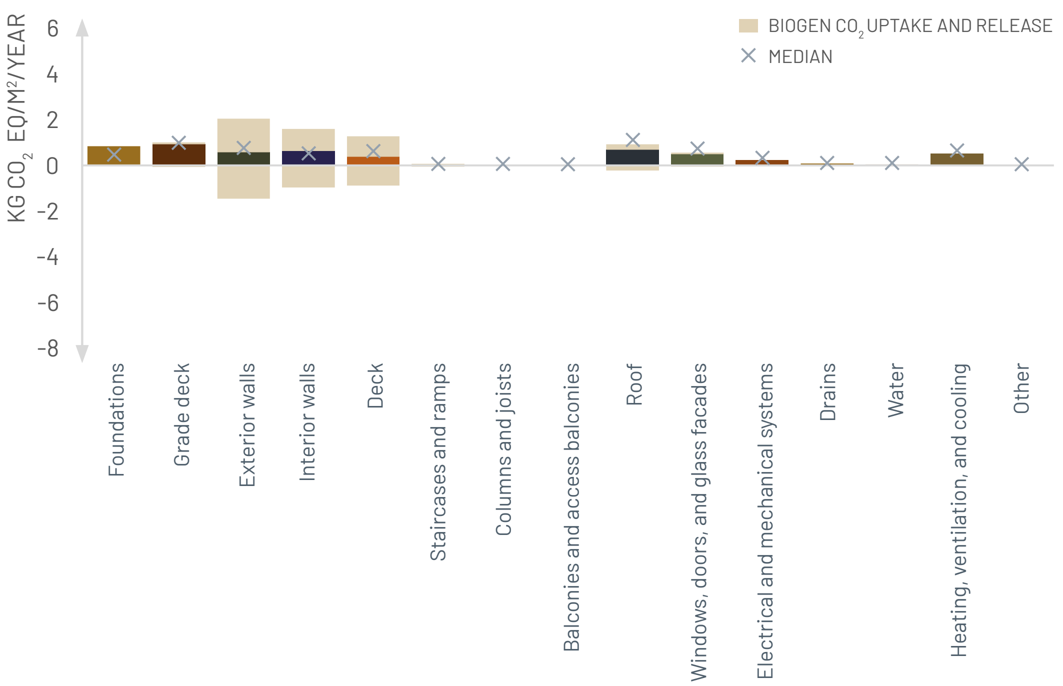


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

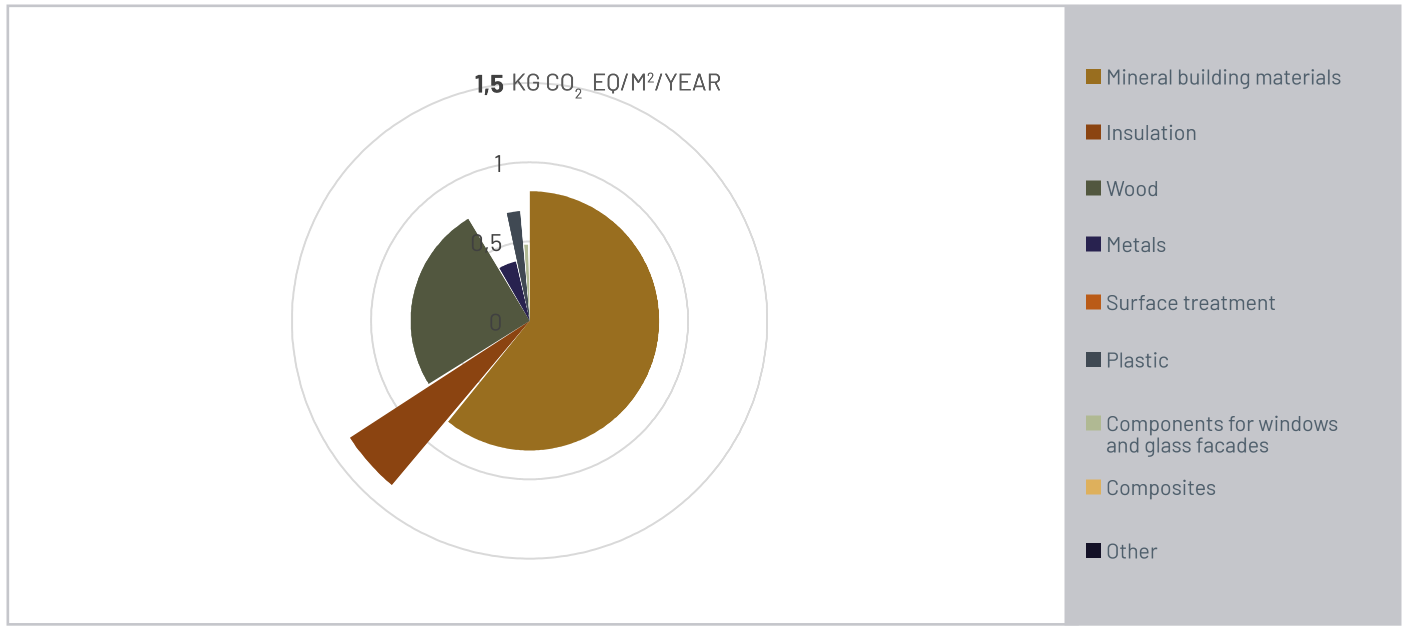


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

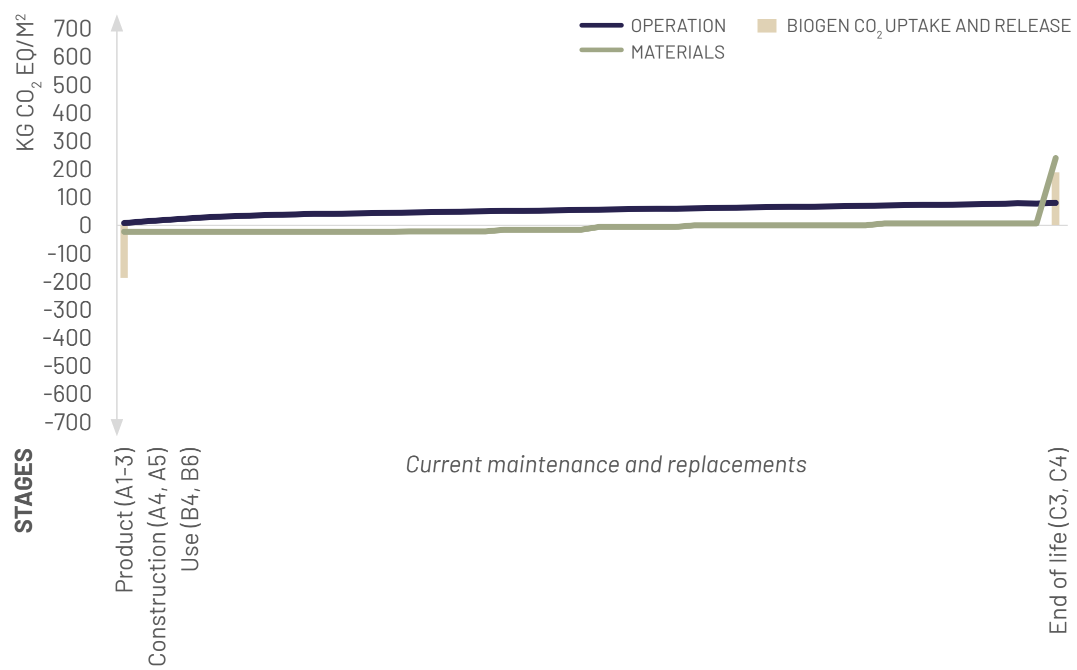


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

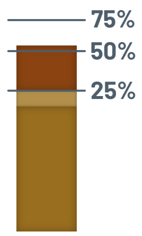
DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

RESULT IN **HIGH IMPACT**	EPS insulation in grade deck Bituminous felt roofing Pressure-resistant mineral wool roof insulation Concrete in grade deck and foundations
RESULT IN **LOW IMPACT**	Material consumption of 461.7 kg/m² is below average (average being 684.6 kg/m²)

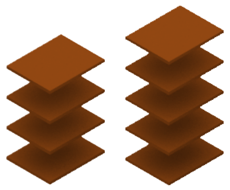
LISBJERG BAKKE

DESCRIPTION

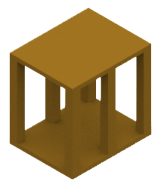
The Lisbjerg Bakke housing project was built in a glulam beam-column system known as Wood Stock, developed by Artelia (formerly MOE) and Vandkunsten. The description for the architecture competition emphasised that the building should present "sustainable buildings of the future" with keywords being flexibility and climate adaptation. It was essential that the project could be realised within the economic framework set for housing schemes. To stay within the framework amount, the project was originally designed with steel facades, but timber facades were eventually selected, since the idea was to reflect aesthetically that these were timber buildings.



Mat.: 6,3
Tech. inst.: 0,8
Operation: 2,3
stated in KG CO_2 EQ/M²/YEAR



3 - 4 storeys



Hybrid

Location	Lisbjerg, Denmark
Year	2018-2021
No. of units	40 dwellings between 50-115 m^2, communal building
Category	Housing scheme
Architect	Vandkunsten
Landscape	Vandkunsten
Engineer	Artelia (formerly MOE)
Client	AL2bolig
Contractor	Hustømrene
Type of contract	Three combined works contracts
Heated area	4.150 m^2
Energy class	Low-energy class BR2015
Total energy consumption	30,4 kWh/m^2/year
Energy source	Projected electricity mix & district heating
Data basis for LCA	Architectural model
Certification	DGNB Gold
Project website	See link

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
The facade cladding failed to meet Building Regulations due to its quality and lack of fire-retarding treatment. A sprinkler system was therefore installed as part of the fire strategy.

Acoustics
The decks were made of glulam to which 9 cm of reinforced concrete was added to stabilise the structure and enhance the sound-proofing properties.

Economy & Aesthetics
Constructive wood protection was used as an integral part of the architectural expression and the over-dimensioned roof overhangs and drip caps help protect the untreated facades of common spruce. In some places, steel beams replaced timber beams, which offered flexibility for designing façade cassettes and placing window holes. LCC (life cycle costing) and LCA were used during the tendering process – as wood placed a severe strain on the LCC. To reduce cost, the building was designed with steel facades. However, the municipality wanted "timber buildings to look like timber buildings", and timber was therefore chosen for the facades. Due to increased costs, the balconies were dropped, kitchens became "do-it-yourself" solutions, and the number of interior walls were reduced. Further, painted areas were minimised to reduce cost and maintenance. Interior wood cladding was treated with an inferior-quality wood lye, which rubs off, unfortunately.

Logistics
Elements and building parts were delivered and installed on the same day. The size of the building sections makes it logical to build upwards.

Construction moisture
Many different types of timber structures were used as well as on-site concrete. It was necessary, therefore, to plan the building process meticulously. Based on recommendations from the Byggeskadefonden, the client required a moisture strategy to be prepared.

Moisture during use
There was much in-house expertise in constructive wood preservation, for example, protecting facades with overhangs and water channels.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

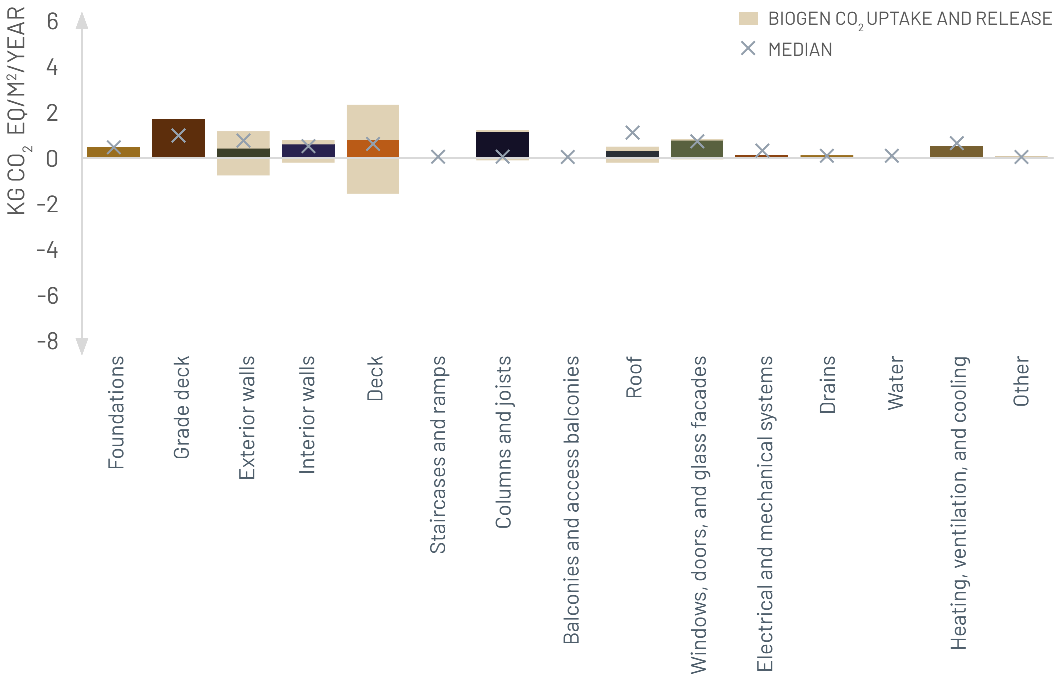


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

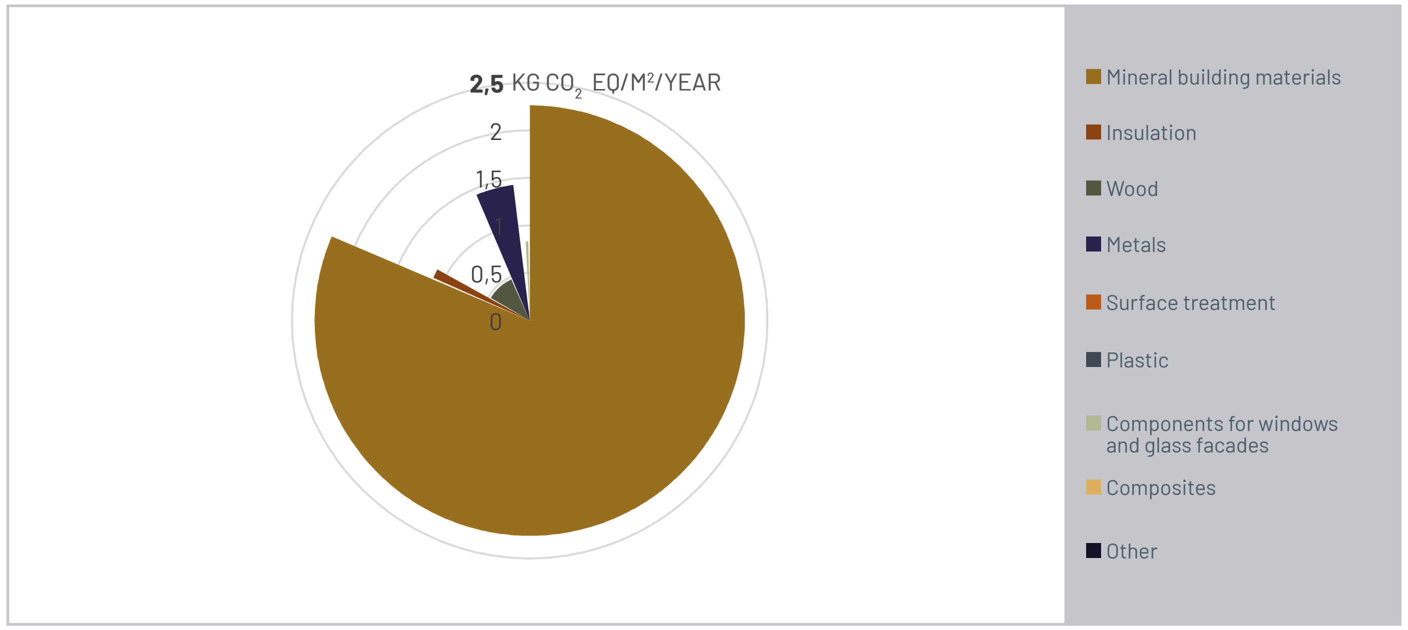


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

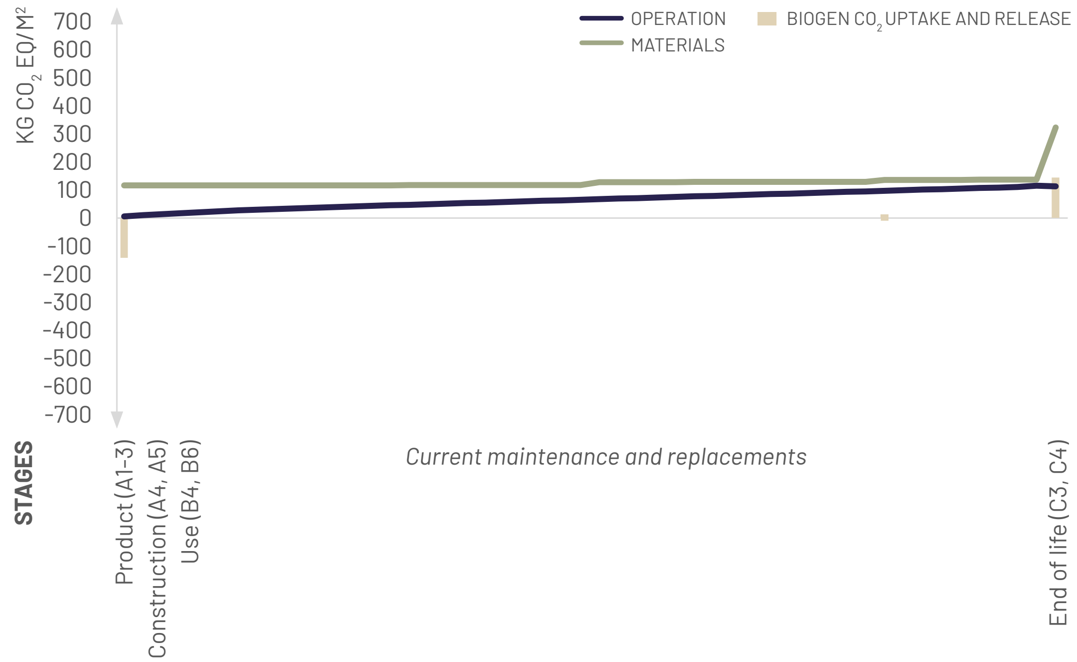


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

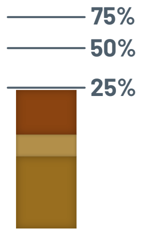
DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

RESULT IN **HIGH IMPACT**	Concrete in grade deck EPS insulation in ground deck Triple glazing in climate envelope Steel beams as supporting structure Material consumption of 892.4 kg/m² is above average (average being 684.6 kg/m²)
RESULT IN **LOW IMPACT**	

Photo Vandkunsten

DESCRIPTION

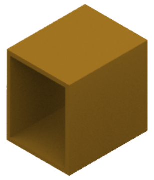
All PensionDanmark's town-planning projects and new tenement buildings begun later than the third quarter of 2016, carry, as a minimum, a DGNB Gold sustainability certificate. This also applies to Studio[Home] Lyngby. As the buildings are youth residences, this was one reason for opting for cassettes as design principle.



Mat.: 3,7
Tech. inst.: 1,1
Operation: 2,2
stated in KG CO_2 EQ/M²/YEAR

Location	Lundtofte, Denmark
Year	2020-2021
No. of units	478 dwellings, common areas
Category	Studio homes
Architect	Vandkunsten
Landscape	Vandkunsten
Engineer	Scandibyg, COWI
Client	Pension Denmark
Contractor	Scandibyg
Type of contract	Turnkey contract
Heated area	17.530 m²
Energy class	Low-energy class BR2018
Total energy consumption	30 kWh/m²/year
Energy source	Projected electricity mix & district heating
Data basis for LCA	Architectural model
Certification	DGNB Gold, Swan label
Project website	See link

3 storeys



Cassette

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
Tyréns, external adviser on fire, was consulted to ensure that fire requirements were complied with. This meant that extra staircases were installed as escape routes along with fire-proof glass in the atria and extra fire-proof ceiling sheets because of PIR/PUR foam being used in the roof.

Economy
The economy dictated the choice of materials, and cassettes were used to keep costs down.

Aesthetics
The architects wanted to prove that timber can be used without huge maintenance costs. This resulted in wood sections in the facade and specially-designed wooden furniture.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

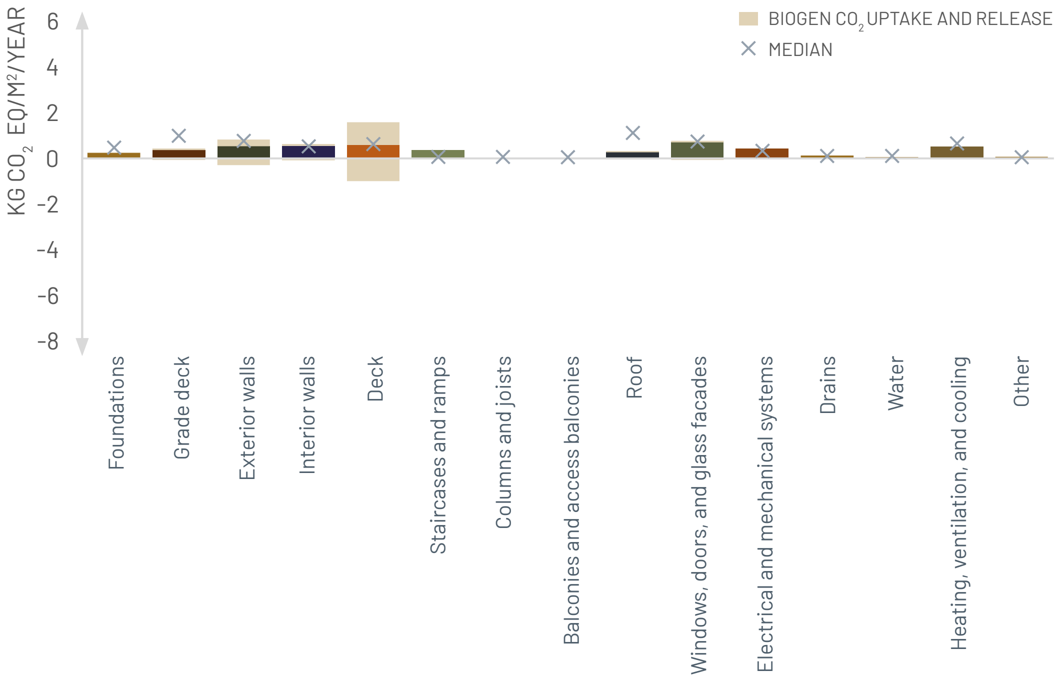


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

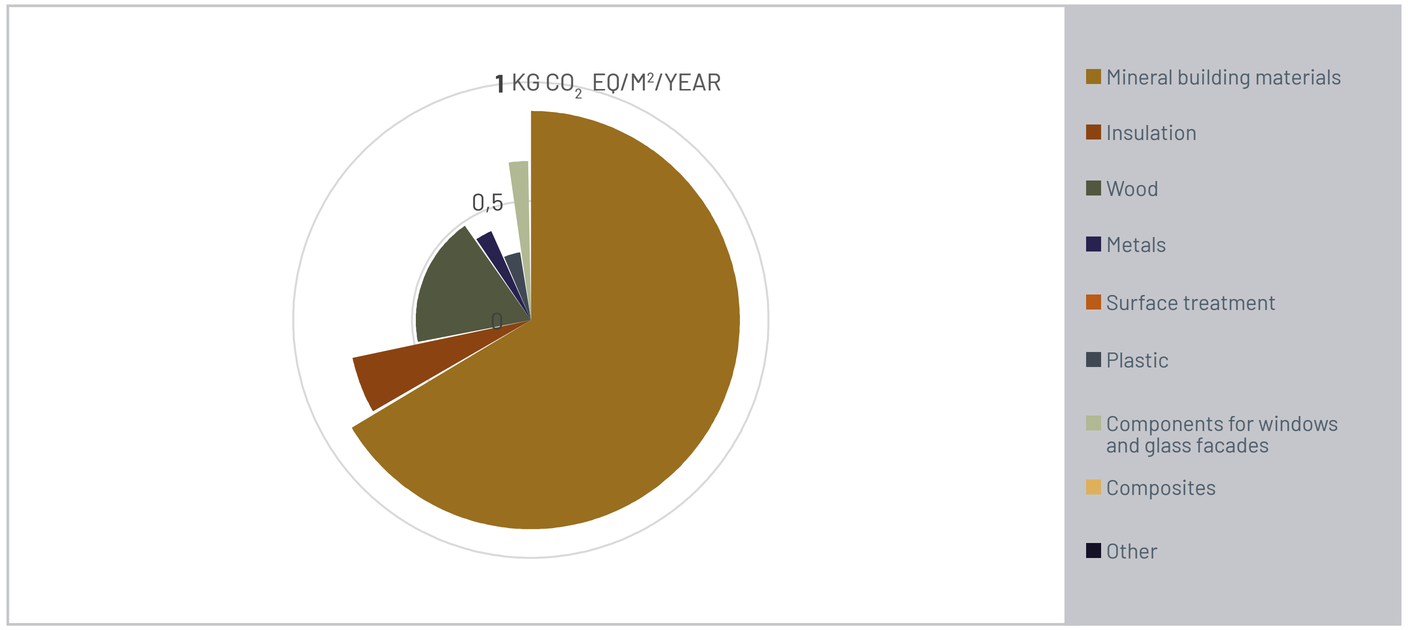


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

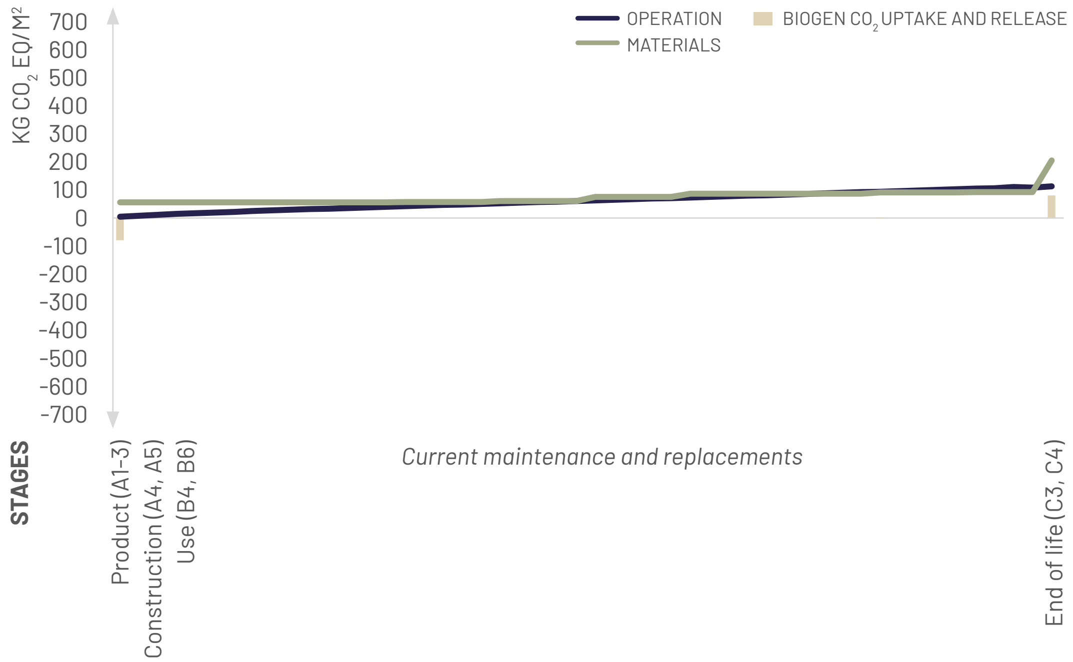


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

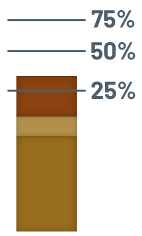
DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

RESULT IN **HIGH IMPACT**	Photovoltaic modules on roof Triple glazing in climate envelope due to large glazed area in facade Slate facade cladding EPS insulation in ground deck
RESULT IN **LOW IMPACT**	Material consumption of 307.7 kg/m² is below average (average being 684.6 kg/m²)

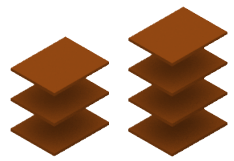
STUDIO[HOME] BALLERUP

DESCRIPTION

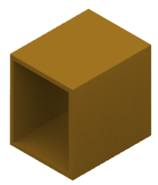
Studio[Home] Ballerup are studio homes in Ballerup comprising eight low-to-medium-rise blocks including common areas. The focal point of the project was on creating a pleasant framework for community life in buildings with low environmental impact. All housing units were commissioned ready for occupation with specially-designed furniture adapted to an efficient plan arrangement. The units are built with cassettes and the project draws on experience gleaned from the project Studio[Home] Lyngby. Accordingly, well-known and proven solutions were used in respect of fire, acoustics, etc



Mat.: 4,8
Tech. inst.: 1,0
Operation: 2,0
stated in KG CO_2 EQ/M²/YEAR



2 - 3 storeys



Cassette

Location	Ballerup, Denmark
Year	2020-2021
No. of units	478 dwellings, common areas
Category	Studio homes
Architect	Vandkunsten
Landscape	Vandkunsten
Engineer	Scandibyg
Client	Pension Denmark
Contractor	Scandibyg
Type of contract	Turnkey contract
Heated area	10.813 m²
Energy class	Low-energy class BR2018
Total energy consumption	28 kWh/m²/year
Energy source	Projected electricity mix & district heating
Data basis for LCA	Architectural model
Certification	DGNB Gold, Swan label
Project website	See link

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
The fire strategy from Studio[Home] Lyngby was repeated and the known solutions facilitated the approvals for statics, fire, and acoustics. The buildings were constructed using cassettes with cellulose insulation, slate facades with wooden sections, and steel staircases were installed as fire-escapes.

Economy
The use of prefabricated cassettes and experience from the project Studio[Home] Lyngby contributed to optimising the process and costs of the project.

Aesthetics
The client wanted low maintenance, and brick was therefore used as facade material, interspersed with a few wooden sections.

Construction moisture
As part of Pension Danmark's sustainability programme, a moisture strategy was required to avoid embedded moisture and reduce electricity consumption needed for drying out. The contractor Scandibyg has expert knowledge in moisture handling and clear guidelines and procedures were therefore in place for the handling of cassettes during construction.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

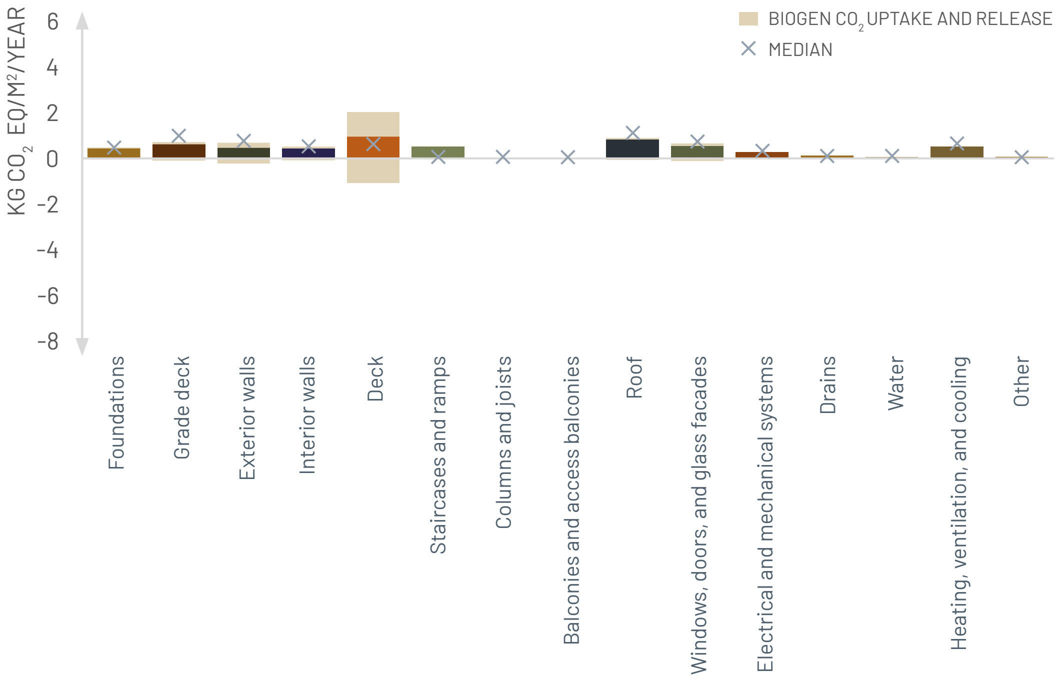


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m^2/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

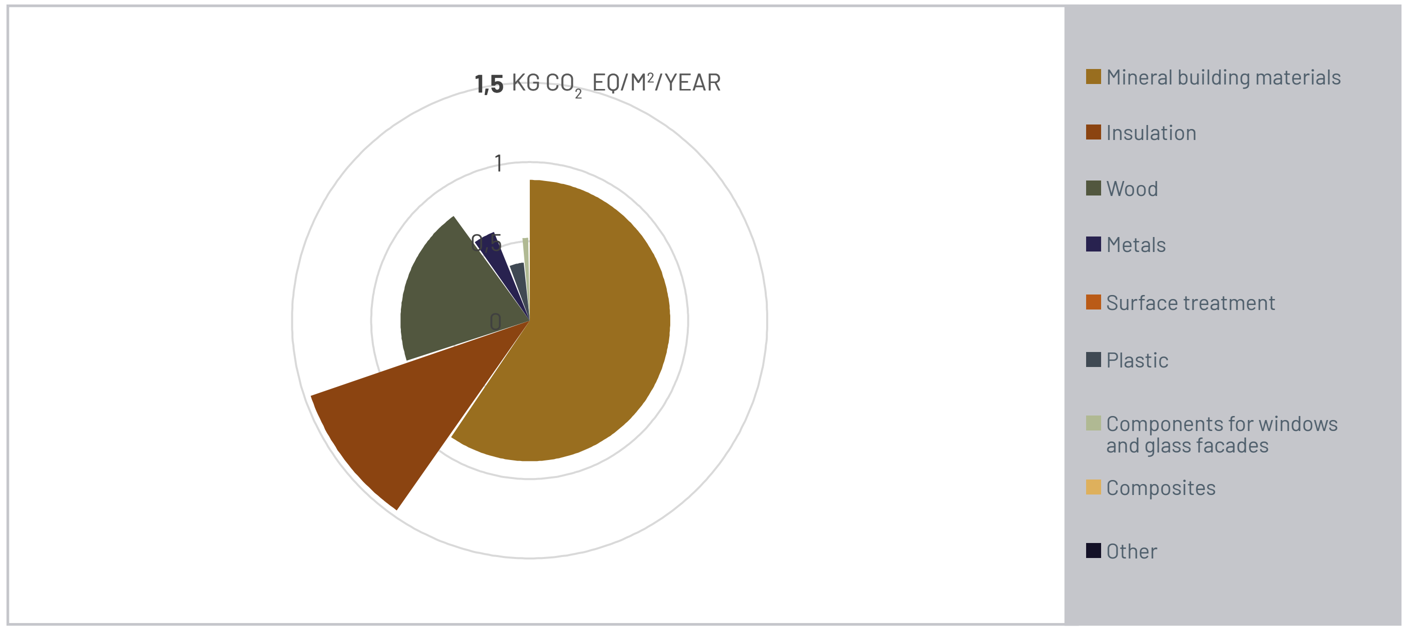


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

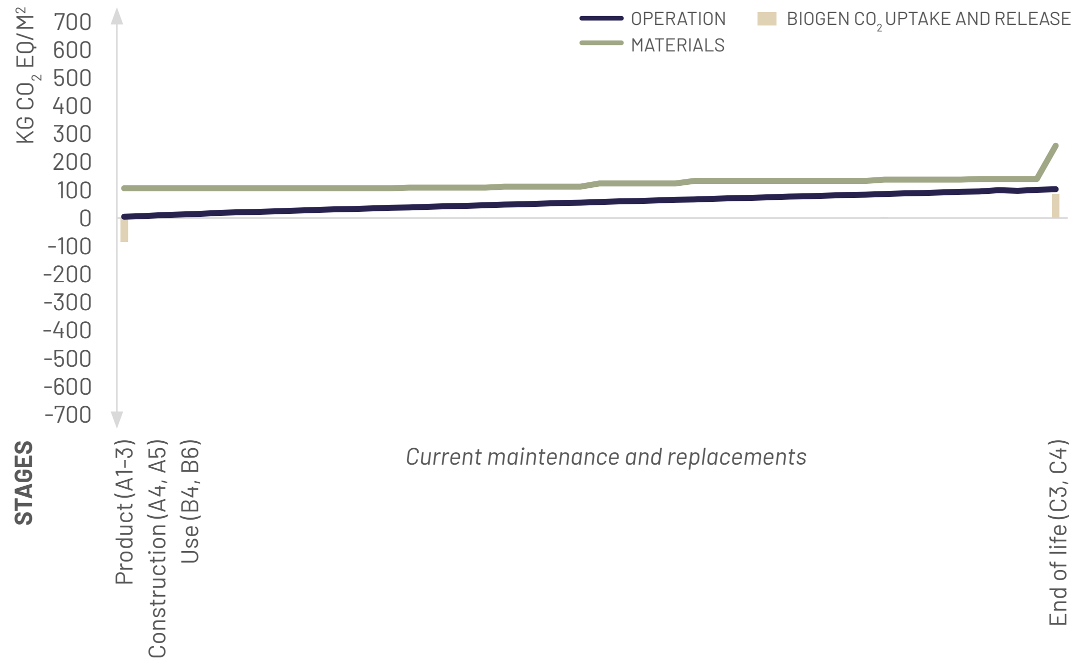


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m^2 distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

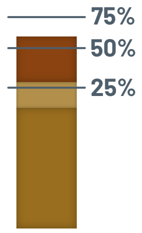
RESULT IN **HIGH IMPACT**	Pressure-resistant mineral wool roof insulation Cement-bonded particle board in storey partition and exterior walls Triple glazing in climate envelope EPS insulation in ground deck Photovoltaic modules on roof
RESULT IN **LOW IMPACT**	Material consumption of 341.8 kg/m² is below average (average being 684.6 kg/m²)

Photo Artelia (formerly MOE)

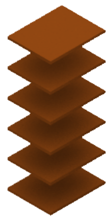
DESCRIPTION

The building system used in Knudrisrækkerne consists of several combined systems. There is a timber column-girder system in the front house, concrete stair towers, wood-and-concrete composite decks, and a middle house made of CLT panels. The project is strongly inspired by the Lisbjerg Bakke project, where the engineering firm Artelia (formerly MOE) also acted as consultants. It was possible, therefore, to make use of proven solutions at a price consistent with the framework amount. Emphasis was on reusing materials from the existing building in the new ones.

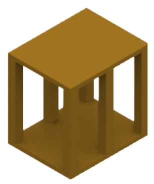
Location	Aarhus, Denmark
Year	2020-2022
No. of units	Approx. 70 dwellings, common premises at ground level
Category	Housing scheme
Architect	Kant Arkitekter
Landscape	VEGA Landskab Aps
Engineer	Artelia (formerly MOE)
Client	BoligOFFICEet Aarhus
Contractor	Q-construction
Type of contract	Turnkey contract
Heated area	7.324 m²
Energy class	Low-energy class BR2018
Total energy consumption	31,5 kWh/m²/year
Energy source	Projected electricity mix & district heating
Data basis for LCA	Engineering model
Certification	DGNB Gold
Project website	-



Mat.: 6,1
Tech. inst.: 1,3
Operation: 2,3
stated in KG CO_2 EQ/M²/YEAR



5 storeys



Hybrid

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
At the time of the project ideas phase, pre-approved solutions only applied to timber buildings of up to four storeys. These five-storey buildings were therefore assessed by comparative analysis. To meet fire requirements, the solution was eventually to establish extra escape routes and concrete stair towers.

Acoustics
The solutions used were based on experience from earlier projects, where acoustic measurements from buildings after completion showed that they meet acoustic requirements by up to 10dB below the stipulated requirements. The decks are so-called composite decks, consisting of Brettstapel system panels glued together and topped with a layer of cast concrete. The deck structure, along with all nodal-centre solutions, is significant to achieve good readings.

Economy & Logistics
To be able to close off the building as quickly as possible, the panels were projected as big as was practicably possible. This would reduce the number of crane lifts as well as the number of seams in the construction process. This also has a bearing on the construction costs.

Construction moisture
A moisture strategy was prepared to protect the buildings against the weather in the construction phase. However, the installation sequence was changed, which made the covering process difficult and resulted in some parts of the buildings getting very wet. This meant that several wet gypsum sheets had to be replaced. To monitor the dehydration process, moisture readings were taken every two weeks during the construction process, particularly in the wet areas. When the project was handed over, indoor climate measurements were made and, at that point, no construction-related mould growth was detectable.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

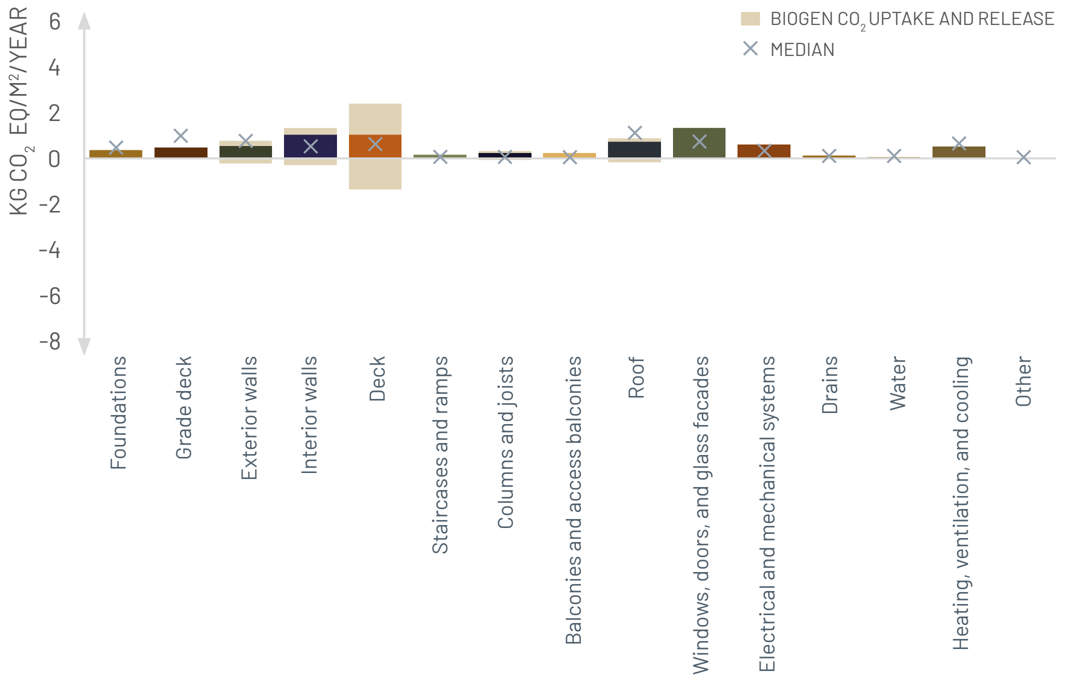


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

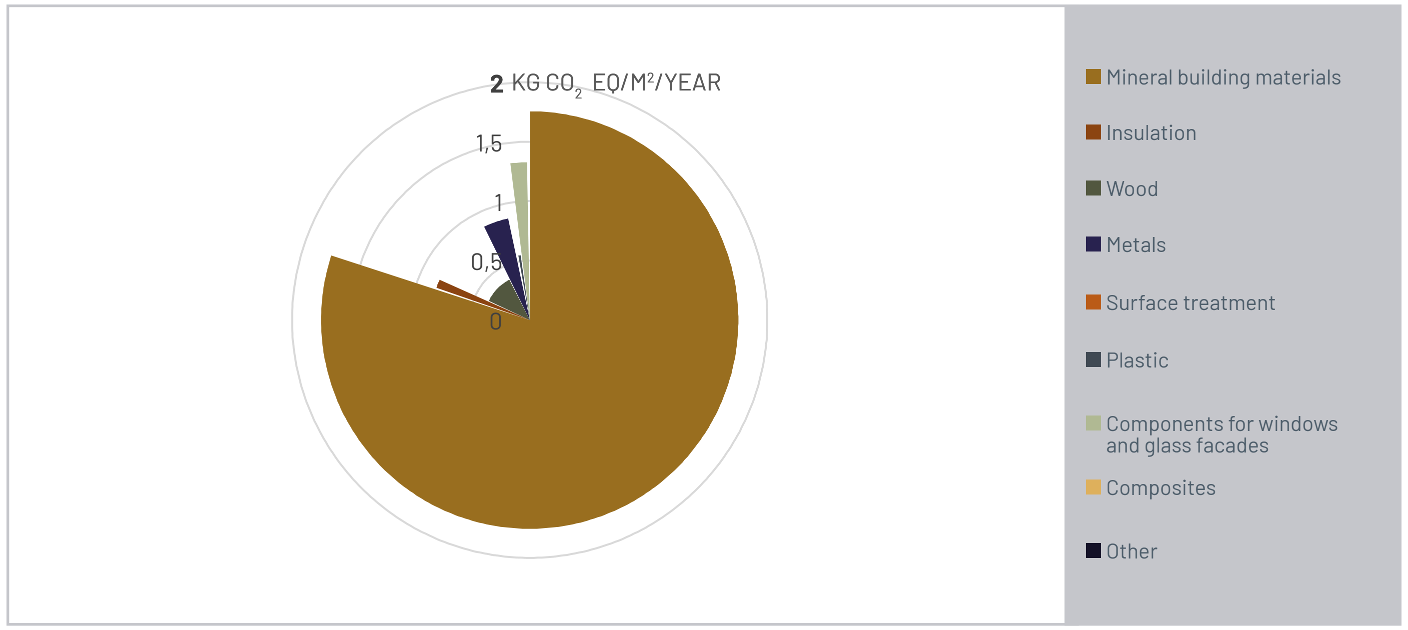


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

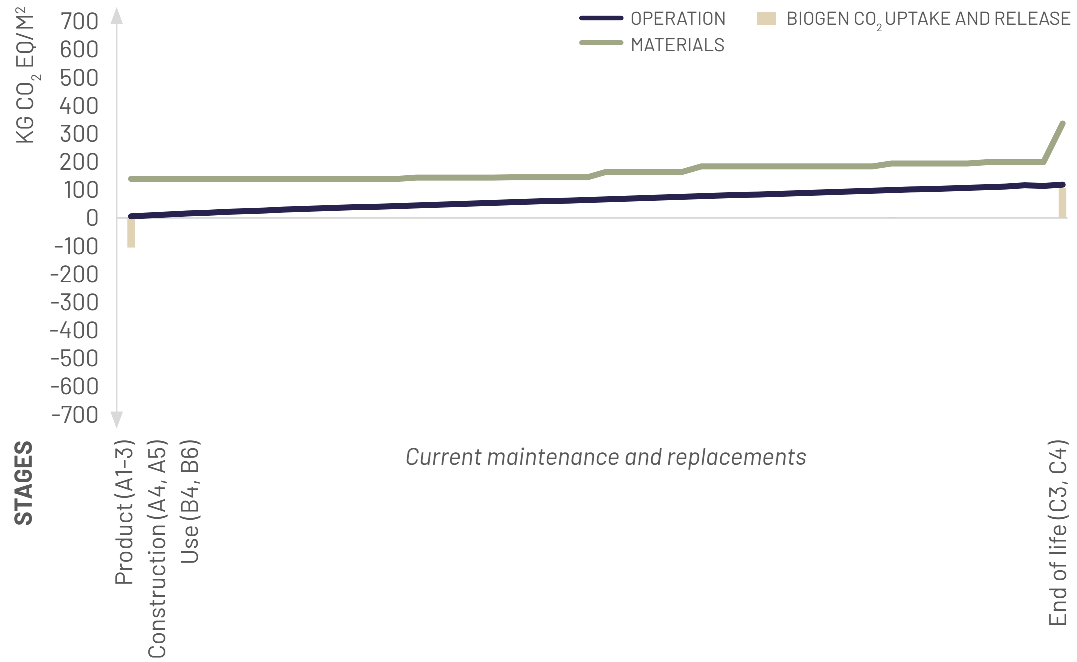


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

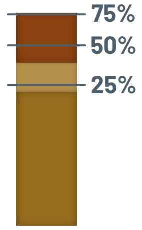
RESULT IN **HIGH IMPACT**	Large interior wall area due to several small rooms, resulting in an increased use of materials Photovoltaic modules on roof Concrete stair cores
RESULT IN **LOW IMPACT**	

Photo Artelia (formerly MOE)

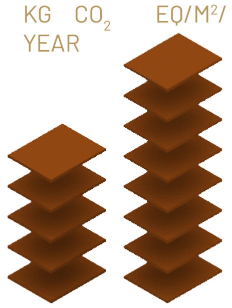
DESCRIPTION

The project UN17 Village seeks to address all the UN 17 Sustainable Development Goals (SDGs): a total of five large-scale housing schemes, each with their own strategy on sustainability. The aim is to have the project certified according to DGNB Gold or Platinum, DGNB Heart, and WELL. From the very start, the client NREP wished to examine how to incorporate most sustainability within the given price restraints. Accordingly, the project comprises various sustainability themes and building types, each of which reduces environmental impact by means of various strategies. The building 'Sundhedsboliger' (Health Housing) is one of five buildings. The premise here being timber housing. The design principle is a hybrid of CLT, glulam beams, concrete walls, and timber cassettes.

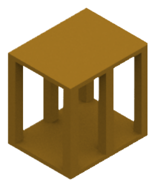
Location	Ørestad, Denmark
Year	2020-2024 (expected)
No. of units	80 dwellings
Category	Housing scheme, Commercial
Architect	Lendager, Sweco Architects
Landscape	SLA
Engineer	Artelia (formerly MOE)
Client	NREP
Contractor	CG Jensen
Type of contract	Turnkey contract
Heated area	6.707 m^2
Energy class	BR2018
Total energy consumption	33,7 kWh/m^2/year
Energy source	Projected electricity mix & district heating
Data basis for LCA	Engineering model
Certification	-
Project website	See link



Mat.: 6,8
Tech. inst.: 1,5
Operation: 2,5
stated in KG CO_2 EQ/M^2/YEAR



4 - 7 storeys



Hybrid

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
To reduce uncertainties and uncover various theoretical challenges, the client opted for fire-testing of timber facade systems and CLT decks by Dansk Brand- og Sikringsteknisk Institut (DBI). The result of the fire-testing of CLT deck panels proved that the joining method between them had the required fire resistance. Further, the tests proved that the adhesive used in the CLT panels met the required fire quality standard. The fire-testing of the timber facade systems proved that flame-spread could be mitigated by incorporating simple steel-sheet overhangs as fire stops.

Logistics
An agreement was signed with a Swedish manufacturer of mass-timber system elements in Gothenburg, reducing the transport distance.

Aesthetics
To comply with requirements for fire and acoustics, timber beams could only be partly exposed.

Statics
Concrete is used for extensive horizontal loads, and timber for simple vertical loads. This optimises the use of materials.

Acoustics
The project features many horizontal boundaries between housing units and wood will transmit low-frequency sound. To find solutions to this, the Technical University of Denmark (DTU) is conducting experiments testing 20 different deck solutions for sound insulation and environmental climate impact.

Economy
Major Danish house-carcase installers generally lack experience of timber buildings, making budgeting and identifying a time schedule for carcase installation in major building projects difficult.

Construction moisture
The consulting engineer prepared a moisture strategy approved by the client and the contractor's insurance company.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

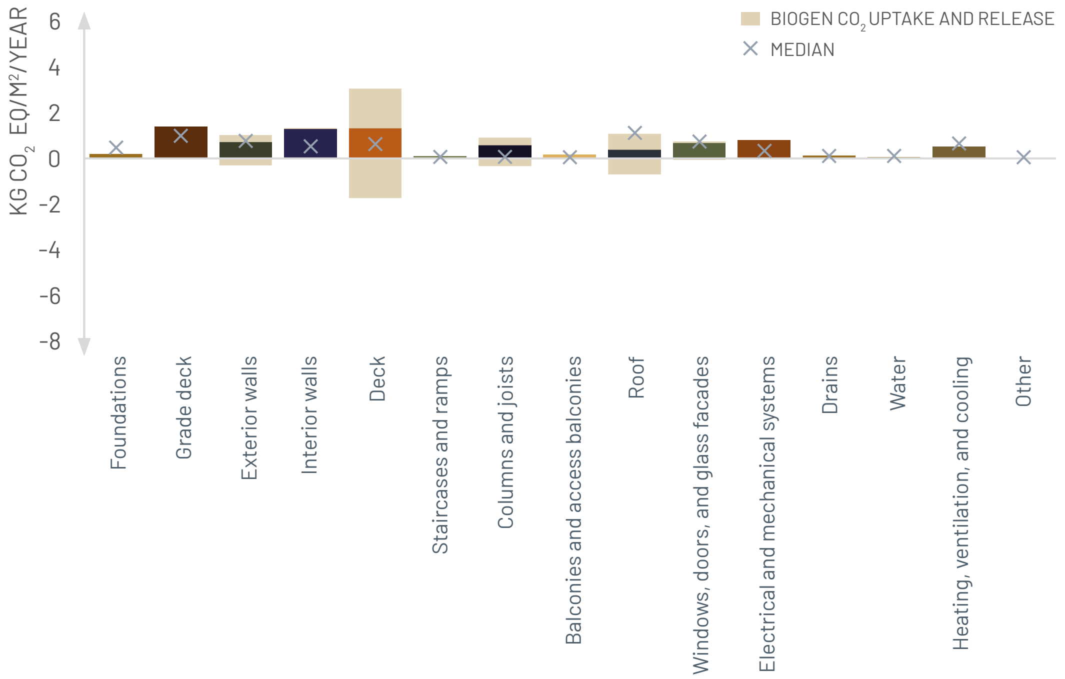


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

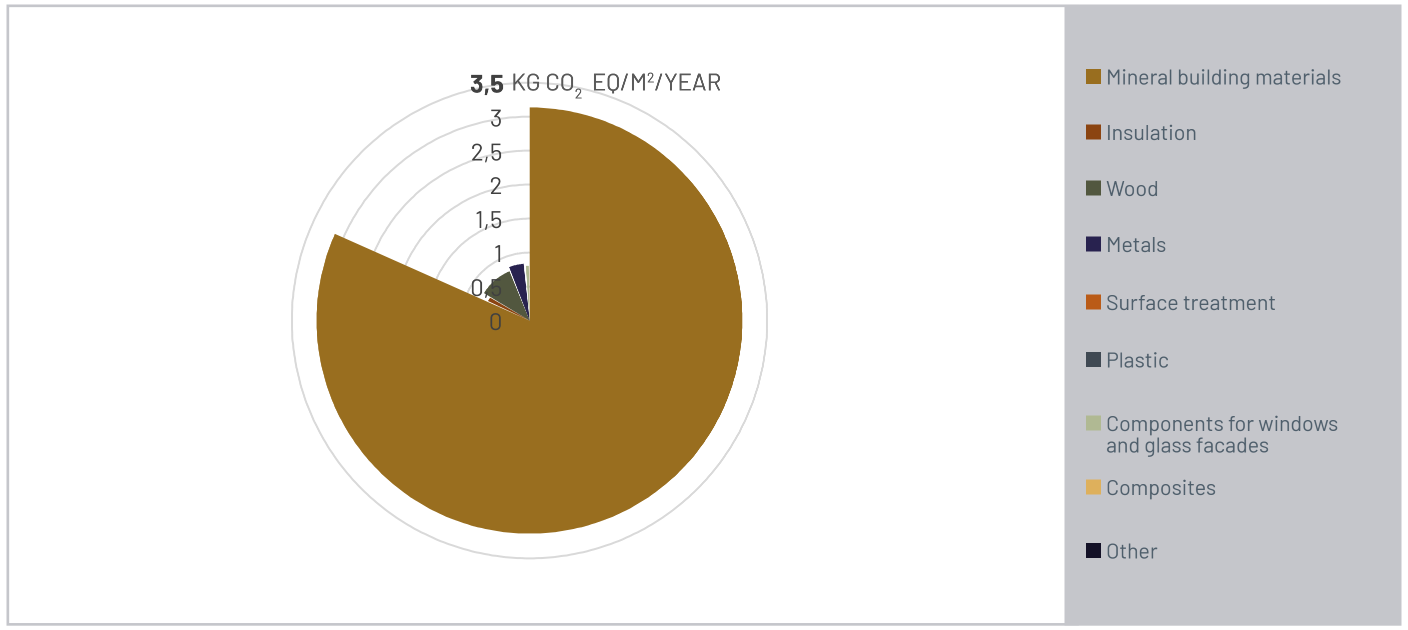


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

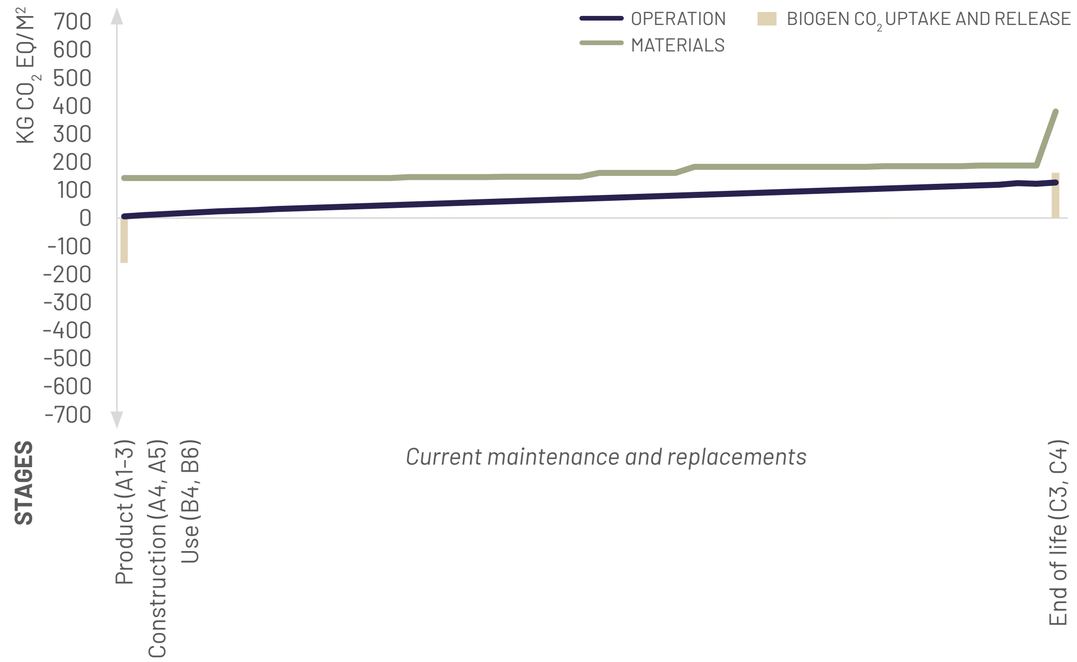


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

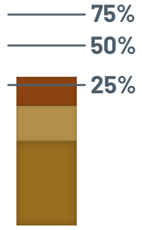
DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

RESULT IN **HIGH IMPACT**	Concrete class C45/50 in grade deck Photovoltaic modules on roof Concrete in interior walls Steel seams Material consumption of 949.2 kg/m² is above average (average being 684.6 kg/m²)
RESULT IN **LOW IMPACT**	


Photo Adserballe & Knudsen

DESCRIPTION

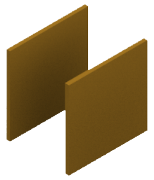
Toppen is part of the same framework agreement as Skademosen and Skousbo I, for which the construction system BoligTræ was developed. BoligTræ is developed to both reduce climate footprints and enhance the efficiency of the project in the manufacture and construction phases. Also, focus was on designing all buildings in digital models, facilitating ongoing optimisation across the projects in the framework agreement. The construction system BoligTræ enables the planning solution to be varied and offsetting the design. The Toppen construction project comprises three-storey buildings and is constructed in solid CLT timber.



Mat.: 4,3
Tech. inst.: 1,8
Operation: 1,5
stated in KG CO_2 EQ/M²/YEAR

Location	Roskilde, Denmark
Year	2019-2021
No. of units	67 dwellings
Category	Housing scheme
Architect	Vilhelm Lauritzen Arkitekter
Landscape	Thing Firet Landskab
Engineer	Holmsgaard A/S
Client	Boligselskabet Sjælland
Contractor	Adserballe & Knudsen A/S
Type of contract	Turnkey contract
Heated area	5.621 m²
Energy class	Low-energy class BR2018
Total energy consumption	26,3 kWh/m²/year
Energy source	Projected electricity mix & piped gas
Data basis for LCA	Engineering model
Certification	-
Project website	See link


3 storeys


Sheeting (CLT)

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
The client wanted to use cellulose insulation material, but this proved impossible, because the material is not rated as fire class A. Instead, mineral wool insulation material was chosen.

Acoustics
Sheeting was used as storey partitions to provide sound insulation between individual housing units. Sound insulation between horizontal boundaries separating housing units proved difficult to handle due to the extensive spans. It was necessary, therefore, to use special system ceilings with suspended acoustic panels to eliminate sound transmission between storeys. The degree of accuracy of these sheets differed from CLT panels, and adaptations were therefore necessary to ensure the correct positioning of the CLT panels.

Construction moisture
A moisture strategy was a set requirement in the competition. An interim site cover was established and the building was constructed vertically. Further, moisture sensors were used but only as a supplement to daily moisture checks. They were placed sporadically throughout the structure.

Moisture during use
Moisture membranes were installed on the underside of the CLT panels using a hammer tacker. The elements were chocked-up on plastic wedges and bituminous felt membranes were welded to the bottom. Next, the edge of the membrane was sprayed with a liquid wax coating to avoid the elements absorbing moisture.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

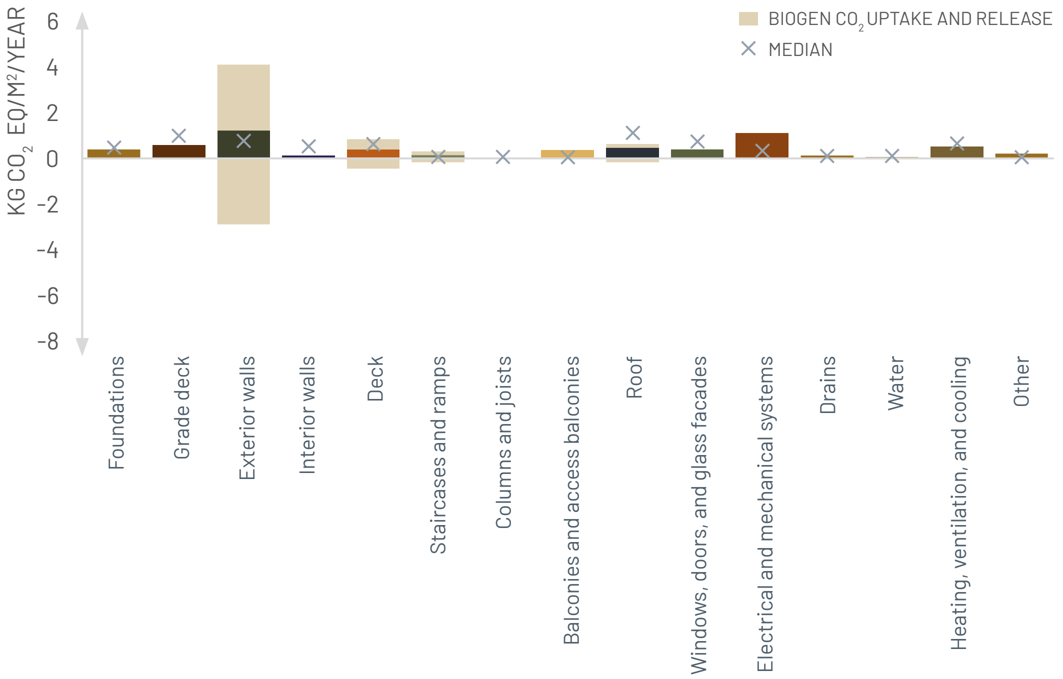


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

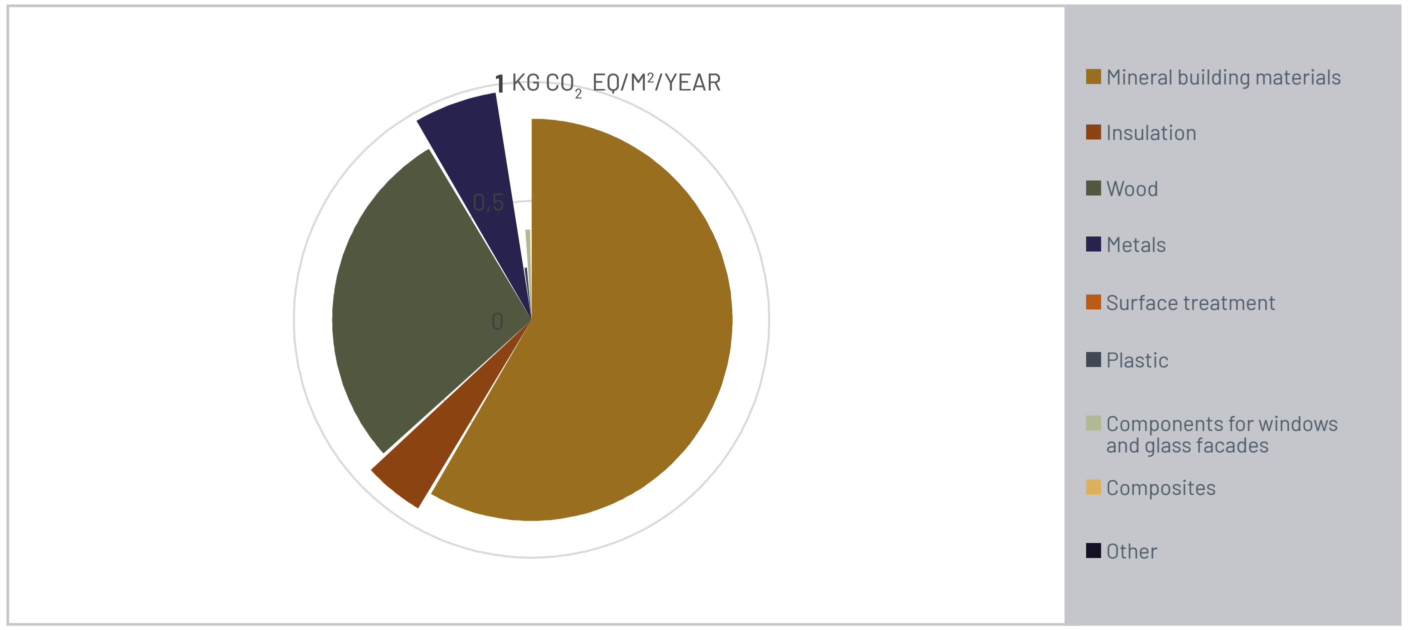


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

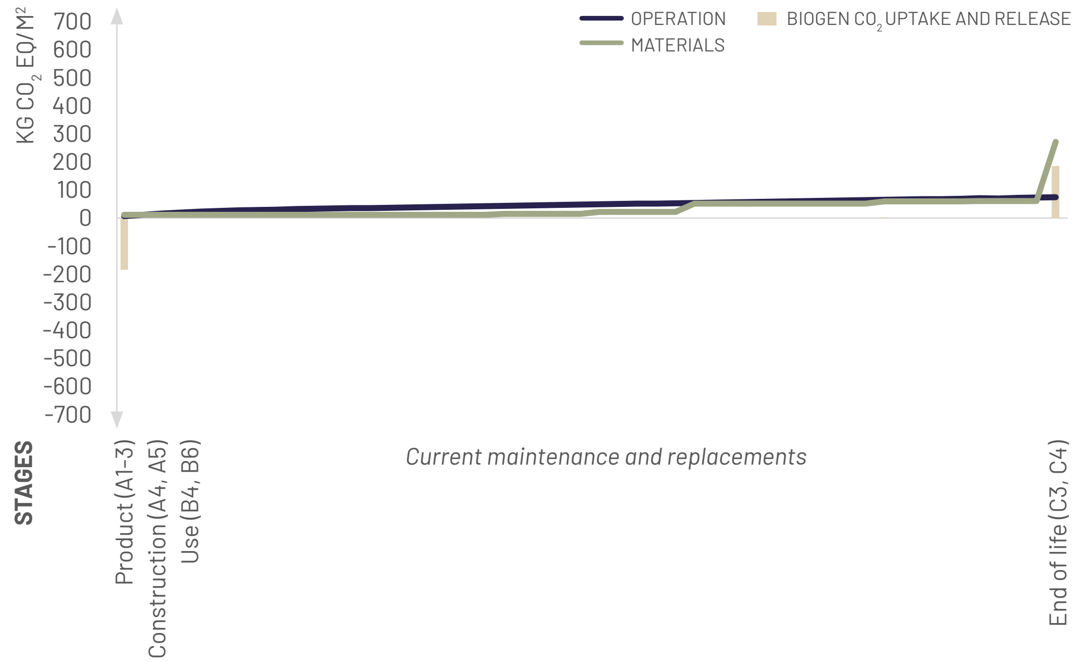


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

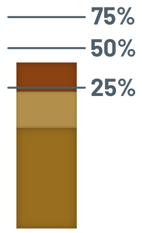
DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

RESULT IN **HIGH IMPACT**	Photovoltaic modules on roof EPS insulation in ground deck Triple glazing in climate envelope Supporting structure of CLT panels in exterior walls Mineral wool insulation in exterior walls Heat-treated timber facade
RESULT IN **LOW IMPACT**	Material consumption of 405.1 kg/m² is below average (average being 684.6 kg/m²)

SKOUSBO I

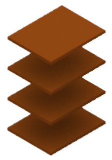
DESCRIPTION

Along with Skademosen and Toppen, this building project is part of the same framework agreement, for which the construction system BoligTræ was developed. The construction system is used as a supporting structure. BoligTræ was developed with a view to reducing climate footprints and streamlining the project in the production and construction phases. The project comprises three-storey buildings with walls and decks in CLT with facade elements alternating between timber and slate. Further, emphasis has been on using environmentally and allergy-friendly building materials.

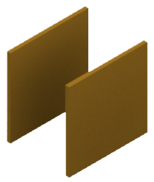


Mat.: 5,1
Tech. inst.: 1,9
Operation: 1,5
stated in KG CO_2 EQ/M²/YEAR

Location	Roskilde, Denmark
Year	2017-2021
No. of units	34 dwellings
Category	Housing scheme
Architect	Vilhelm Lauritzen Arkitekter
Landscape	Thing Firet Landskab
Engineer	Holmsgaard A/S
Client	Boligselskabet Sjælland
Contractor	Adserballe & Knudsen A/S
Type of contract	Turnkey contract
Heated area	2.534 m²
Energy class	Low-energy class BR2018
Total energy consumption	26,3 kWh/m²/year
Energy source	Projected electricity mix & piped gas
Data basis for LCA	Engineering model
Certification	-
Project website	See link



3 storeys



Sheeting (CLT)

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
The client wanted to use cellulose insulation material, but this proved impossible, because the material is not rated as fire class A. Instead, mineral wool insulation material was chosen.

Acoustics
Sheeting was used as storey partition to provide sound insulation between individual housing units.

Logistics
Based on experience from Skademosen, the contractor opted for CLT decks rather than classic sheeting. The reason being that extra working hours would be needed to install CLT on top of the sheeting.

Construction moisture
The grade deck comprises CLT, membranes, and sand. To avoid moisture damage, it was decided not to use concrete. Further, it is easier to dismantle the chosen deck type into pure material fractions without a layer of fast-drying concrete.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

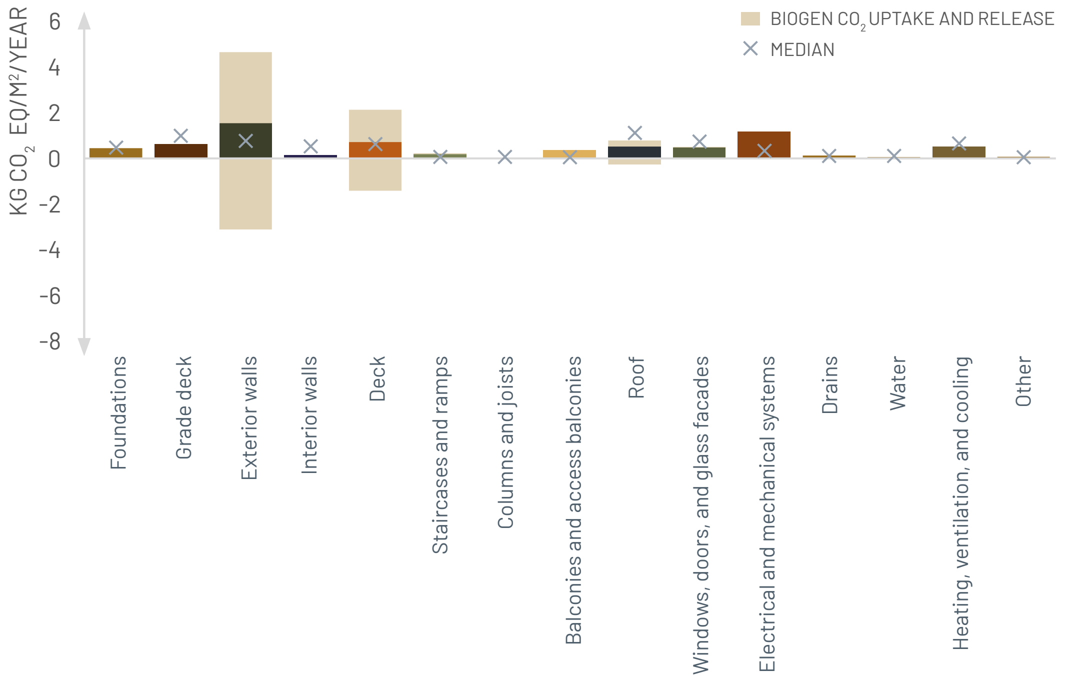


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

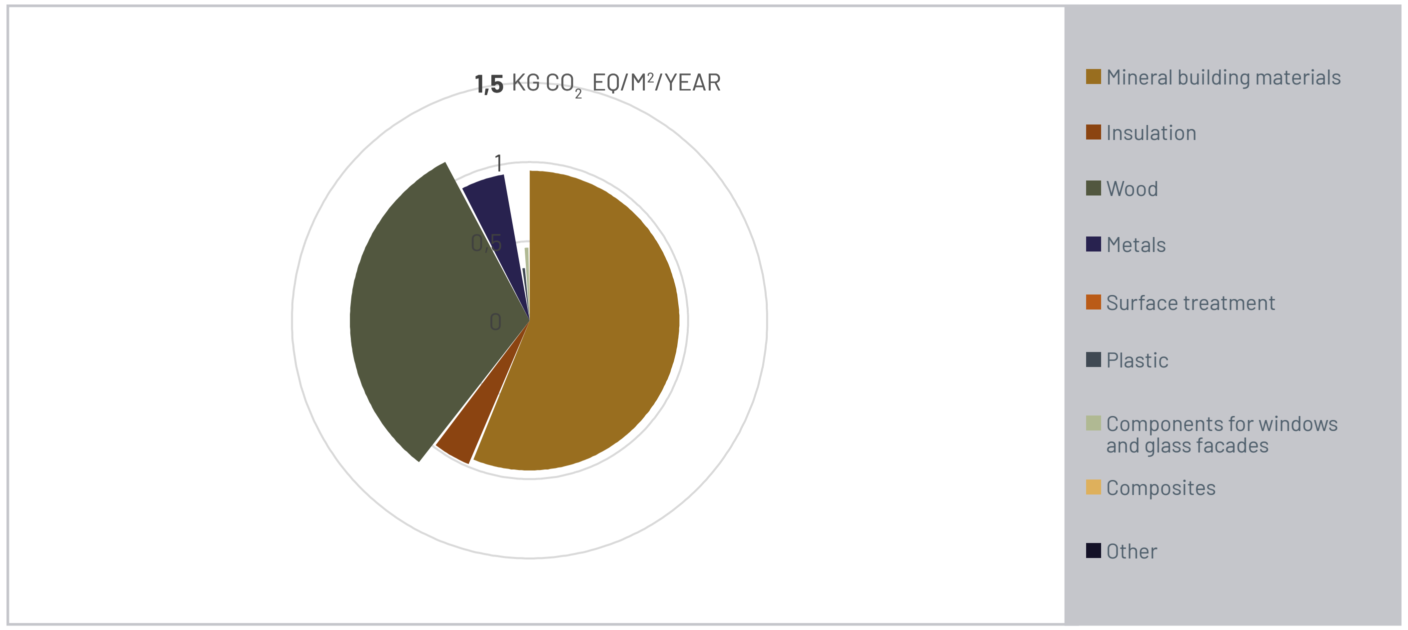


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

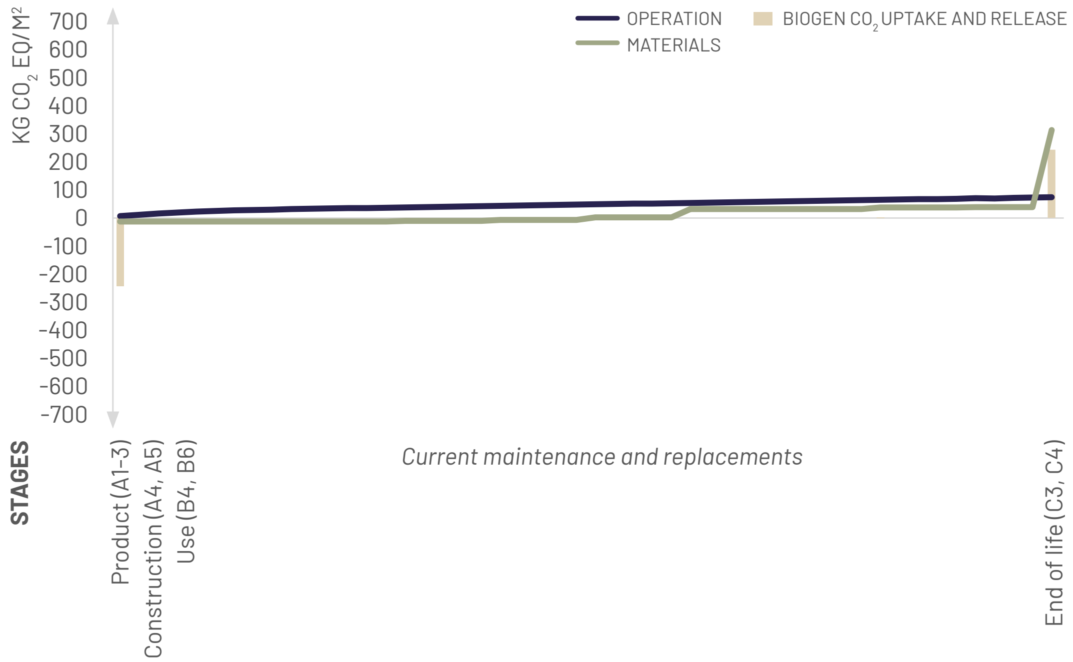


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

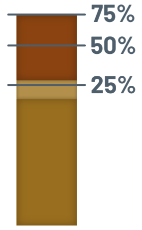
RESULT IN **HIGH IMPACT**	Photovoltaic modules on roof EPS insulation in ground deck Triple glazing in climate envelope Mineral wool exterior wall insulation Supporting structures of CLT panels in exterior walls
RESULT IN **LOW IMPACT**	Material consumption of 479.4 kg/m² is below average (average being 684.6 kg/m²)

STORKENS KVARTER

Photo Vandkunsten

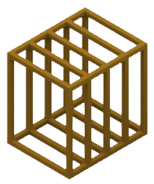
DESCRIPTION

The idea of this project was to assemble employees, administration, and machinery from the housing association Albertslund Syd at a single location. This was achieved through focusing on the building's dimensions and design. Comprising a single storey, the building is relatively small, which made it easy to use timber for facades, structures, floors, and interior cladding.



Mat.: 6,4
Tech. inst.: 0,9
Operation: 3,3
stated in KG CO_2 EQ/M²/YEAR

1 storey



Timber frame

Location	Albertslund, Denmark
Year	2014-2016
No. of units	2
Category	Office
Architect	Vandkunsten
Landscape	Vandkunsten
Engineer	Wissenberg
Client	Albertslund Boligselskab afd. Syd
Contractor	SB Entreprise A/S, Henning Carlsen VVS, ENCO A/S
Type of contract	Turnkey contract
Heated area	1.036 m^2
Energy class	Low-energy class BR2015
Total energy consumption	40,9 kWh/m^2/year
Energy source	Projected electricity mix & district heating
Data basis for LCA	Architectural model
Certification	DGNB Gold
Project website	Se link

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
No specific fire measures since the building is a single-storey building and pre-approved solutions were used.

Statics and economy
The project was originally designed in prefabricated system elements, but because the contractor wanted to build in timber, it was decided to change the type of construction. This made the project more expensive.

Aesthetics and moisture
Vandkunsten had wanted to reuse parquet flooring from a related residential building as wall cladding, but the time schedule made this impossible. Instead, the client decided to use new parquet flooring on the walls to retain the imagined expression.

The architect was familiar with constructive wood protection, and large overhangs were installed to protect the facade. However, no horizontal skirting was fitted to the lower part of the facade, resulting in exposed areas. No moisture strategy was implemented on an ongoing basis in the project, as the construction follows traditional construction practices.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

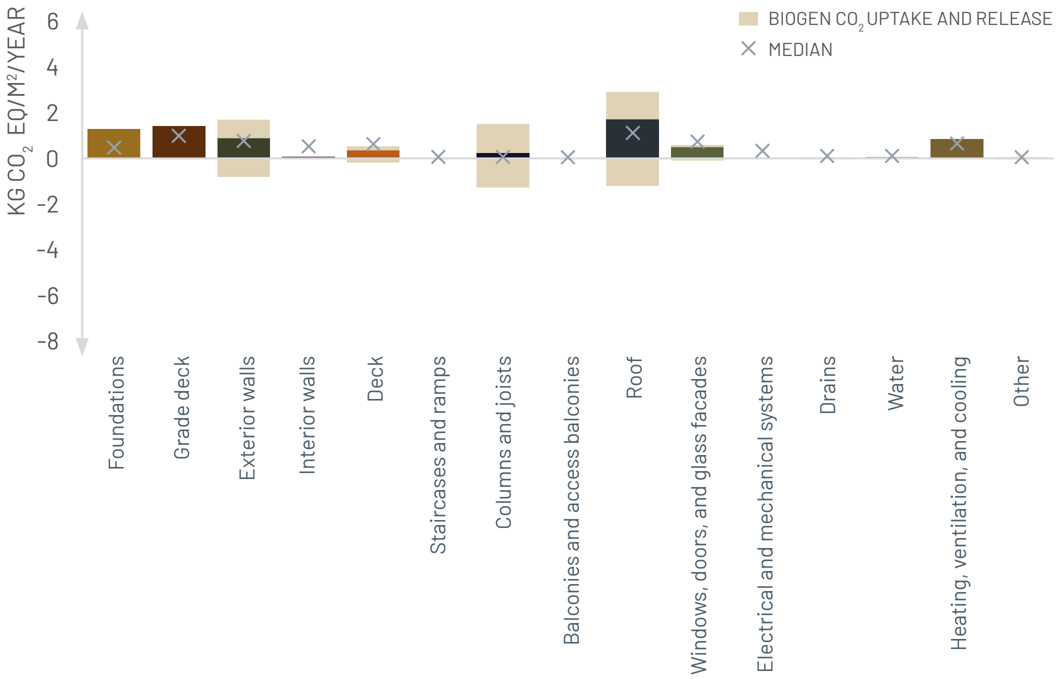


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

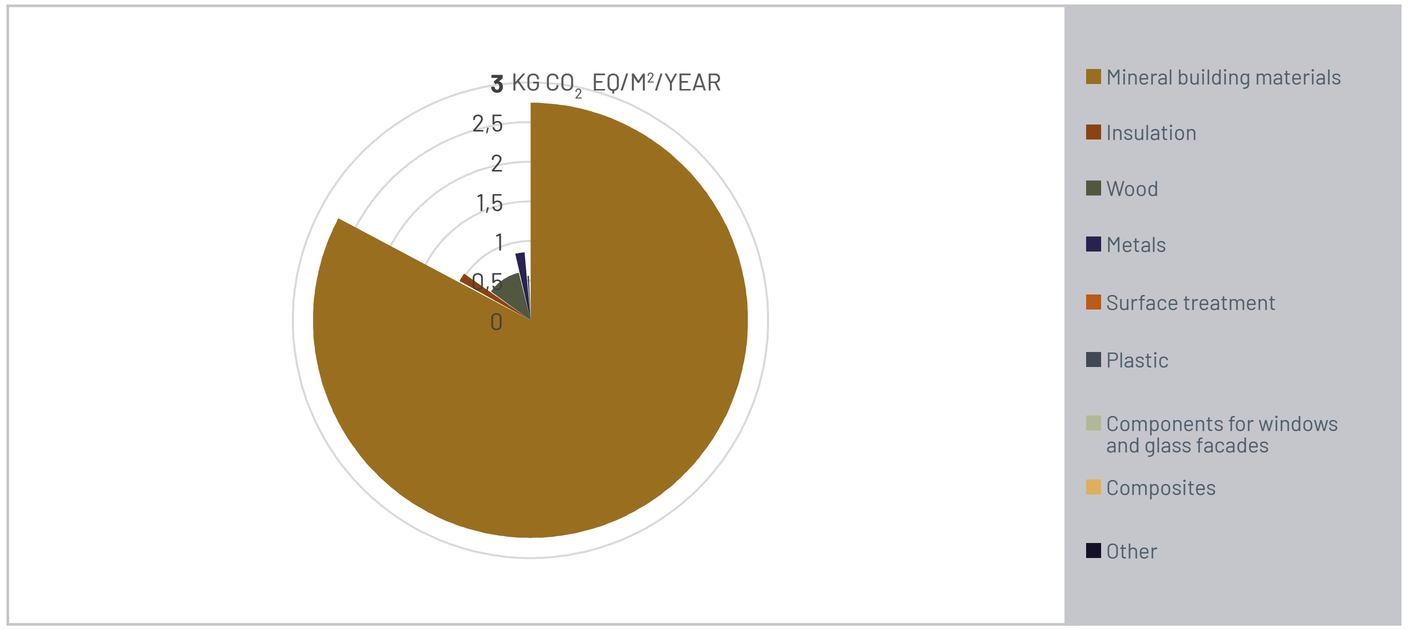


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

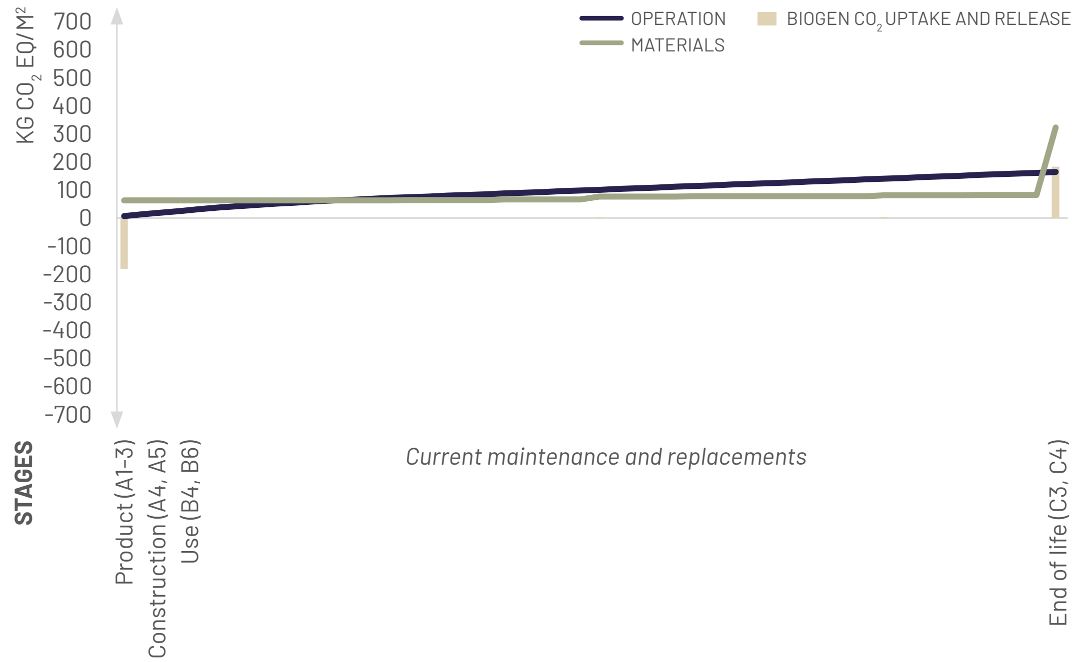


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

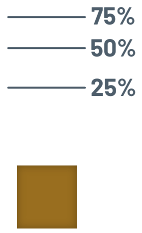
RESULT IN **HIGH IMPACT**	High-pitch roof and single-storey design means increased use of materials Material consumption of 1035.7 kg/m² is above average (average being 684.6 kg/m²) Concrete in grade deck and foundations EPS insulation in grade deck Steel-sheet roofing material
RESULT IN **LOW IMPACT**	

UNINSULATED STREET GAMES HALL

Photo Vandkunsten

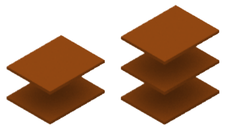
DESCRIPTION

The project was commissioned by the foundation Lokale og Anlægsfonden (L&A) in response to a general request for uninsulated sports halls. Accordingly, Vandkunsten and three other architects' studios were given a parallel task: they received funding to develop a concept for an uninsulated hall. The task specified sustainability as a parameter and for this reason, Vandkunsten decided to predesign the concept in CLT rather than steel. The four concepts were grouped in a catalogue held by L&A, who offered a grant of DKK 5 million to municipalities who agreed to build one of these uninsulated halls. Gentofte Municipality wanted an uninsulated hall and opted for Vandkunsten's version, which was subsequently re-dimensioned to accommodate street games rather than handball facilities which had originally been proposed.

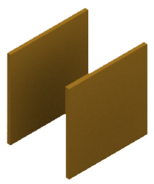


Mat.: 3,2
Tech. inst.: -
Operation: -
stated in KG CO_2 EQ/M²/YEAR

Location	Gentofte, Denmark
Year	2015-2015
No. of units	1
Category	Uninsulated hall
Architect	Vandkunsten
Landscape	Vandkunsten
Engineer	Artelia (formerly MOE)
Client	Gentofte Municipality
Contractor	Lilleheden (supplier)
Type of contract	Main contract
Heated area	1.026 m²
Energy class	-
Total energy consumption	-
Energy source	-
Data basis for LCA	Architectural model
Certification	-
Project website	See link



1 - 2 storeys



Sheeting (CLT)

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
Fire dimensioning of the uninsulated hall focused on integrating fire-prevention measures. Alarms were installed to ensure that fires would be discovered even if starting at night. Further, various scenarios were dimensioned in the event of evacuation.

Statics
The crosswise rafter structure in the hall was originally designed as two symmetrical rafters held in place by steel ties, however, to enhance the load-bearing capacity, they were eventually built as a single structure.

Economy
The idea of the project was to construct uninsulated, low-cost halls totalling DKK 5000 per m². Had steel been used for the supporting structures, the profiles could have been made to standard hall measurements, however, Vandkunsten was convinced that it was possible to stay within the budget and still use glulam beams.

Aesthetics and moisture during use
There had been emphasis, in the project, on reducing maintenance and avoiding undesirable moisture. The architects therefore deployed principles of constructive wood preservation by designing the building with large roof overhangs and incorporating horizontal skirting at the lower part of the facade. Further, larch was selected for the facades, which is a very durable material.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

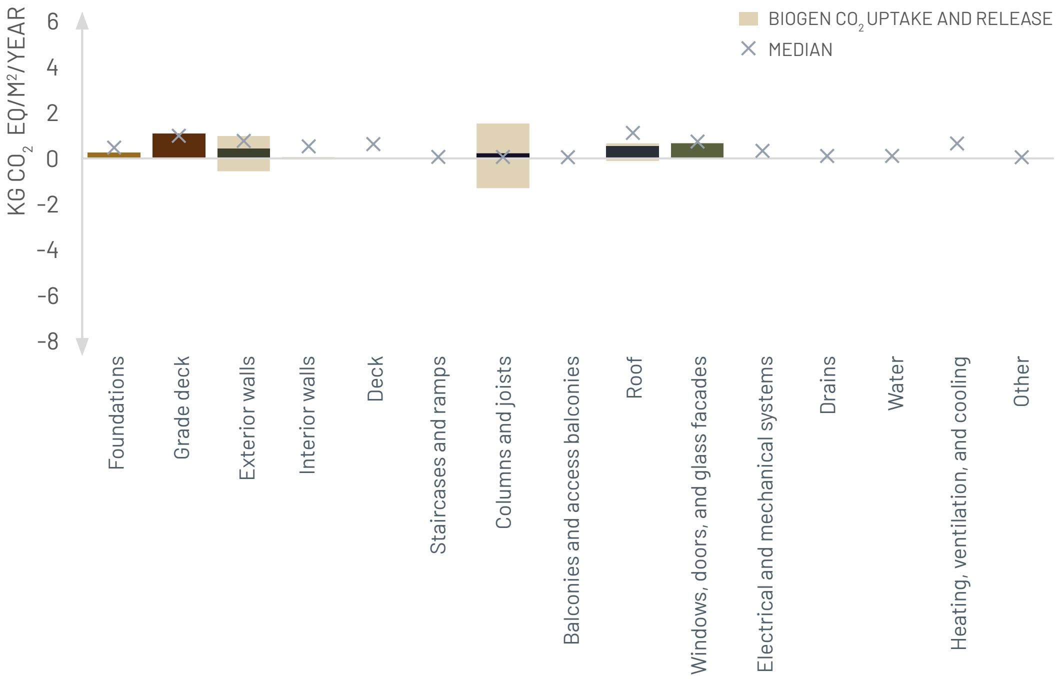


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

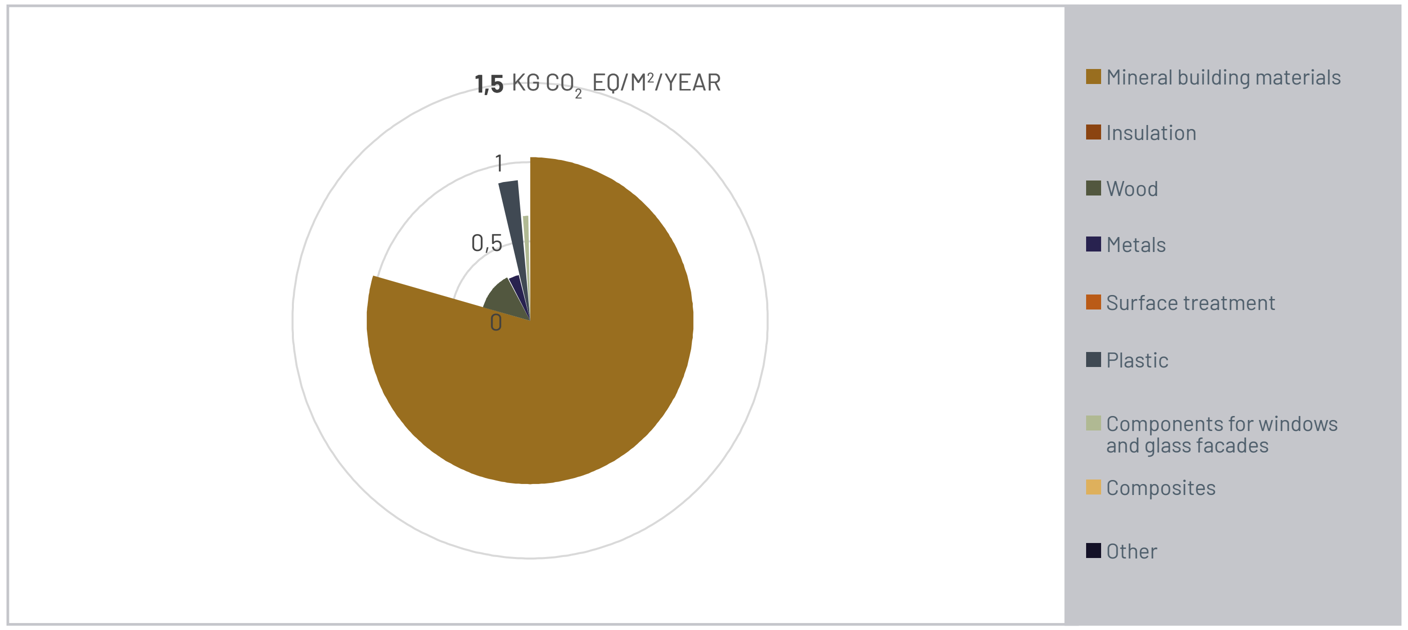


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

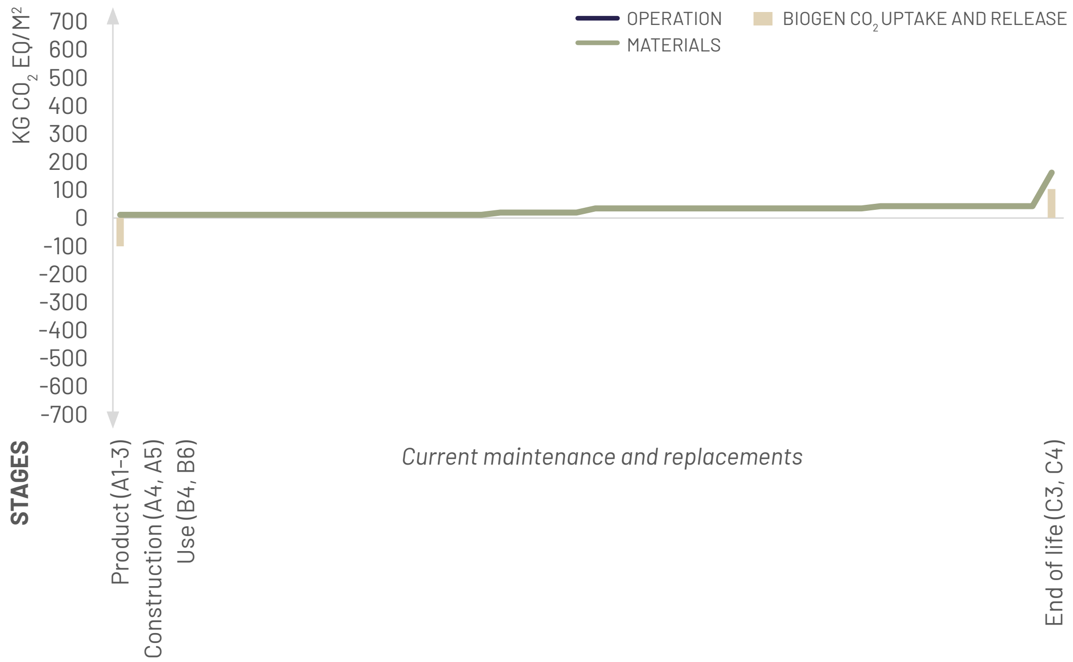


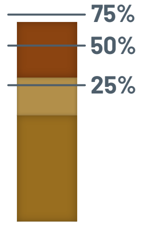
Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

RESULT IN **HIGH IMPACT**	Concrete in grade deck Triple glazing in climate envelope Polycarbonate facade sheets Bituminous felt roofing Glulam beams as carrying structure
RESULT IN **LOW IMPACT**	Material consumption of 491.4 kg/m² is below average (average being 684.6 kg/m²) Plain architectural expression and simple uninsulated structure

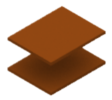
DESCRIPTION

This forms part of a larger project to build two out-of-school clubs in Albertslund Municipality: Klub Svanen and Bakkens Hjerte. Hence the description and experience outline cover both projects. Albertslund Municipality wanted increased focus on sustainability, which the architects' studio Vandkunsten had interpreted as a structure with wood as the primary material. Besides using wood to a very great extent, the buildings do not have vapour barriers and are insulated with cellulose.

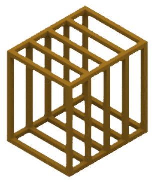


Mat.: 5,5
Tech. inst.: 2,0
Operation: 2,9
stated in KG CO_2 EQ/M²/YEAR

Location	Albertslund, Denmark
Year	2018-2022
No. of units	1
Category	Out-of-school club
Architect	Vandkunsten
Landscape	Vandkunsten
Engineer	Regnestuen
Client	Albertslund Kommune
Contractor	Egen Vinding & Datter
Type of contract	Turnkey contract
Heated area	470 m²
Energy class	BR2018
Total energy consumption	38,5 kWh/m²/year
Energy source	Projected electricity mix & district heating
Data basis for LCA	Architectural model
Certification	-
Project website	-



1 storey



Timber frame

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
A fire strategy was adopted and an external consultant was called in. It had been a great advantage that the architects were familiar with the fire-technical properties of wood, although the external consultant was responsible for the design. This resulted in larger fire cells than in pre-approved solutions, which made it difficult to comply with the Building Regulations.

Acoustics
The architects had trouble finding reference projects with the same goal and type of material as this one. Further, tools and experience in calculating acoustic values in timber buildings were lacking. This made it difficult to comply with acoustics requirements, notably footfall transmission, which added to project costs.

Economy
The project had a limited and predetermined budget. The limited economic framework had a significant bearing on the project, for example, dictating the choice of materials.

Construction moisture
The architects proposed to construct a breathable building of bio-based materials, leaving out the vapour barrier. For this reason, a contractor was selected who had expert knowledge of this type of building as well as with its design and construction.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

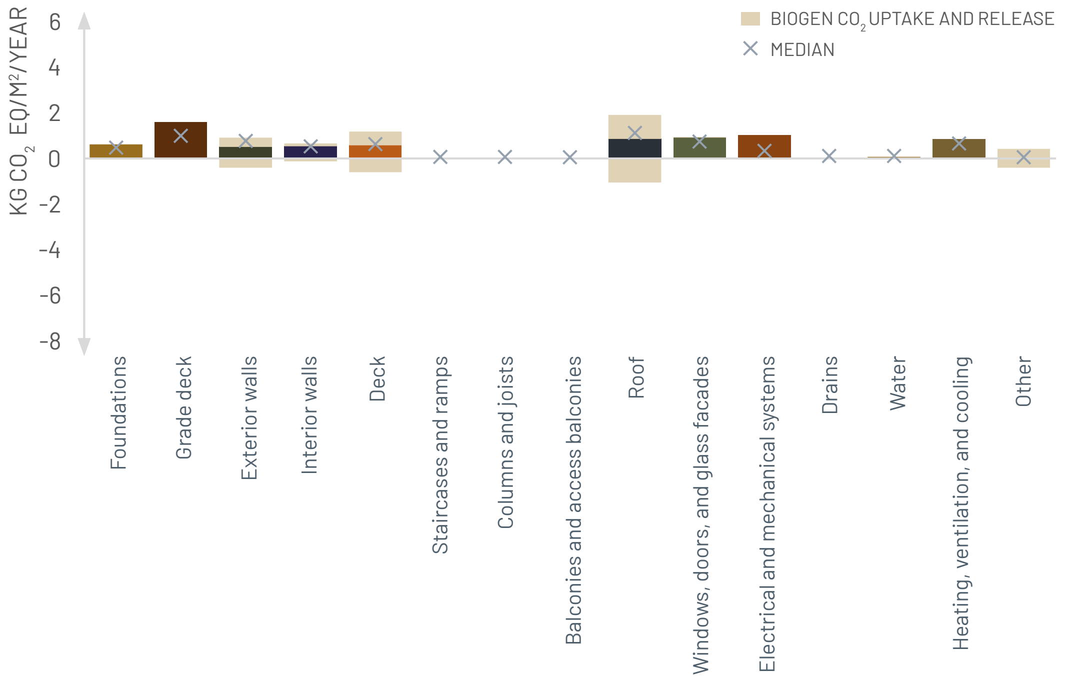


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m^2/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m^2 distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

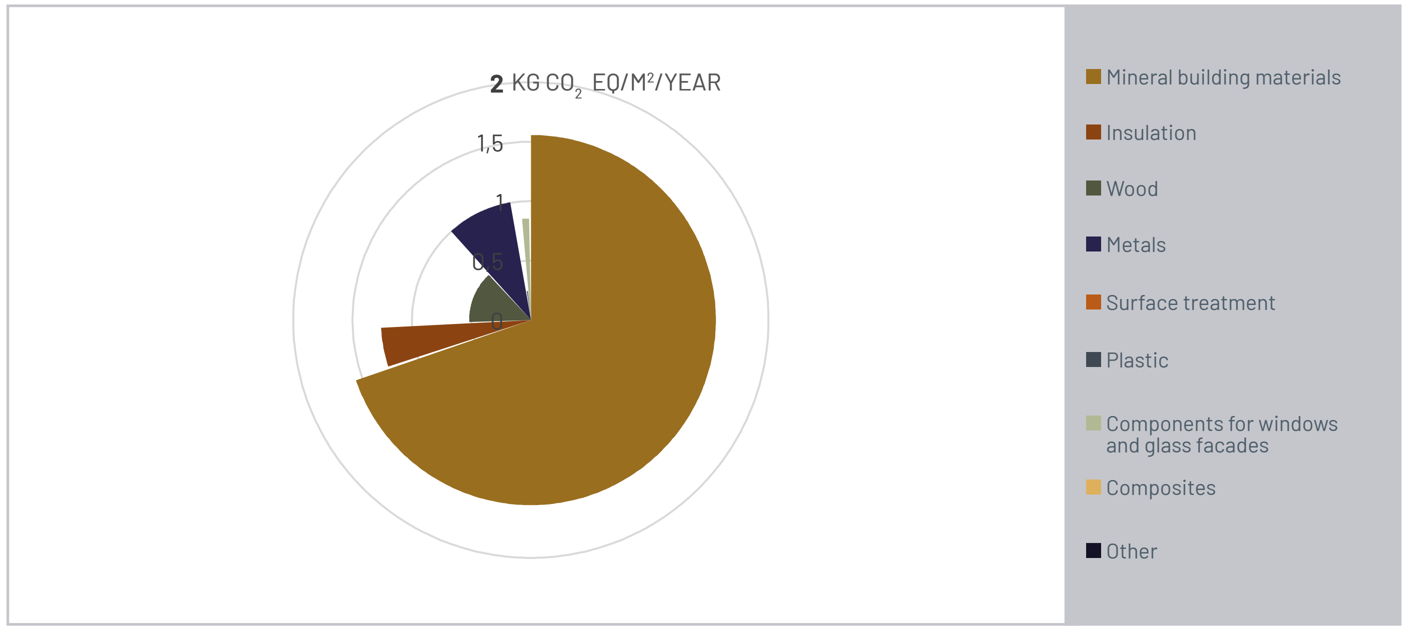


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

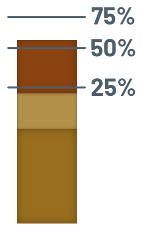
DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

RESULT IN **HIGH IMPACT**	Photovoltaic modules on roof EPS insulation in grade deck Concrete in grade deck Triple glazing in climate envelope Large glazed area in climate envelope Steel-sheet roofing material
RESULT IN **LOW IMPACT**	

Photo Vandkunsten

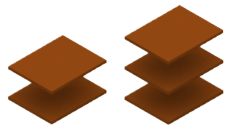
DESCRIPTION

This forms part of a larger project to build two out-of-school clubs in Albertslund Municipality: Klub Svanen and Bakkens Hjerte. Hence the description and experience outline cover both projects. Albertslund Municipality wanted increased focus on sustainability, which the architects' studio Vandkunsten had interpreted as a structure where wood is the primary material. Besides using wood to a very great extent, the buildings do not have vapour barriers and are insulated with cellulose.

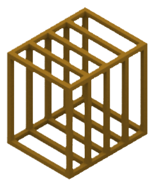


Mat.: 4,9
Tech. inst.: 1,9
Operation: 2,8
stated in KG CO_2 EQ/M²/YEAR

Location	Albertslund, Denmark
Year	2018-2022
No. of units	1
Category	Out-of-school club
Architect	Vandkunsten
Landscape	Vandkunsten
Engineer	Regnestuen
Client	Albertslund Kommune
Contractor	Egen Vinding & Datter
Type of contract	Turnkey contract
Heated area	1.038 m²
Energy class	BR2018
Total energy consumption	38,2 kWh/m²/year
Energy source	Projected electricity mix & district heating
Data basis for LCA	Architectural model
Certification	-
Project website	-



1 - 2 storeys



Timber frame

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
A fire strategy was adopted and an external consultant was called in. It had been a great advantage that the architects were familiar with the fire-technical properties of wood, although the external consultant was responsible for the design. This resulted in larger fire cells than in pre-approved solutions, which made it difficult to comply with the Building Regulations.

Acoustics
The architects had trouble finding reference projects with the same goal and material type as this one. Further, tools and experience in calculating acoustic values in timber buildings were lacking. This made it difficult to comply with acoustics requirements, notably footfall transmission, which added to project costs.

Economy
The project had a limited and predetermined budget. The limited economic framework had a significant bearing on the project, for example, dictating the choice of materials.

Construction moisture
The architects proposed to construct a breathable building of bio-based materials, leaving out the vapour barrier. For this reason, a contractor was selected who had expert knowledge of this type of building as well as with its design and construction.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

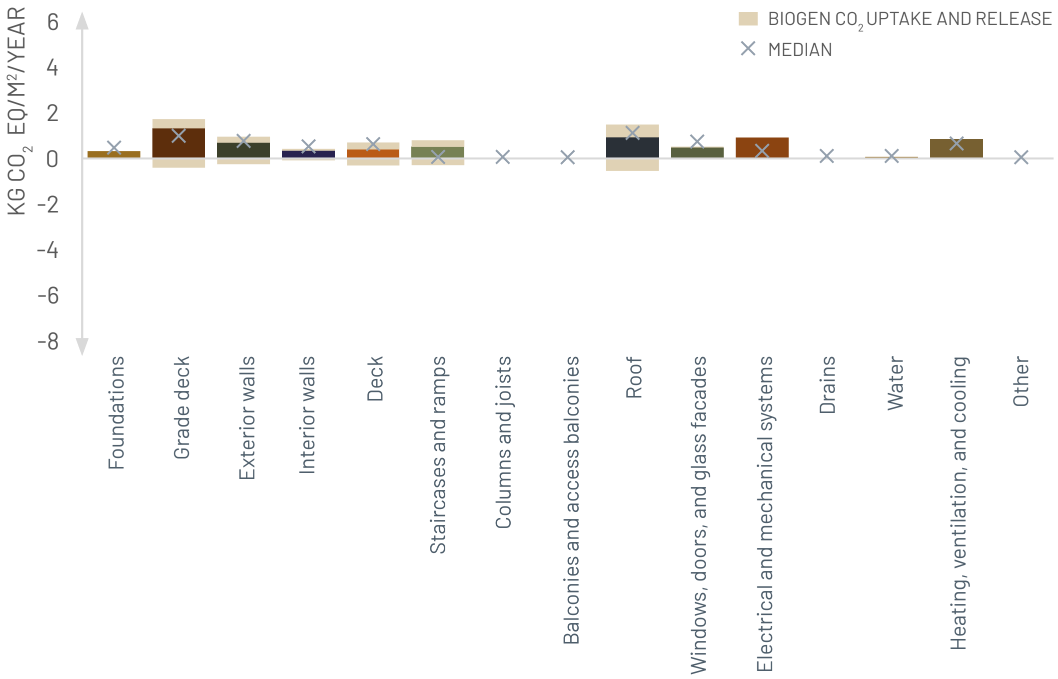


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m^2/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

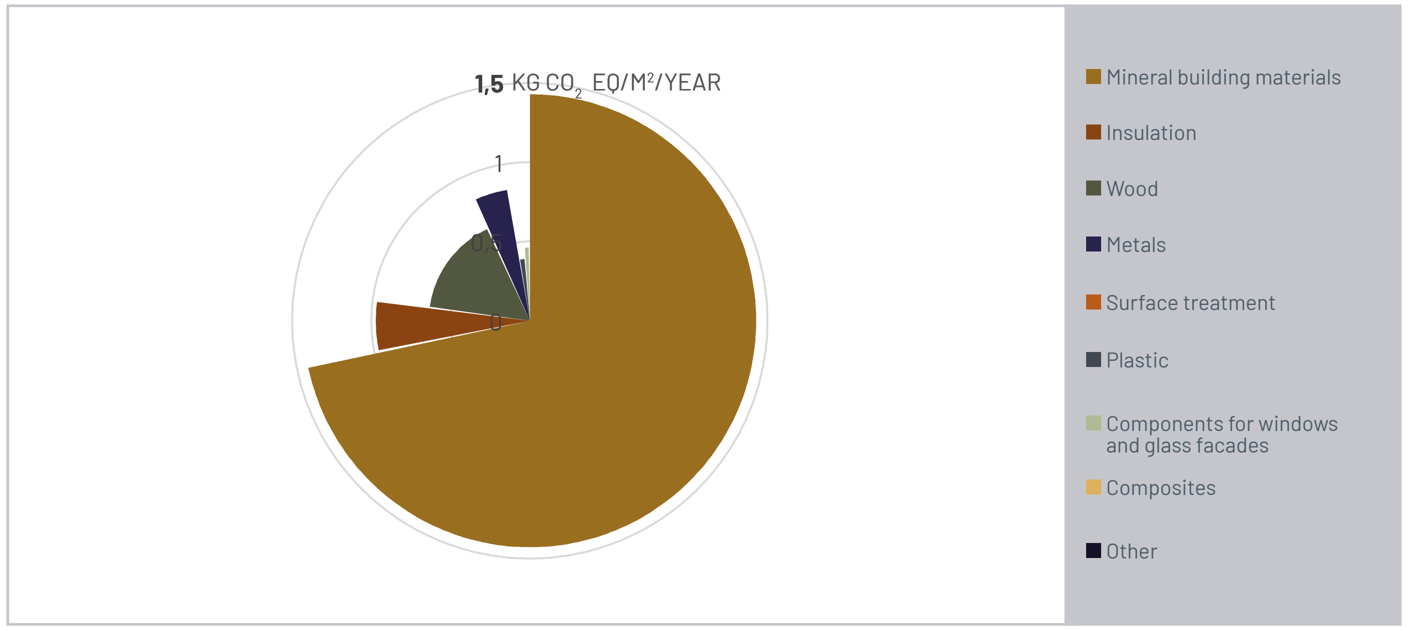


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m^2 distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

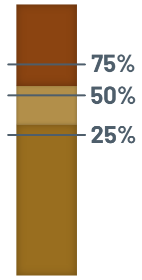
DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

RESULT IN **HIGH IMPACT**	Photovoltaic modules on roof Concrete in grade deck Steel-sheet facade cladding EPS insulation in grade deck Triple glazing in climate envelope High-density wood-fibre roof insulation
RESULT IN **LOW IMPACT**	Material consumption of 427.5 kg/m² is below average (average being 684.6 kg/m²)


Photo Lars Rex Christensen

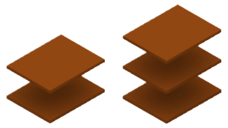
DESCRIPTION

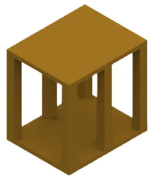
The cultural centre Kulturhus Risbjerggård KUGA was developed as a beacon project for future construction projects in Hvidovre. The cultural centre is home to local societies and municipal cultural activities organised by Hvidovre Municipality, adding to the urban life in the area. The idea was to create synergies with other neighbouring public institutions: the library, community centre, and the town hall across Hvidovrevej. The project makes use the existing building, adding a new timber building. A timber building was not a requirement, but the architects' studio Vandkunsten chose this material in response to a wish to reduce the climate footprint.



Mat.: 7,7
Tech. inst.: 2,0
Operation: 4,1
stated in KG CO_2 EQ/M²/YEAR

Location	Hvidovre, Denmark
Year	2017-2020
No. of units	1
Category	Cultural centre
Architect	Vandkunsten
Landscape	Vandkunsten
Engineer	WSP, DBI, Gade Mortensen, Bunch Bygningsfysik
Client	Hvidovre Kommune
Contractor	Jakon, Tscherning
Type of contract	Main contract
Heated area	2.886 m²
Energy class	BR 2018
Total energy consumption	73,9 kWh/m²/year
Energy source	Projected electricity mix
Data basis for LCA	Architectural model
Certification	-
Project website	See link


1 - 2 storeys


Hybrid

USE OF WOOD: KEY ACTORS' EXPERIENCE

No interview conducted on this building, and hence no experience was shared.


Photo Lars Rex Christensen

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

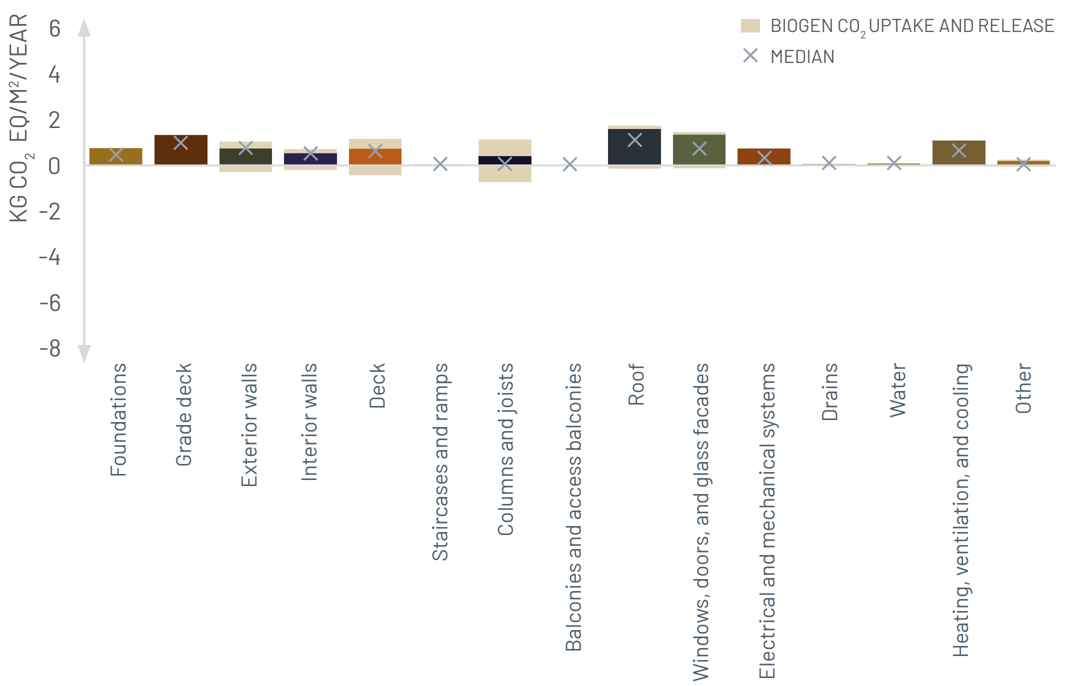


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

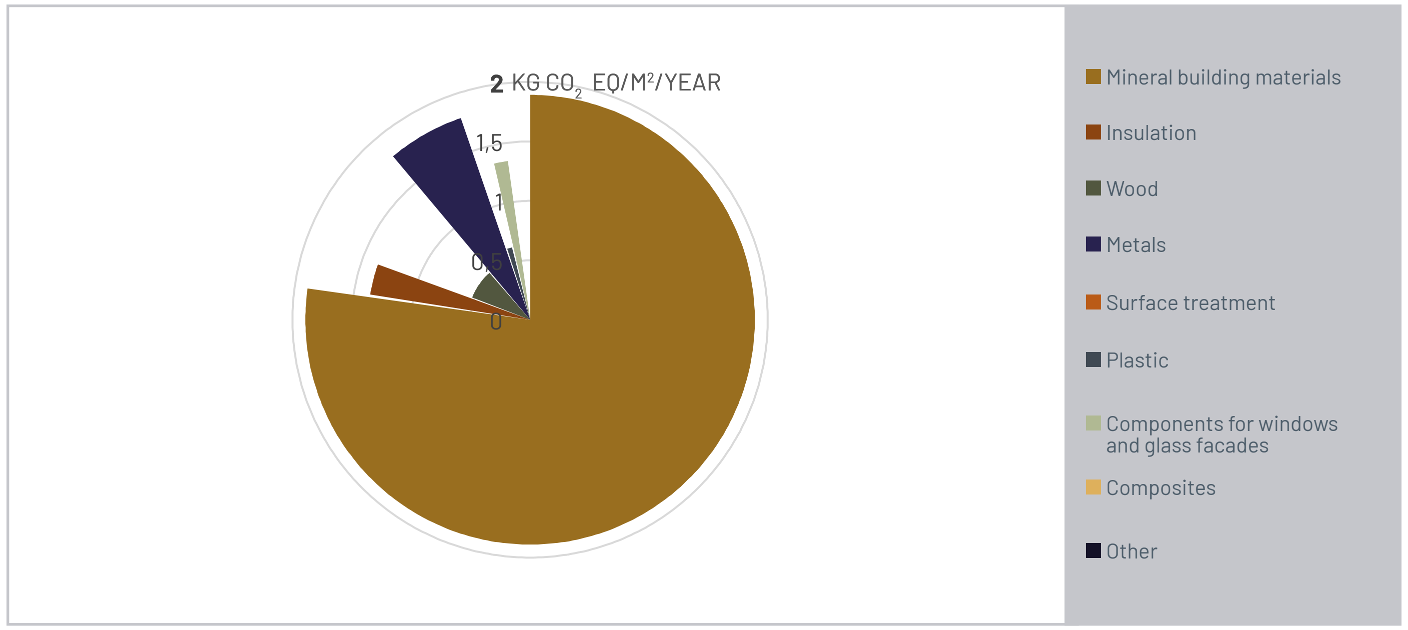


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

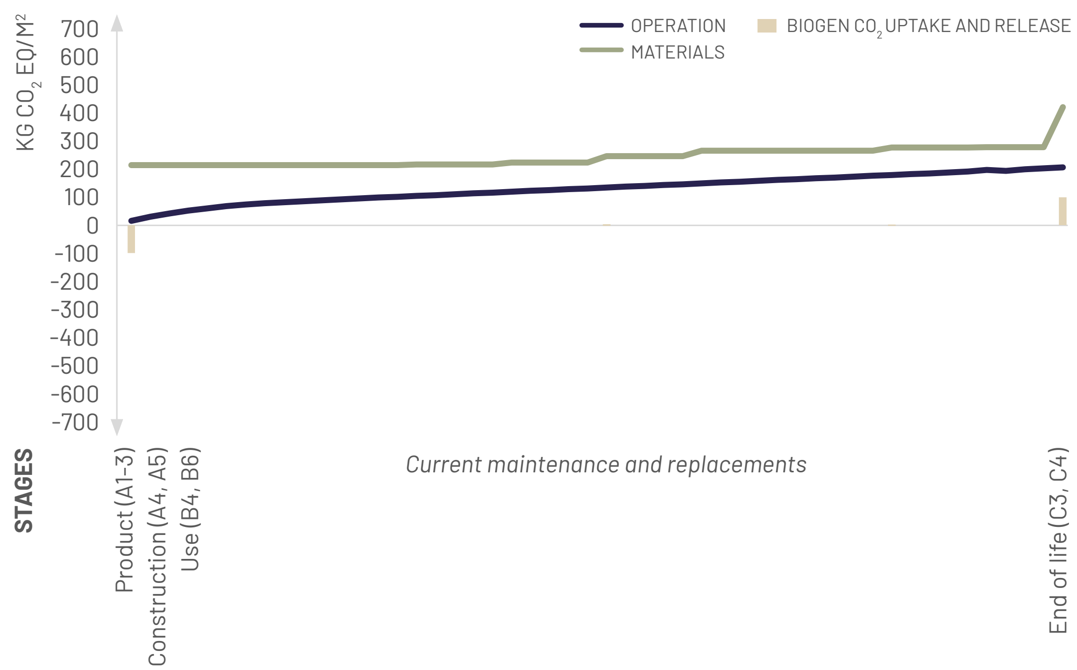


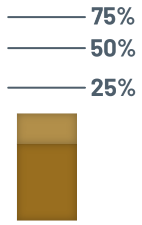
Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

RESULT IN **HIGH IMPACT**	Material consumption of 837.9 kg/m² is above average due to special needs (average being 684.6 kg/m²) Photovoltaic modules on roof EPS insulation in grade deck Concrete in grade deck and foundations Pressure-resistant mineral wool roof insulation Large glazed areas in climate envelope Interior glass walls
RESULT IN **LOW IMPACT**	

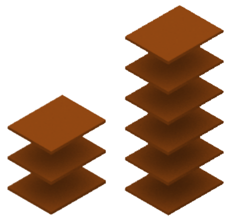
DESCRIPTION

The project is part of a major development of a former aerodrome in Oksenøya, Norway, into a residential and treatment centre, kindergarten, and school. The client Bærum Municipality is environmentally ambitious, written into the local plan as a requirement. The client did not specify CLT as a design principle, but wanted to use this material. Further, the building is part of the Norwegian innovation programme FutureBuilt and certified according to BREEAM Outstanding. All building components are designed for easy dismantling in the future.

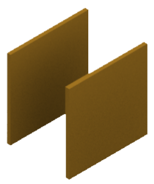


Mat.: 4,0
Tech. inst.: 1,6
Operation: -
stated in KG CO_2 EQ/M²/YEAR

Location	Oksenøya, Norge
Year	2019 - 2023 (expected)
No. of units	1
Category	Residential and treatment centre
Architect	Arkitema
Landscape	Østengen and Bergo
Engineer	WSP, Erichsen & Horgen, Heiberg og Tveter AS, Brekke & Strand, Binderholz
Client	Bærum Municipality
Contractor	Veidekke A/S
Type of contract	Turnkey contract
Heated area	18.400 m²
Energy class	-
Total energy consumption	-
Energy source	-
Data basis for LCA	Architectural model
Certification	BREEAM Outstanding, FutureBuilt
Project website	See link



2 - 5 storeys



Sheeting (CLT)

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
A fire strategy was introduced already in the pre-project study to safeguard carrying capacities and to avoid flame-spread between fire cells. As a rule, CLT will retain its carrying capacity during a fire, but was clad with fire-rated gypsum boards due to the risk of smoke development. Accordingly, there is only one bare CLT wall per housing unit.

Acoustics & Aesthetics
The consulting engineers Bekke and Strand are responsible for the acoustics. A layer of on-site concrete was cast on the CLT deck to avoid sound transmission between storeys, despite specifying as much CLT to be visible as possible. Interior CLT walls were covered with insulation and gypsum boards, which further reduces visible CLT.

Economy
Consultants on daylight, acoustics, energy, building physics, and fire were called upon in the early phase of the project to reduce the risk of having to redesign the project.

Logistics
Since CLT panels are produced with all specified details from the factory, it was essential to plan the project in every detail at an early stage. This resulted in a lengthy design process, and it proved difficult to keep deadlines in respect of the supplier. On the other hand, the installation of the CLT panels proved more efficient than traditional Norwegian half-timbering.

Construction moisture
The building was constructed in phases, and it became apparent that the wood patinated differently due to moisture. This could mean that a moisture upgrading should be carried out on completion.

Moisture during use
Exterior rafters were covered by aluminium for moisture protection and to enhance the durability of the materials.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

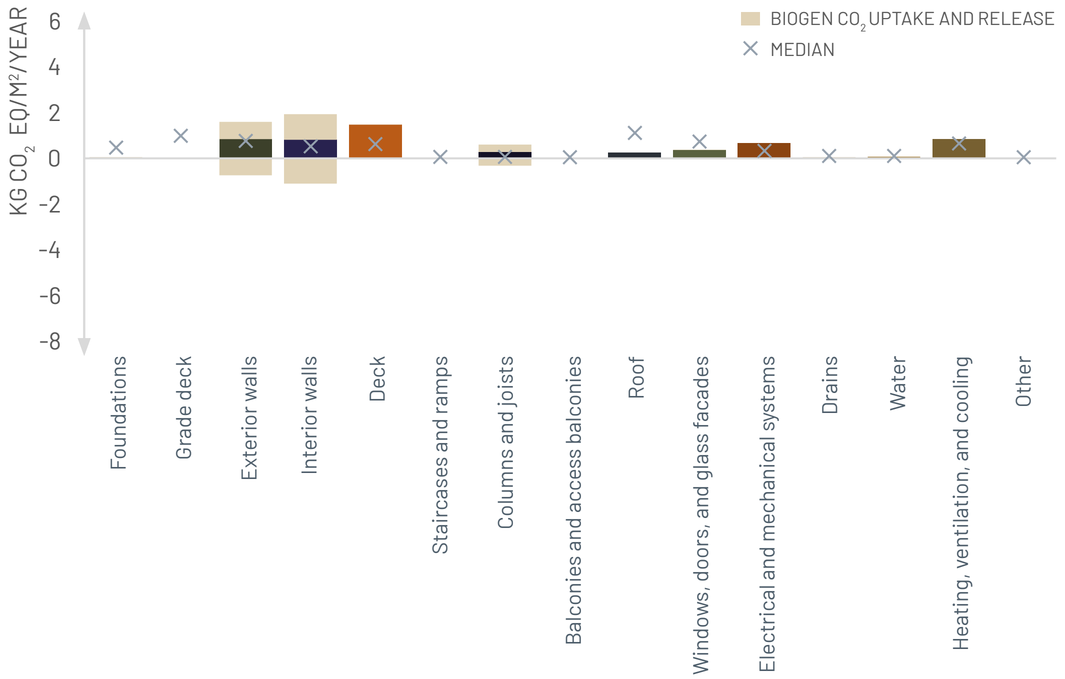


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

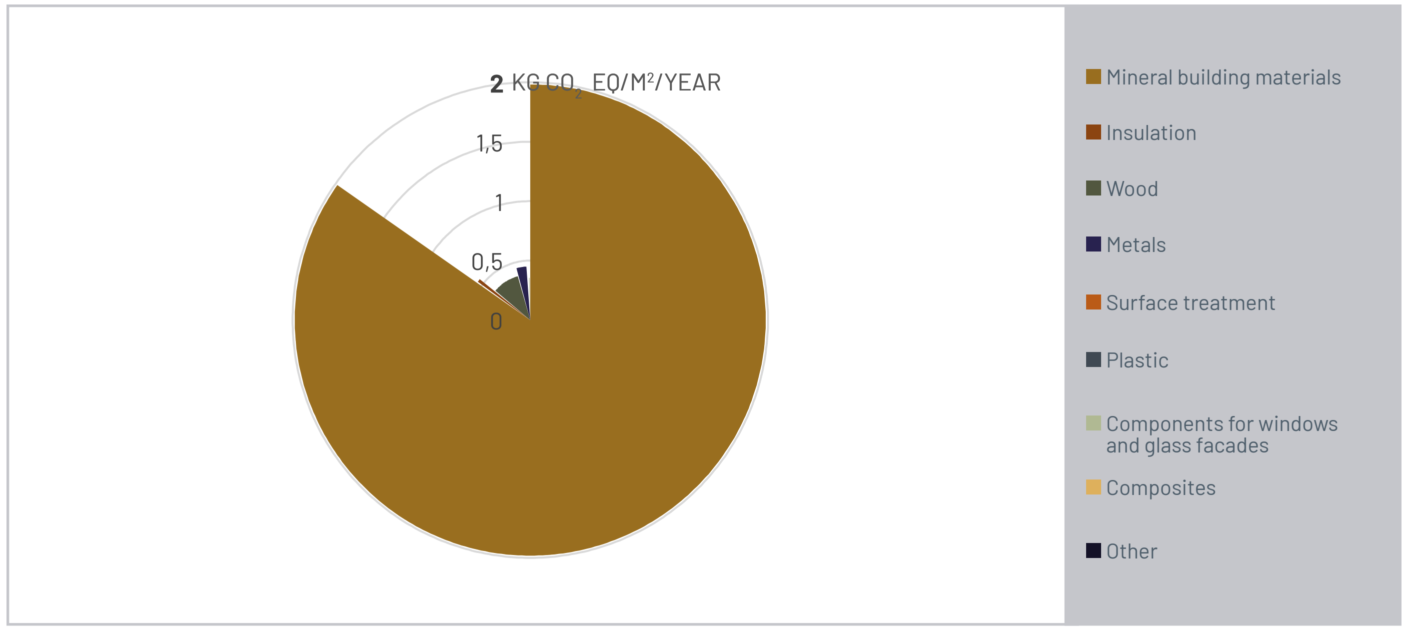


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

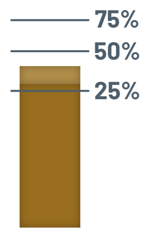
RESULT IN **HIGH IMPACT**	Material consumption of 736.9 kg/m² is above average (average being 684.6 kg/m²) Concrete in deck Photovoltaic modules on roof Pressure-resistant mineral wool roof insulation Steel profile as carrying structure Triple glazing in climate envelope
RESULT IN **LOW IMPACT**	

OKSENØYA KINDERGARTEN

Photo Arkitema

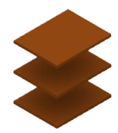
DESCRIPTION

The project is part of a major development of a former aerodrome in Oksenøya, Norway, into a residential and treatment centre, kindergarten, and school. The client Bærum Municipality is environmentally ambitious, written into the local plan as a requirement. The client did not specify CLT as a design principle, but wanted to use this material. Further, the building is part of the Norwegian innovation programme FutureBuilt and certified according to BREEAM Outstanding. All building components are designed for easy dismantling in the future.

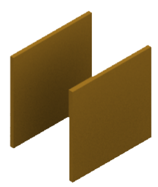


Mat.: 7,5
Tech. inst.: 0,9
Operation: -
stated in KG CO_2 EQ/M²/YEAR

Location	Oksenøya, Norge
Year	2019 - 2022
No. of units	1
Category	Kindergarten
Architect	Arkitema
Landscape	Østengen & Bergo
Engineer	WSP
Client	Bærum Kommune
Contractor	Veidekke
Type of contract	Turnkey contract
Heated area	3.650 m²
Energy class	-
Total energy consumption	-
Energy source	-
Data basis for LCA	Architectural model
Certification	BREEAM Outstanding, FutureBuilt
Project website	-



2 storeys



Sheeting (CLT)

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
To comply with fire requirements, certain walls were covered with gypsum. A fire consultant was called in for the project, but the expertise of fire consultants was found to vary considerably when it came to timber buildings.

Acoustics
All CLT decks were covered with on-site concrete to meet the high acoustics requirements applicable to institutions. Further, acoustics ceilings of a combination of gypsum and absorbant were installed. Mineral wool and gypsum were installed on the walls.

Economy
Changes were made late in the process, which meant that the plan solution was changed, and the project was therefore redesigned. The architects did not have the expertise to build in timber, and extra resources were therefore allocated for the preliminary design phase.

Construction moisture
It is a requirement for substructures to be cast 30 cm above grade to break contact between biological materials and grade level. It proved challenging to cover the panels during construction, as it rained excessively during the period.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

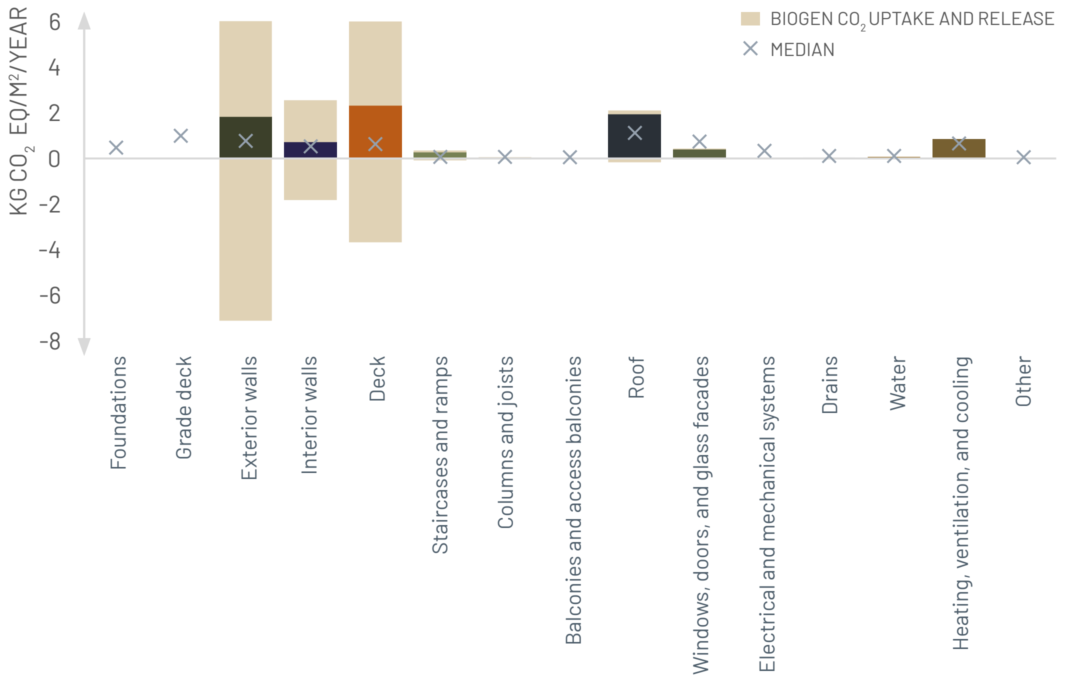


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

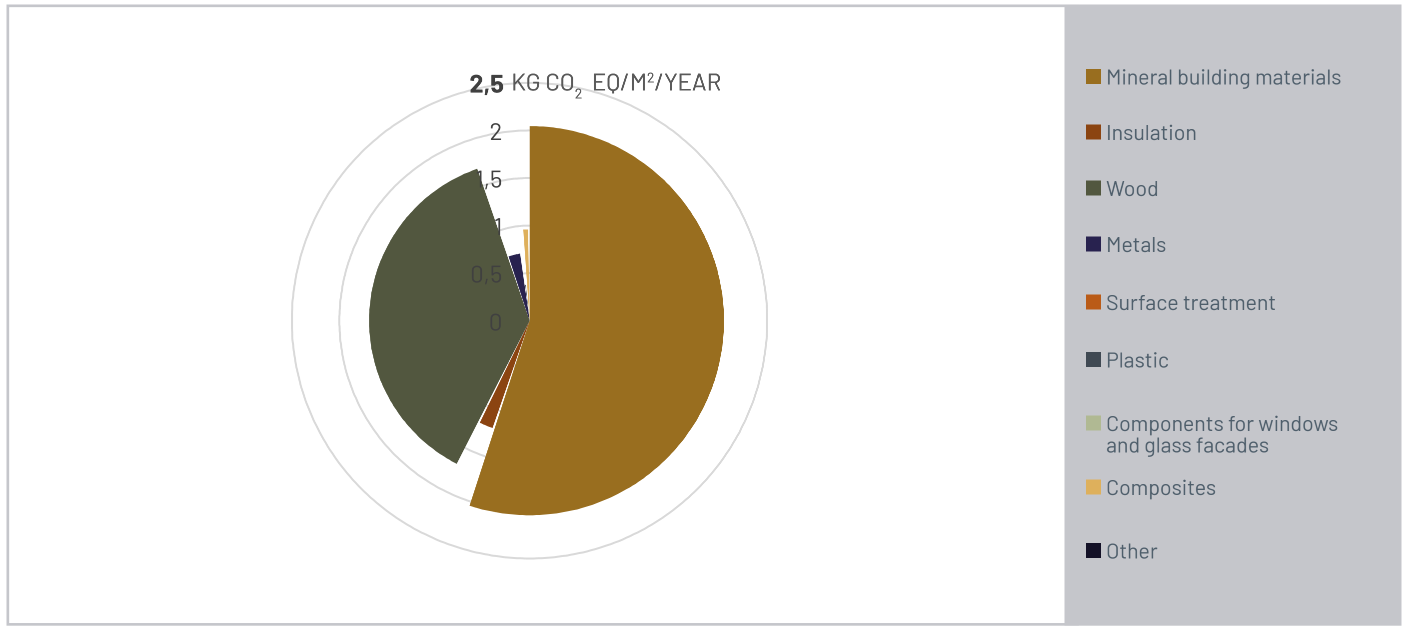


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

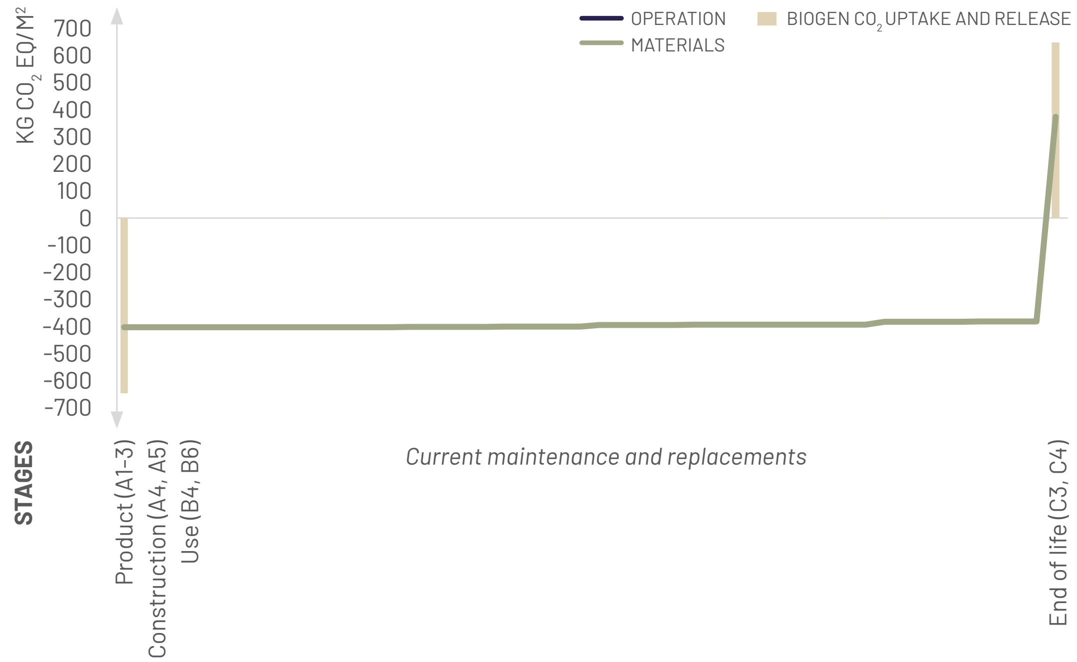


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

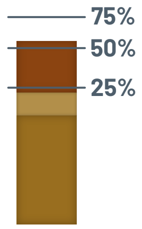
DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

RESULT IN **HIGH IMPACT**	Material consumption of 1090.2 kg/m² is above average (average being 684.6 kg/m²) Sedum roof Pressure-resistant mineral wool roof insulation Concrete in deck CLT as carrying structure in deck and roof
RESULT IN **LOW IMPACT**	

Photo Niels Nygaard

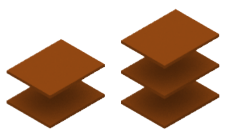
DESCRIPTION

In the design of Erlev School, emphasis was on creating a visionary learning environment with focus on social sustainability. The school comprises a wealth of different room types, supportive of activity-based teaching forms – through open shared spaces, standard classrooms, and small niches. Erlev School was built as a glulam structure and is among the country's first timber-built schools.

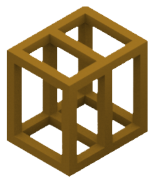


Mat.: 5,7
Tech. inst.: 1,2
Operation: 2,7
stated in KG CO_2 EQ/M²/YEAR

Location	Haderslev, Denmark
Year	2017-2020
No. of units	1
Category	School
Architect	Arkitema
Landscape	Arkitema
Engineer	Sloth Møller
Client	Haderslev Kommune
Contractor	Ommen & Møller
Type of contract	Turnkey contract
Heated area	6.014 m²
Energy class	BR2015
Total energy consumption	24,6 kWh/m²/year
Energy source	Projected electricity mix
Data basis for LCA	Architectural model
Certification	-
Project website	See link



1 - 2 storeys



Glulam

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire & Statics
All structural glulam beams were statically over-dimensioned to meet fire requirements. It proved challenging to run cables and piping without weakening the glulam structures, which necessitated some redesigning. All interior timber was impregnated, and no sprinkler system was installed. Instead, gypsum panels were installed on selected walls to comply with fire requirements.

Acoustics
A lightweight deck was used to comply with requirements for sound insulation, and gypsum was fitted to several timber walls to comply with acoustic requirements. Sound may potentially be transmitted between the rooms via the glulam beams, and some of these were divided up to reduce sound transmission.

Economy
The final project lacks wood in its aesthetic expression relative to what the client had originally wanted. The reason being that many timber solutions were replaced by traditional standard solutions to reduce costs. Engineers and architects collaborated on the project from the very start, which helped the process.

Construction moisture
All timbers were soaked by rain during the construction phase, since no moisture strategy had been implemented, and it proved problematic to cover them. Subsequently, there were drying-out problems and water damage, and it was therefore necessary to dehydrate, sand down, and apply surface treatment all over again. Further, the Accoya treatment of the timber facade corroded the screws and speciality screws had to be developed. Finally, much of the facade material was changed to steel to increase durability.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

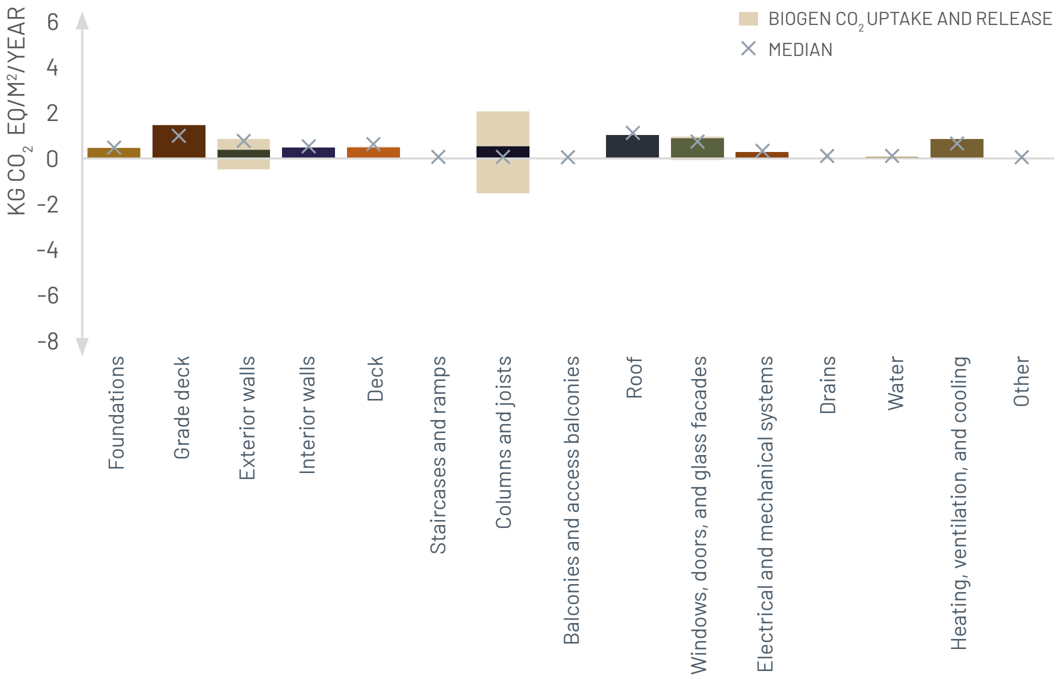


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

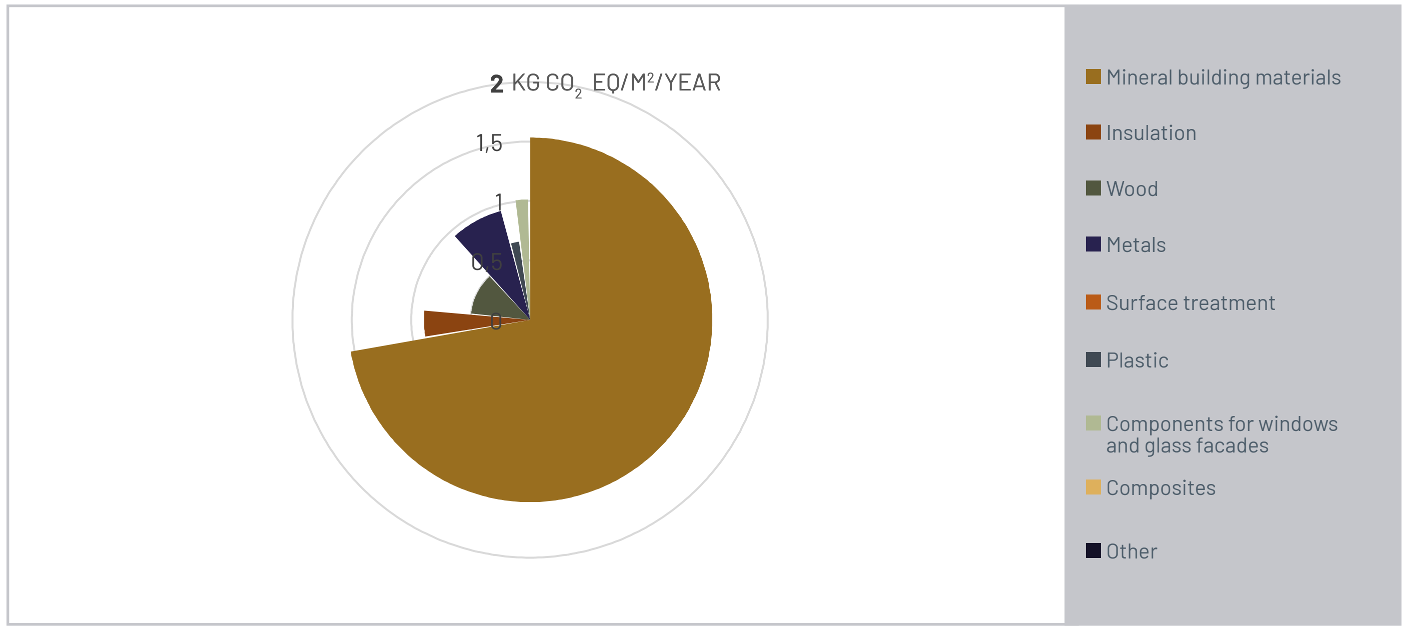


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

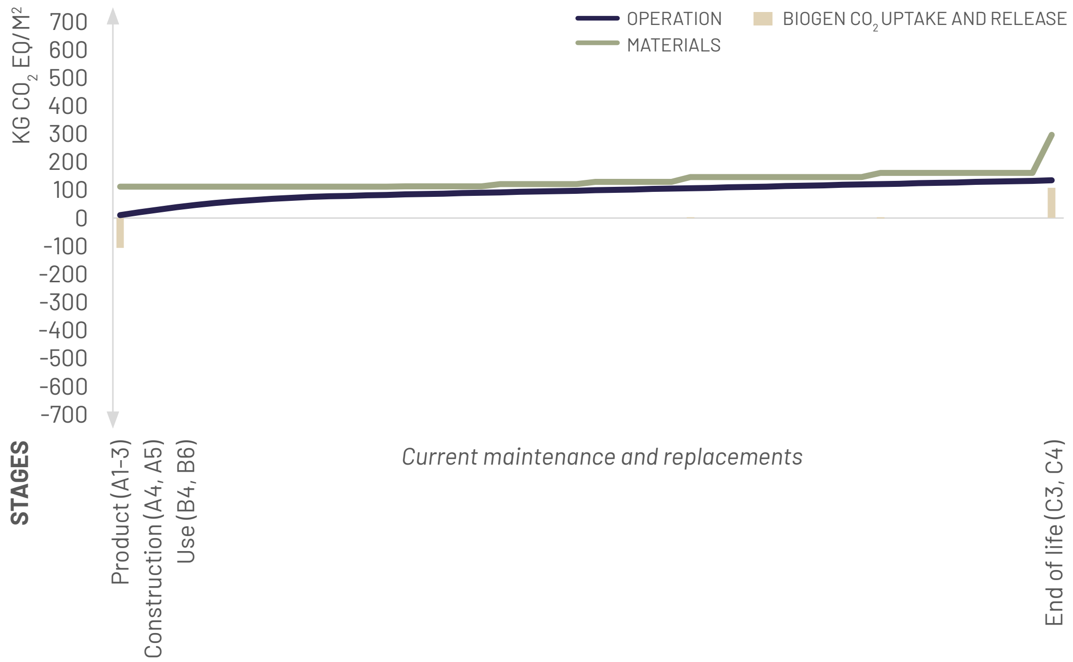


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

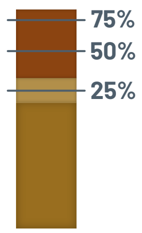
DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

RESULT IN **HIGH IMPACT**	Concrete in grade deck and foundations Reinforced concrete deck Bituminous felt roofing Interior glass walls Photovoltaic modules on roof Triple glazing in climate envelope
RESULT IN **LOW IMPACT**	Material consumption of 592.9 kg/m² is below average (average being 684.6 kg/m²)


Photo Arkitema

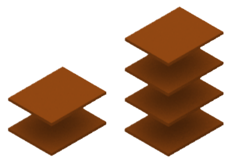
DESCRIPTION

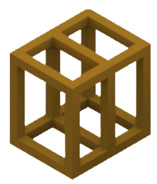
The client Viborg Municipality had a vision about a sustainable school project, and Arkitema therefore decided to design the building with wood as the main feature. Further, it was based on experience from Erlev School, one of the first schools in Denmark with wood as its main material. This school was built along the same lines as Erlev School, where the supporting structures were glulam. As part of an overall idea of a sustainable project, it was decided to go for a DGNB Gold certificate, where the architects responded to the requirements directly.



Mat.: 6,5
Tech. inst.: 1,3
Operation: 3,5
stated in KG CO_2 EQ/M²/YEAR

Location	Overlund, Denmark
Year	2023 (expected)
No. of units	1
Category	School
Architect	Arkitema
Landscape	Arkitema
Engineer	OJ Rådgivende Ingeniør
Client	Viborg Kommune
Contractor	-
Type of contract	Seperate works contract
Heated area	12.967 m^2
Energy class	BR2018
Total energy consumption	29,2 kWh/m²/year
Energy source	Projected electricity mix & piped gas
Data basis for LCA	Architectural model
Certification	DGNB Gold
Project website	See link


1 - 3 storeys


Glulam

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
An internal fire consultant from Arkitema was called in to carry out the fire-dimensioning. Further, the building project was subjected to third-party control. Today, Arkitema call on COWI consultants to ensure that building projects comply with fire requirements. Inside, most surfaces (approx. 80%) were clad with non-combustible materials to comply with fire requirements.

Acoustics
Deck thickness and sound insulation requirements were instrumental in increasing the amount of concrete in the building. This was done to mitigate the added cost that using wood would have incurred.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

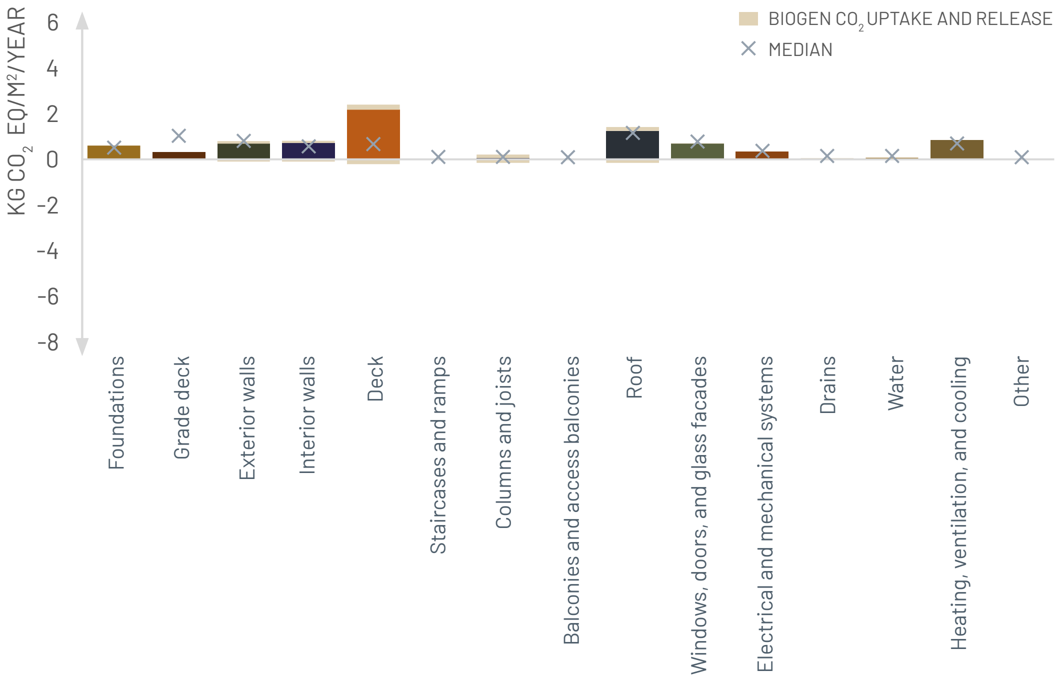


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

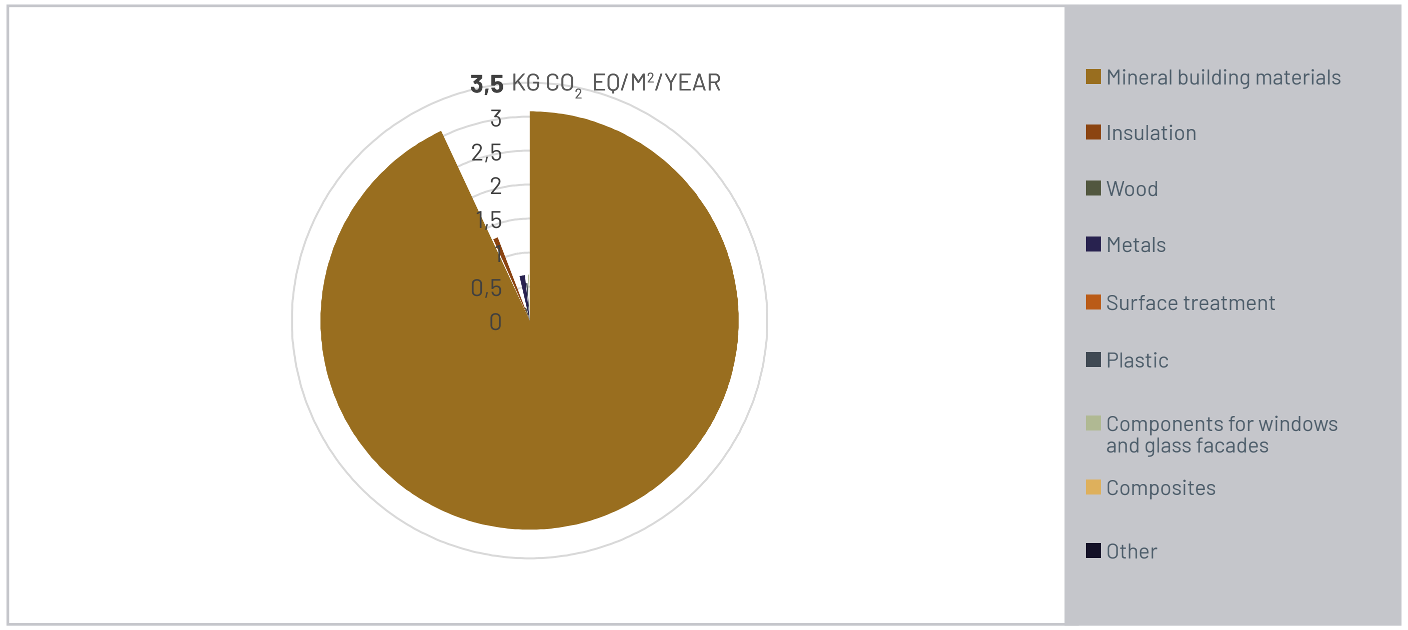


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

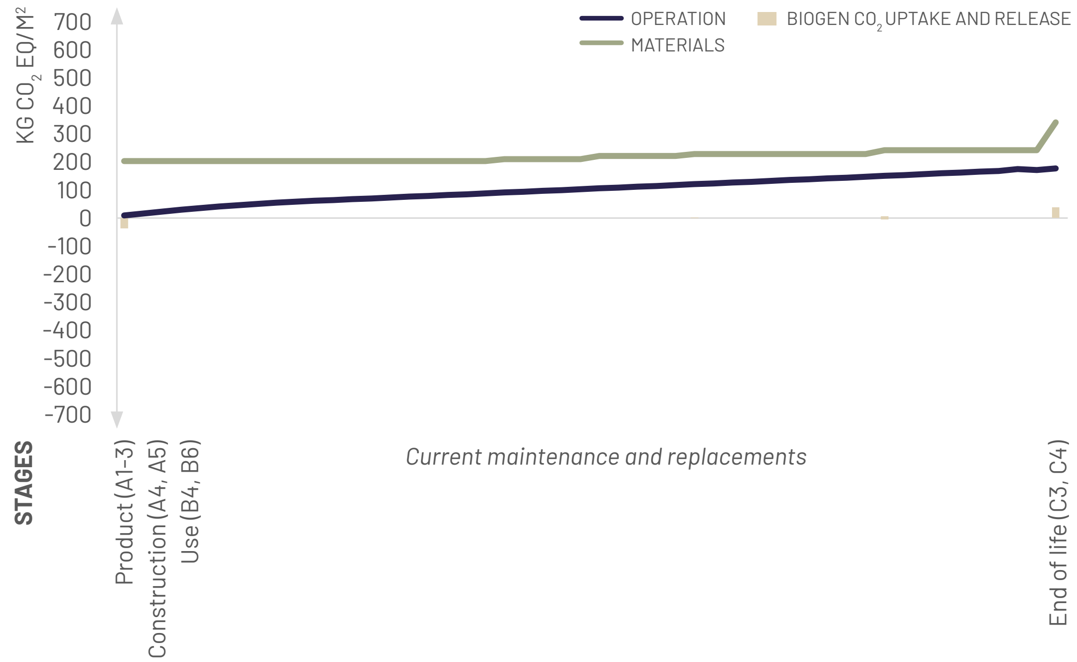


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

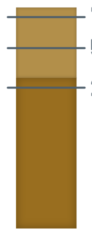
DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

RESULT IN **HIGH IMPACT**	Material consumption of 1228.9 kg/m² is above average (average being 684.6 kg/m²) Concrete in grade deck, foundations, and deck EPS insulation in ground deck Triple glazing in climate envelope
RESULT IN **LOW IMPACT**	

Photo Arkitema

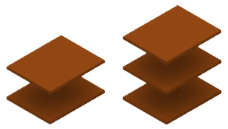
DESCRIPTION

Samsø Energiakademi was built as a demo project for sustainable energy solutions. The building serves as conference centre, exhibition space, school-field-trip hostel, and office. The project was built in 2007 and therefore not rated in an energy class as such, but because of the client's wish to construct a sustainable building, the ambition was to remain 25% below the existing BR95 framework. The building is constructed in wood with biological insulation material, without vapour barrier, and as a passive house. The exterior of the building is a zinc facade with sections of black-painted timber sheeting. The building is a pole structure comprising glulam frames placed on top of crosswise concrete girders. The deck is raised 20-30 cm above grade.

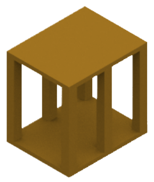


Mat.: 7,6
Tech. inst.: 3,5
Operation: -
stated in KG CO_2 EQ/M²/YEAR

Location	Samsø, Denmark
Year	2007
No. of units	1
Category	Commercial
Architect	Arkitema
Landscape	Arkitema
Engineer	Planenergi
Client	Samsø Energiakademi
Contractor	-
Type of contract	Seperate works contract
Heated area	600 m^2
Energy class	Low-energy class 2 cf. BR2008
Total energy consumption	-
Energy source	-
Data basis for LCA	Architectural model
Certification	-
Project website	-



1,5 storeys



Hybrid

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
To make the structure fire safe, gypsum boards were used on top of cellulose insulation, and the ceiling was covered with mineral wool and cement-bonded wood wool.

Statics
It was difficult to determine whether it was the engineer or the joist manufacturer who was responsible for the carrying capacity of the glulam structure.

Acoustics
The cement-bonded wood-wool ceiling with a backing of mineral wool ensures a fine interior acoustic environment.

Economy
Optimising details and solutions were done in collaboration with local workmen, which aided the process.

Construction moisture
To mitigate construction moisture, key actors collaborated across the project group. Everyone agreed that the building must be kept dry and covered for the duration of the process.

Moisture during use
Zinc surfaces were used as exterior moisture protection. Further, the structure is raised above grade, as the ground is flooded for shorter or longer periods.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

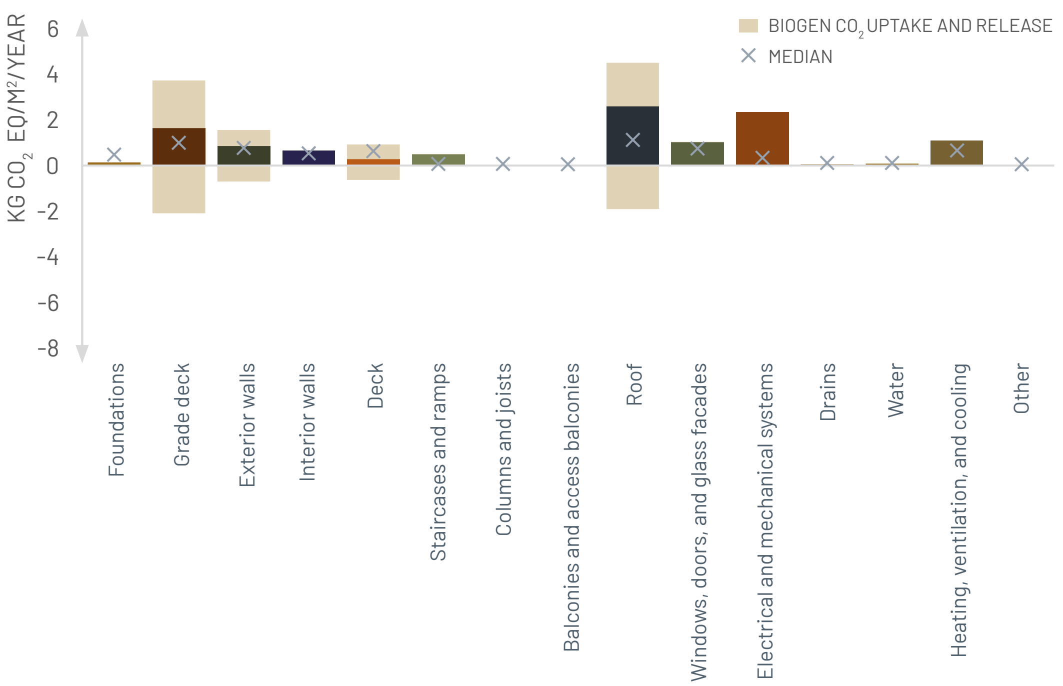


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

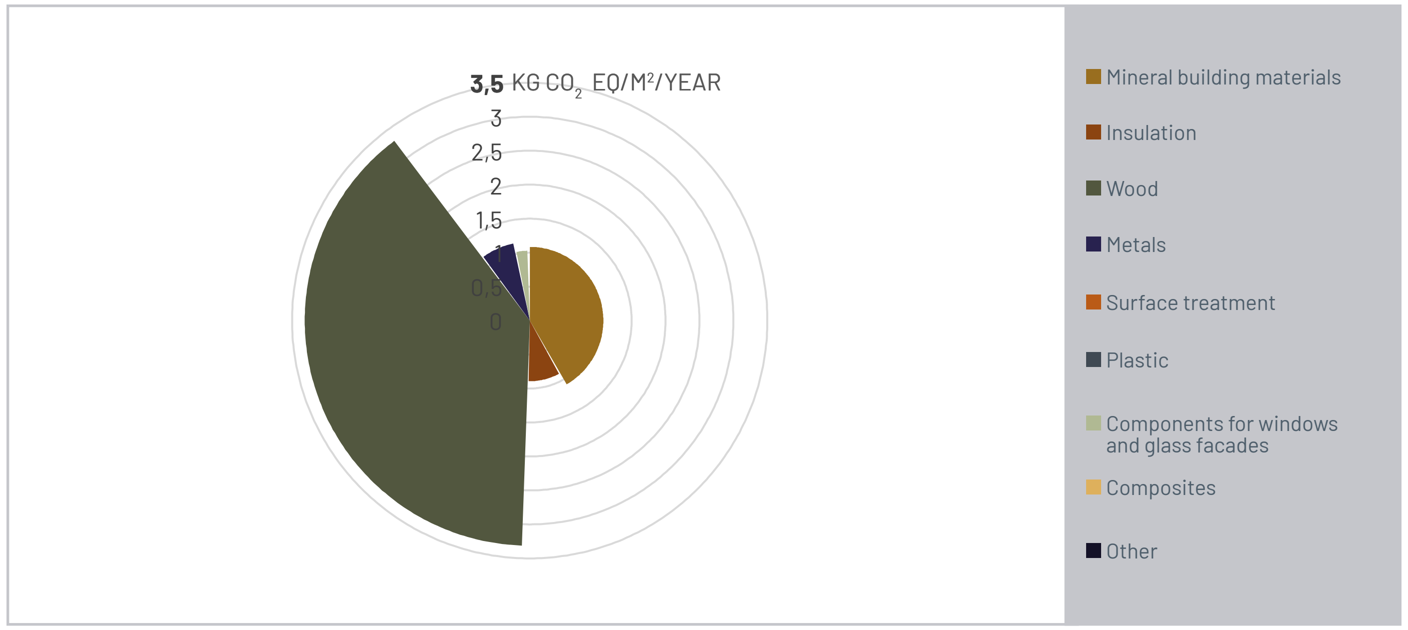


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

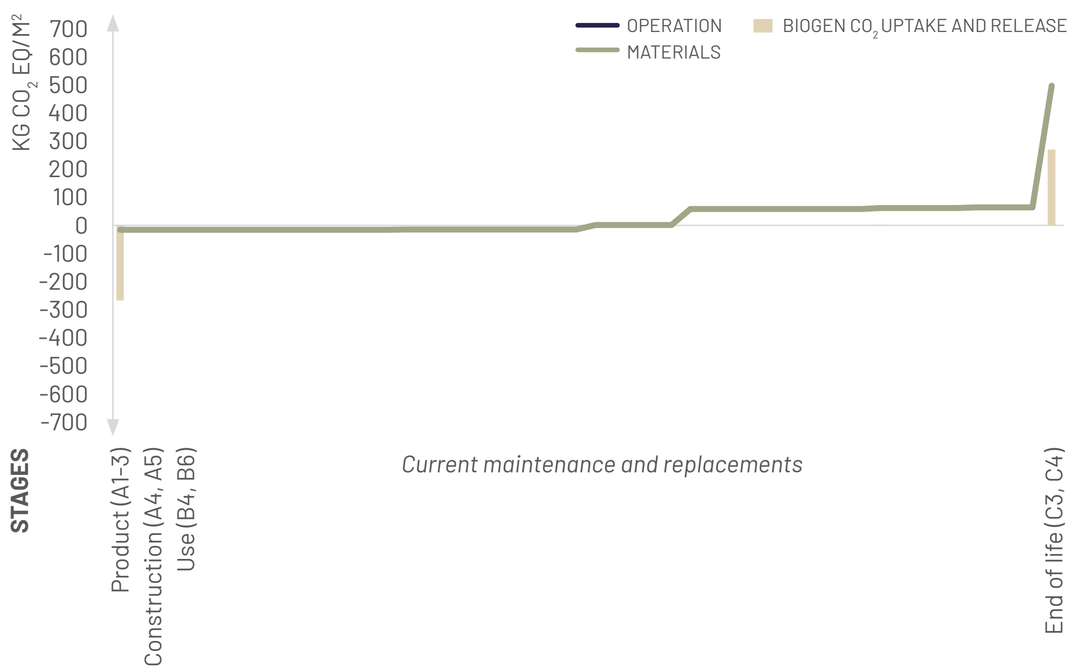


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

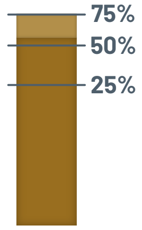
RESULT IN **HIGH IMPACT**	Photovoltaic modules on roof Cement-bonded particle boards in roof and grade deck Patinated zinc facade
RESULT IN **LOW IMPACT**	Material consumption of 550.9 kg/m² is below average (average being 684.6 kg/m²)

TRONDHEIM CENTRAL STATION

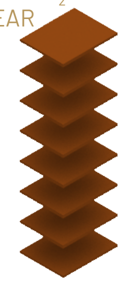
Photo Arkitema

DESCRIPTION

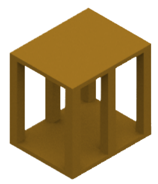
Trondheim Central Station is a major building project and a nodal point for train traffic in the central part of Norway. The station must be constructed without interrupting train services, which places great demands on the whole process. For this reason, architects, engineers, and contractors work closely together already at the early stages of the design process. Trondheim is known for its ancient timber buildings, and it was decided, therefore, to build the project in wood. Wood is the chief material both in the supporting structures and in the visible parts of the building.



Mat.: 9,5
Tech. inst.: 1,2
Operation: -
stated in KG CO_2 EQ/M²/YEAR



8 storeys



Hybrid

Location	Trondheim, Norge
Year	2023 - 2025 (expected)
No. of units	1
Category	Train station
Architect	Arkitema & PKA Arkitekter
Landscape	Arkitema
Engineer	-
Client	Bane NOR Eiendom & Trøndelag Fylkeskommune
Contractor	Veidekke
Type of contract	-
Heated area	10.000 m^2
Energy class	-
Total energy consumption	-
Energy source	-
Data basis for LCA	Architectural model
Certification	BREEAM-NOR Excellent
Project website	See link

USE OF WOOD: KEY ACTORS' EXPERIENCE

No interview conducted on this building, and hence no experience was shared.

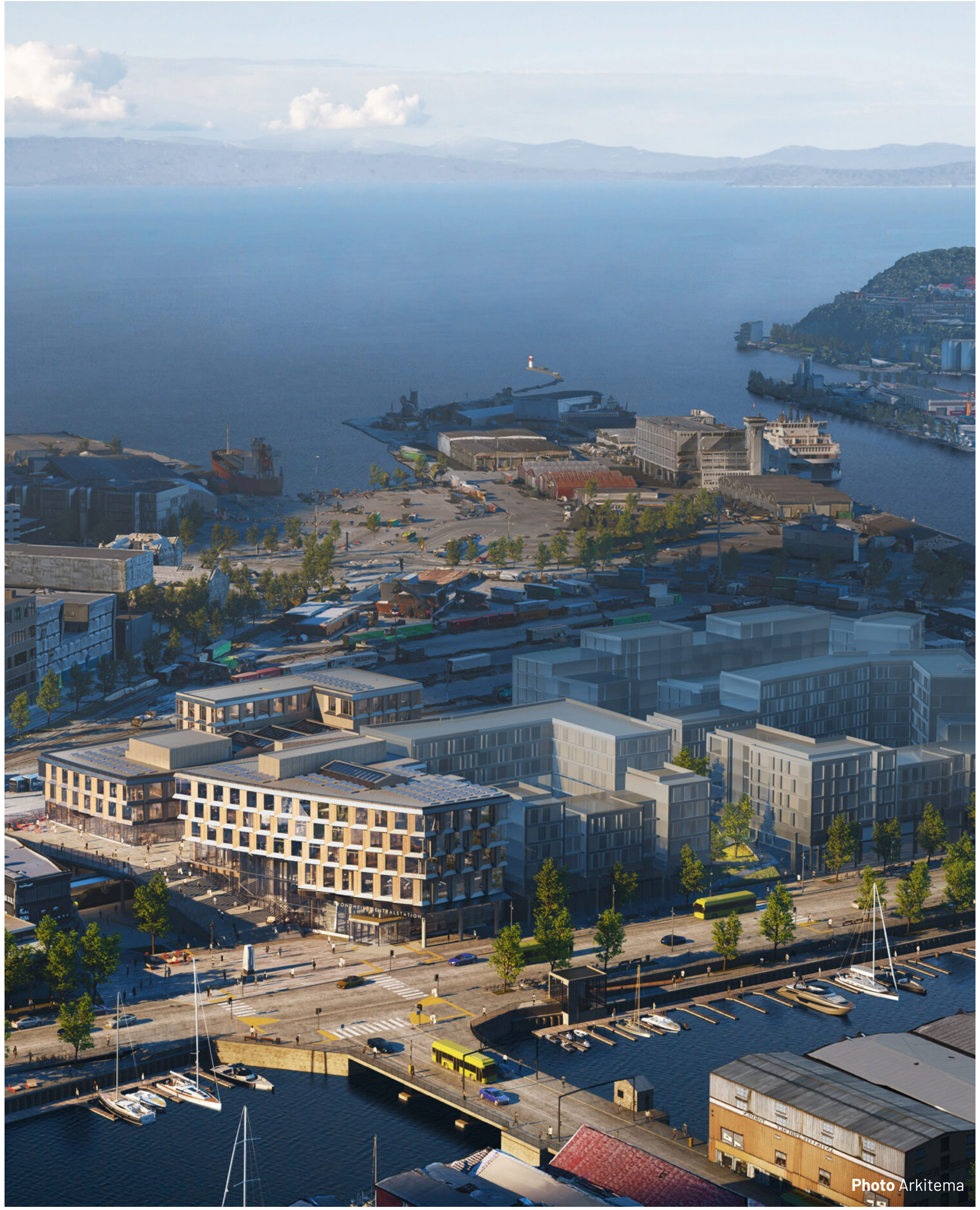


Photo Arkitema

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

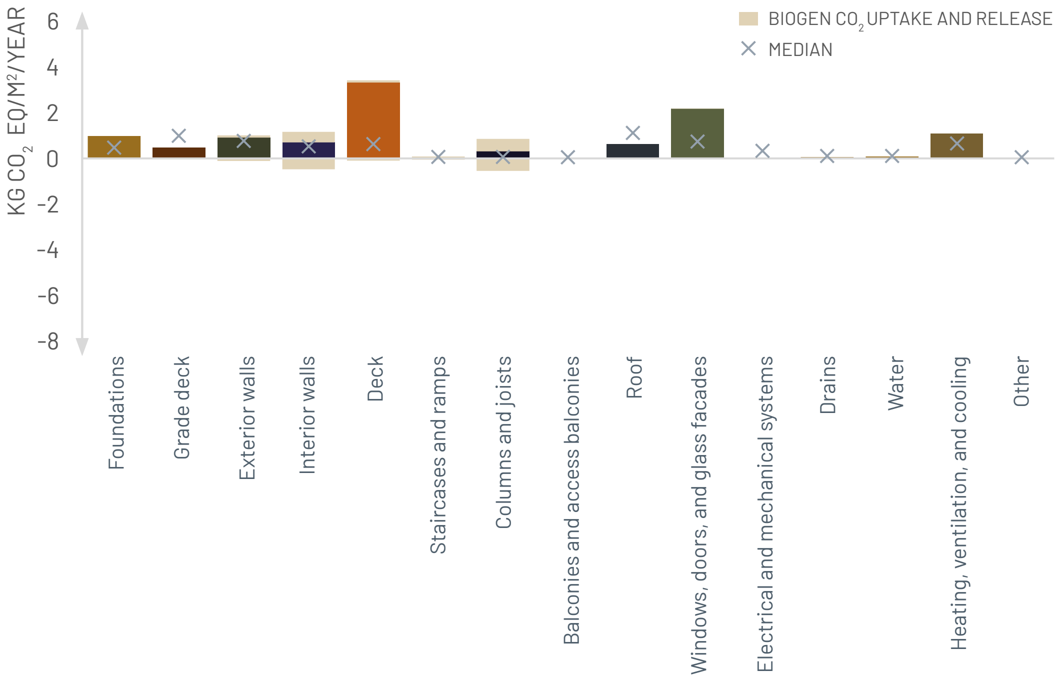


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

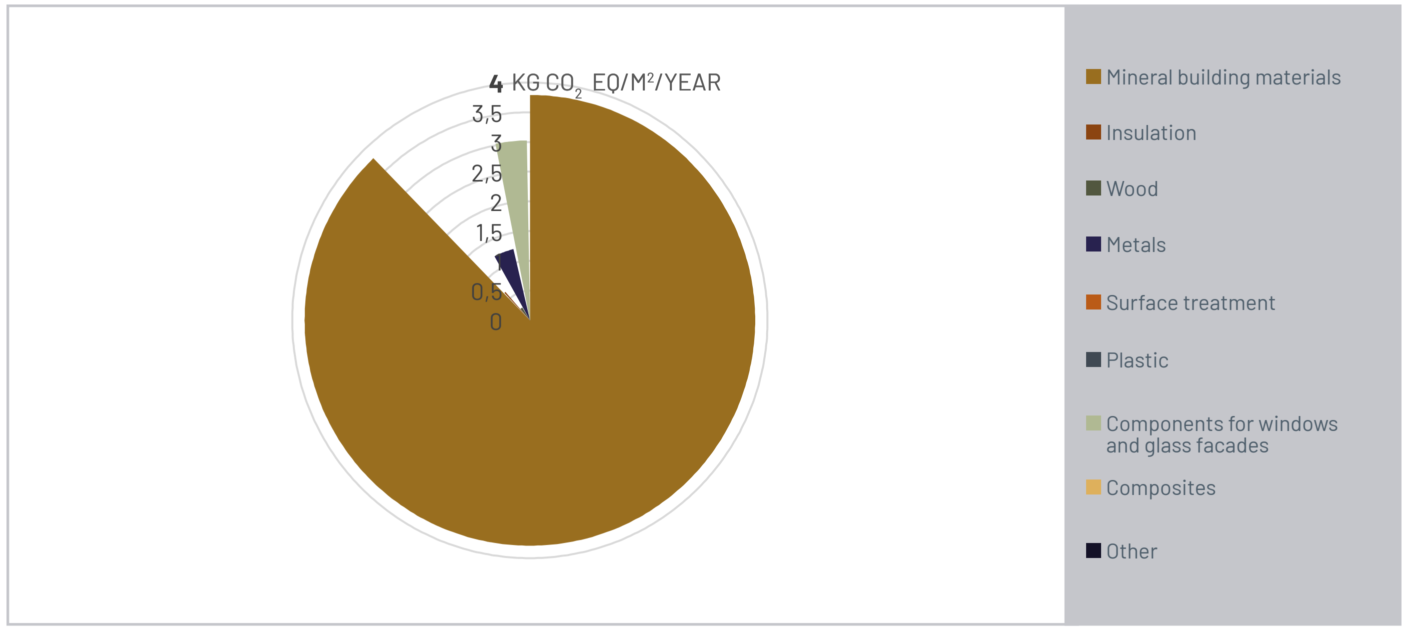


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

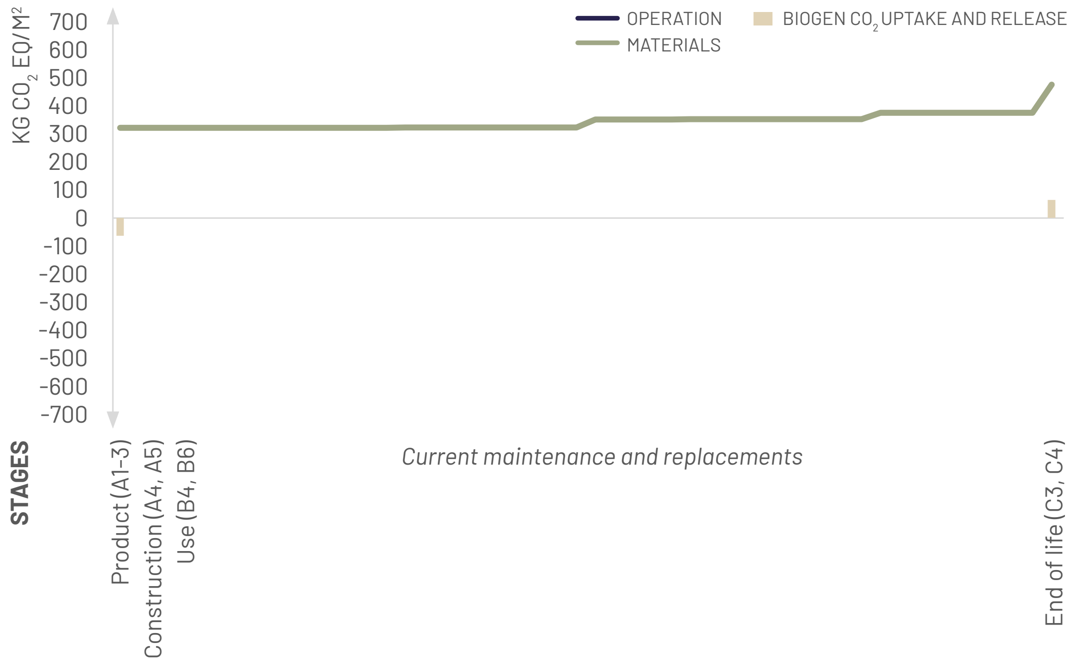


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

RESULT IN **HIGH IMPACT**

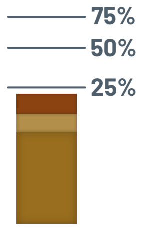
- Material consumption of 1300.4 kg/m² is above average due to special needs (average being 684.6 kg/m²)
- Triple glazing in climate envelope
- Concrete hollow-core deck slabs in deck and roof structure
- Glazed areas in the facade and interior glass walls
- Concrete in grade deck and foundations
- Steel profiles as carrying columns

RESULT IN **LOW IMPACT**


Photo Henning Larsen Architects

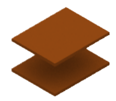
DESCRIPTION

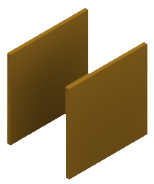
When Feldballe primary and lower secondary school was closed down, it reopened later as Feldballe Friskole. Ten years later, the number of pupils had doubled, and an extension was therefore added. Feldballe Friskole wanted a sustainable building, utilising of as many local and bio-based materials as possible. In the local area, which includes the housing association Friland Andelsforening, not only sustainable construction, but also sustainable living is a focal point. The client wanted an extension constructed with straw bales. The extension is primarily used by grades 8 and 9 as a science lab.



Mat.: 4,8
Tech. inst.: 0,9
Operation: 1,0
stated in KG CO_2 EQ/M²/YEAR

Location	Djursland, Denmark
Year	2021
No. of units	1
Category	School, extension
Architect	Henning Larsen Architects
Landscape	-
Engineer	Reeholm & Bredahl
Client	Feldballe Friskole
Contractor	Høgh & Sønberg
Type of contract	Hovedentreprise & selvbyg (forældresamarbejde)
Heated area	259 m^2
Energy class	BR2018
Total energy consumption	17,4 kWh/m^2/year
Energy source	Projected electricity mix
Data basis for LCA	Architectural model
Certification	-
Project website	See link


1 storey


Sheeting

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
The straw-bale panels carry a fire certificate, and since it is only a one-storey extension, there were no problems concerning fire-dimensioning.

Acoustics
Ventilation panels identical to those in the main building were used, which reduce outside road noise when the ventilation is on and absorb sound when the ventilation is off. Wood-fibre insulation is installed on the ceilings in preference to mineral wool for acoustic regulation. This resulted in added costs but was prioritised to ensure a better indoor climate.

Aesthetics
Achieving a high-quality architectural expression with bio-based building materials had been an important project parameter. The size and shape of the straw-bale panels defined the frequency of window openings.

Economy
Local self-builders gave a hand where possible to reduce costs. Originally, the idea had been to construct the grade deck from wood-fibre sheets, massive wood, and wood-fibre insulation. However, according to advice from BUILD, this would require ventilation via ground screws. This solution was abandoned due to cost and lack of expertise. The main contract option meant that it had been impossible to award a contract on a trade basis, and consequently a substructure was laid and the panels installed on this.

Logistics
The carcase consists of straw-bale panels manufactured on a client contract and installed by the client's parents on site over a period of five days.

Construction moisture
A moisture strategy was implemented, applicable to both the work procedure and tendering control plan. The elements were transported under cover, and moisture measurements were made on despatch and receipt.

Moisture during use
Natural ventilation was used in the building.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

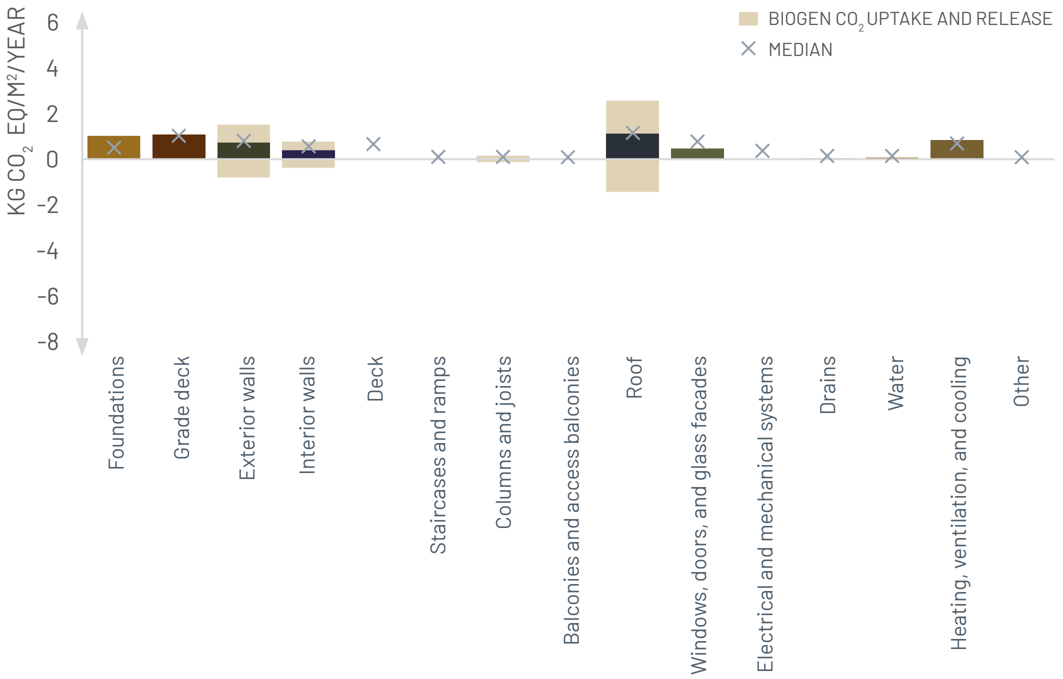


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m^2/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

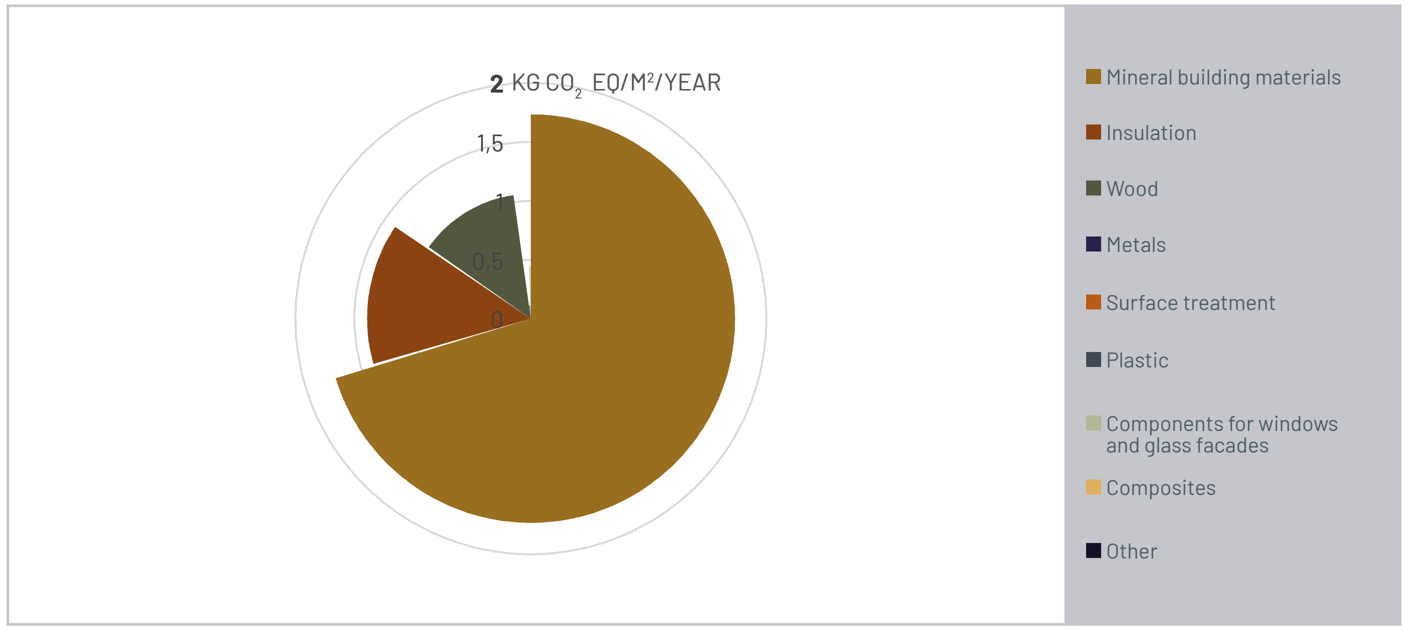


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

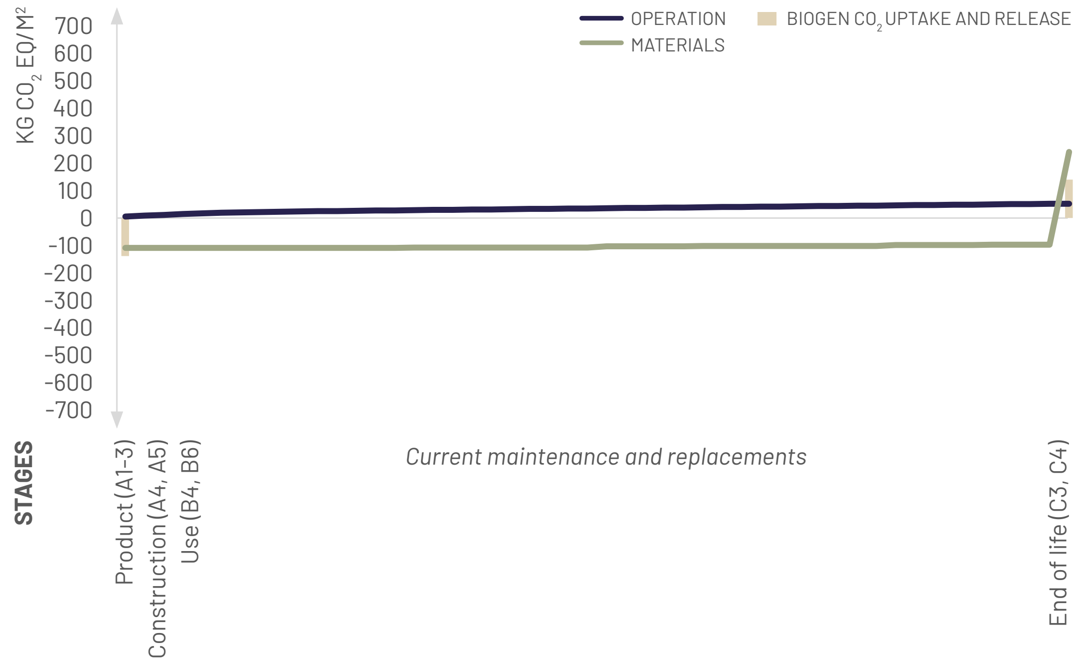


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m^2 distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

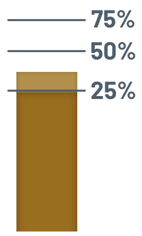
DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

RESULT IN **HIGH IMPACT**	Concrete in grade deck and foundations EPS insulation in ground deck Wood-fibre roof insulation
RESULT IN **LOW IMPACT**	

ROSA DAY-CASE INSTITUTION

DESCRIPTION

The project is an extension to an existing day-care institution. The client, the City of Copenhagen, wanted to use CLT as construction material to acquire expertise in using the material. Lendager advised on the use of CLT when and where it makes structural sense to do so. Focus is on using wood and reusing as much as possible. All materials in the existing building are healthy and in good condition, hence early studies were made as to how the existing materials could be reused for the extension. However, the timber facades of the old building could not be reused due to fire requirements, and because it was not fully known whether or not the fire impregnation would be leached over time.



Mat.: 7,1
Tech. inst.: 0,9
Operation: -
stated in KG CO_2 EQ/M²/YEAR

Location	Copenhagen S, Denmark
Year	2023-2024 (expected)
No. of units	1
Category	Day-care
Architect	Lendager
Landscape	Lendager
Engineer	Søren Jensen
Client	The City of Copenhagen
Contractor	-
Type of contract	Main contract
Heated area	2.475 m^2
Energy class	Low-energy class 2020
Total energy consumption	-
Energy source	District heating
Data basis for LCA	Architectural model
Certification	-
Project website	-

2 storeys

Sheeting (CLT)

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
For the project to comply with fire requirements, it was necessary to make certain fire-protective solutions in gypsum fibreboard. Further, there are exits from all rooms, complying with requirements for buildings in a high-usage class.

Acoustics
The idea was to construct decks in CLT and system ceilings to meet requirements for room acoustics. This will also have an effect on footfall transmission between storeys.

Aesthetics
White walls and uniformity in all the rooms were specified, however, the architects suggested making the rooms unique and using a variety of reusable materials for each room.

Economy
The client provided extra funding during the process because of increased material costs. Further, the project received DKK 1.3 million earmarked funds from Realdania via SoBB (Sammen om Bæredygtigt Byggeri) (Together for Sustainable Building), which focuses on starting up sustainable building projects in the wake of the corona pandemic.

Construction moisture
The project is still in its early stages, and no moisture strategy plan has yet been devised. However, one in the pipeline.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

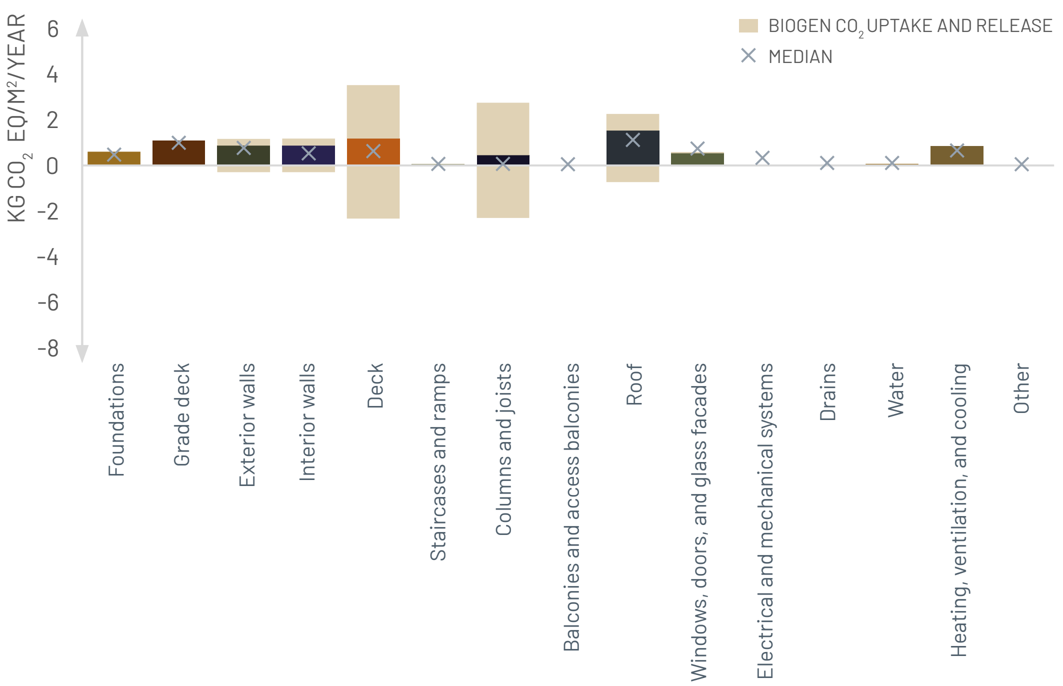


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

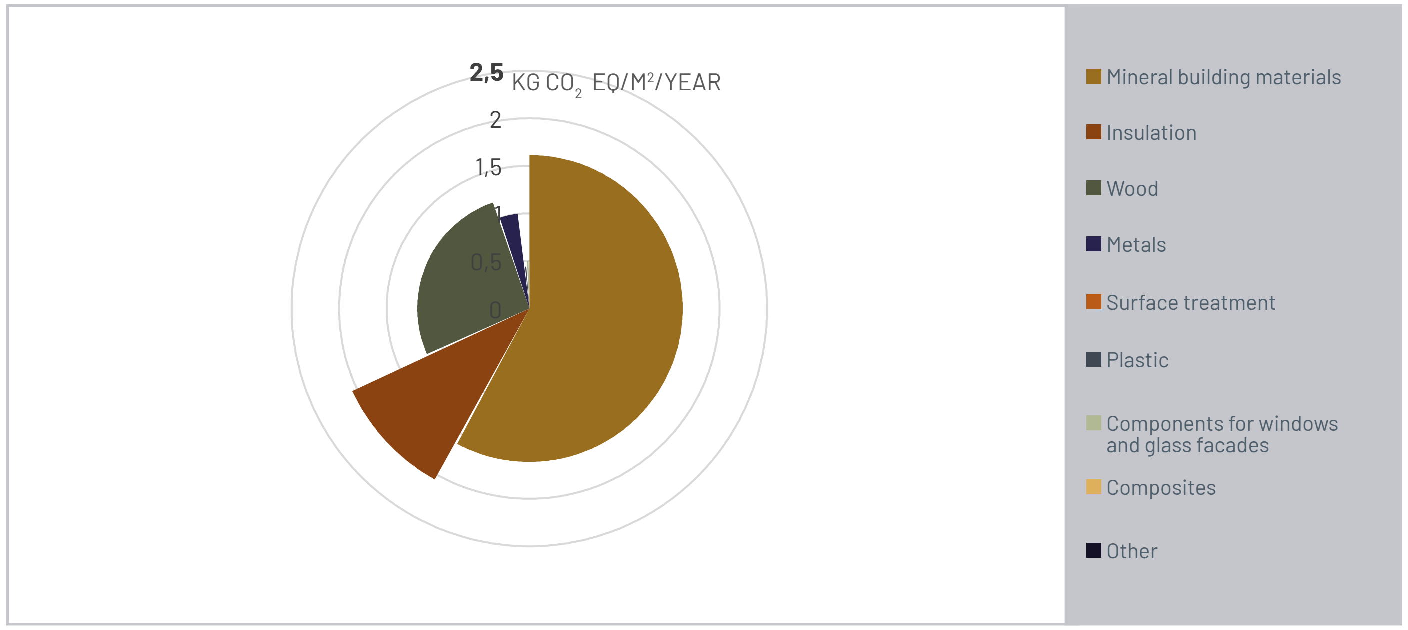


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

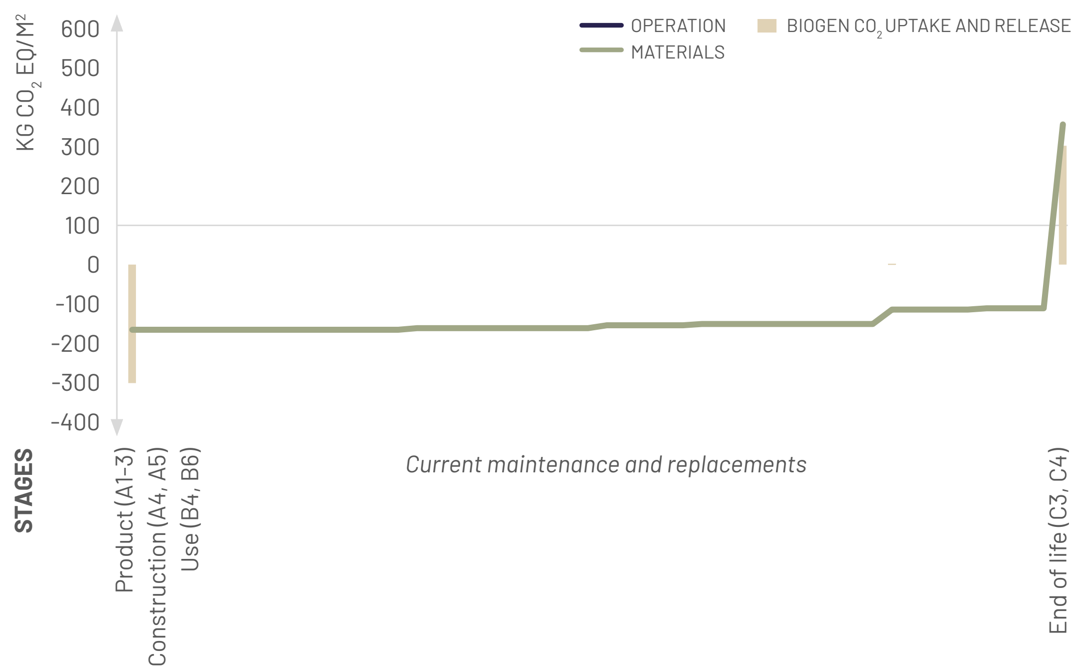


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

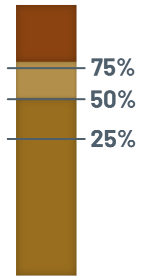
RESULT IN **HIGH IMPACT**	EPS insulation in ground deck Wood-fibre roof insulation CLT carrying structures in exterior decks Roof surface of steel sheets
RESULT IN **LOW IMPACT**	

KAROLINELUND KINDERGARTEN

Photo Artelia (formerly MOE)

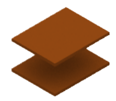
DESCRIPTION

The client wanted a climate-friendly building and hence a timber building was specified. The task was offered as a reverse tender with a DGNB certificate as competition parameter. The kindergarten is the first day-care institution in Denmark to be receive a DGNB Platinum award, and the building meets a series of sustainability criteria, including energy optimisation, overall economy, and choice of materials. The building is constructed using a column-beam structure with glulam beams supporting the green roof.

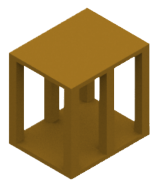


Mat.: 9,2
Tech. inst.: 1,9
Operation: 2,9
stated in KG CO_2 EQ/M²/YEAR

Location	Aalborg, Denmark
Year	2016 - 2017
No. of units	1
Category	Day-care institution
Architect	Bjerg Arkitektur
Landscape	By+Land
Engineer	Artelia (formerly MOE)
Client	Aalborg Municipality
Contractor	Lund & Staun
Type of contract	Turnkey contract
Heated area	851 m²
Energy class	BR2015
Total energy consumption	39,7 kWh/m²/year
Energy source	Projected electricity mix & district heating
Data basis for LCA	Engineering model
Certification	DGNB Platinum
Project website	-



1 storey



Hybrid

USE OF WOOD: KEY ACTORS' EXPERIENCE

Via interviews, key building actors shared the following experience about using wood in the specific project.

Fire
All building parts are R60 classified and designed as a fire section subdivided into fire cells.

Economy
During the construction process, the contractor and the consulting engineer worked closely together, as the building was constructed on site.

Acoustics
Acoustic plans and requirements were developed in the detail phase. On completion, the building was measured to ensure that requirements were complied with.

Aesthetics
The facade is made in thermowood with an estimated durability of 50 years. This was selected to achieve a patinated facade.

Statics & Logistics
The building comprises three building volumes connected by a common roof. This resulted in static problems, as the roof is separate from the interior building structures, and further support was required. No standard solutions for glulam construction existed, and the wood supplier did not provide calculations for a complete system of beams. Consequently, the project team spent many hours trying to solve statics details, especially in the overlap area between architects and engineers.
There was woodworking expertise on hand in the engineer's organisation, and it was decided to construct the building on site. Moreover, it was difficult to work with the plan arrangement, as it was problematic to determine which were supporting walls because the static load is distributed on columns.

Construction moisture
A plan was prepared for measuring the moisture content in the building and requirements defined for approval of moisture content of mass timber prior to packaging.

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

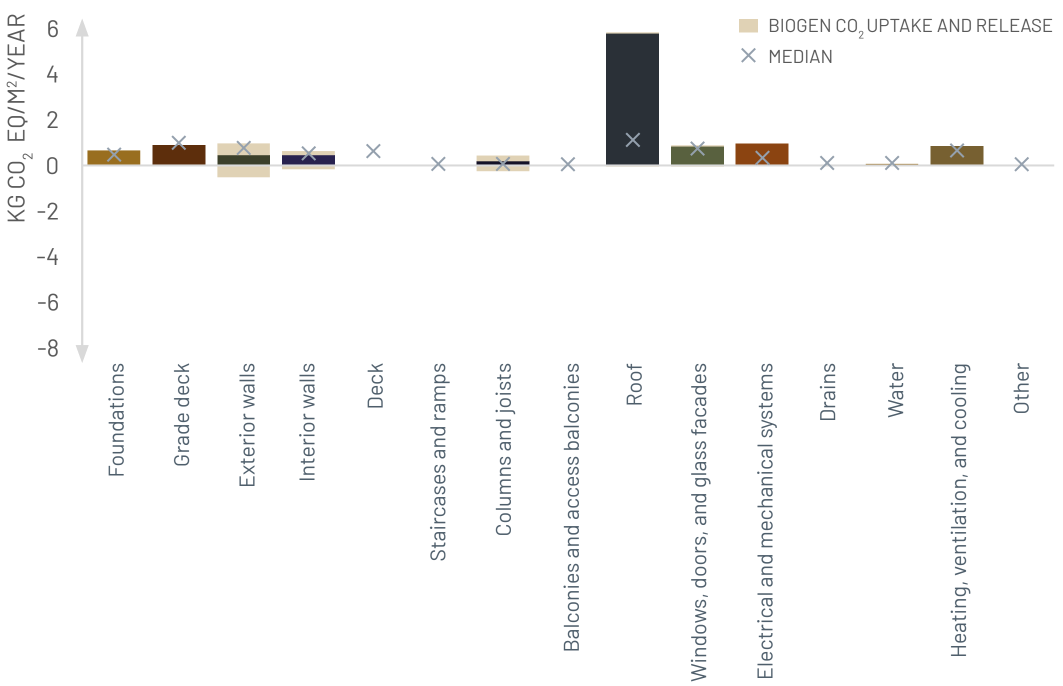


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

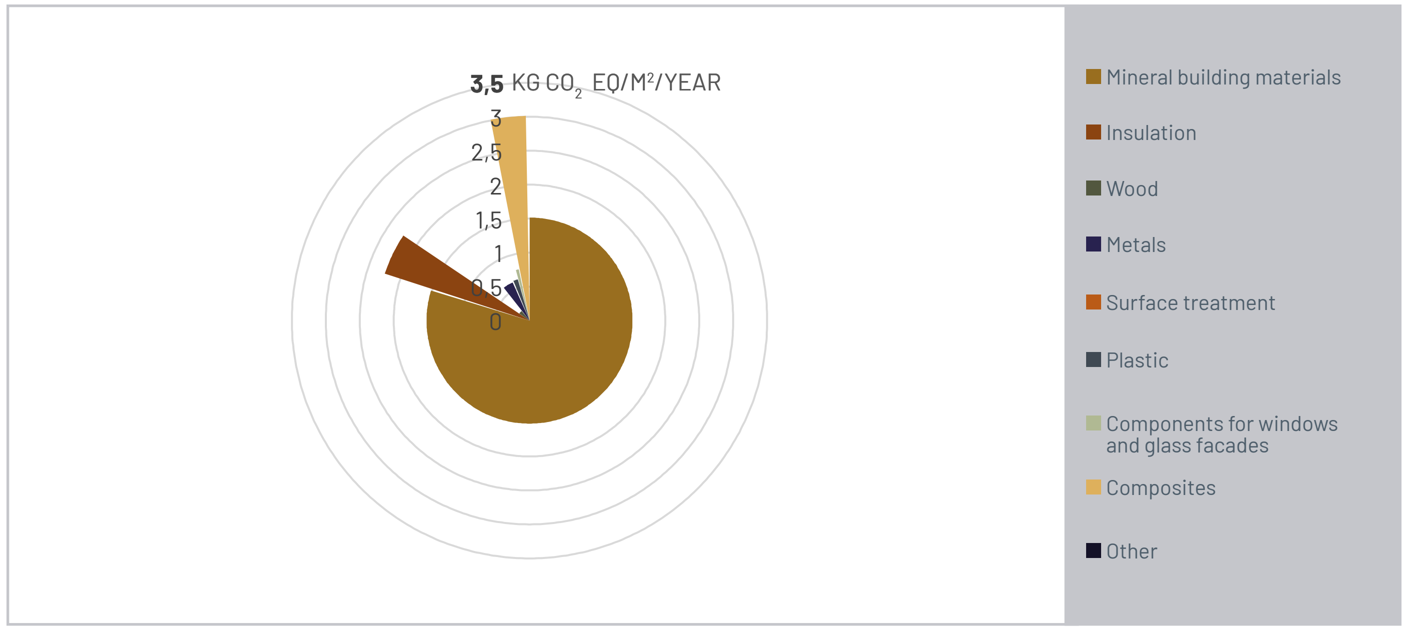


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

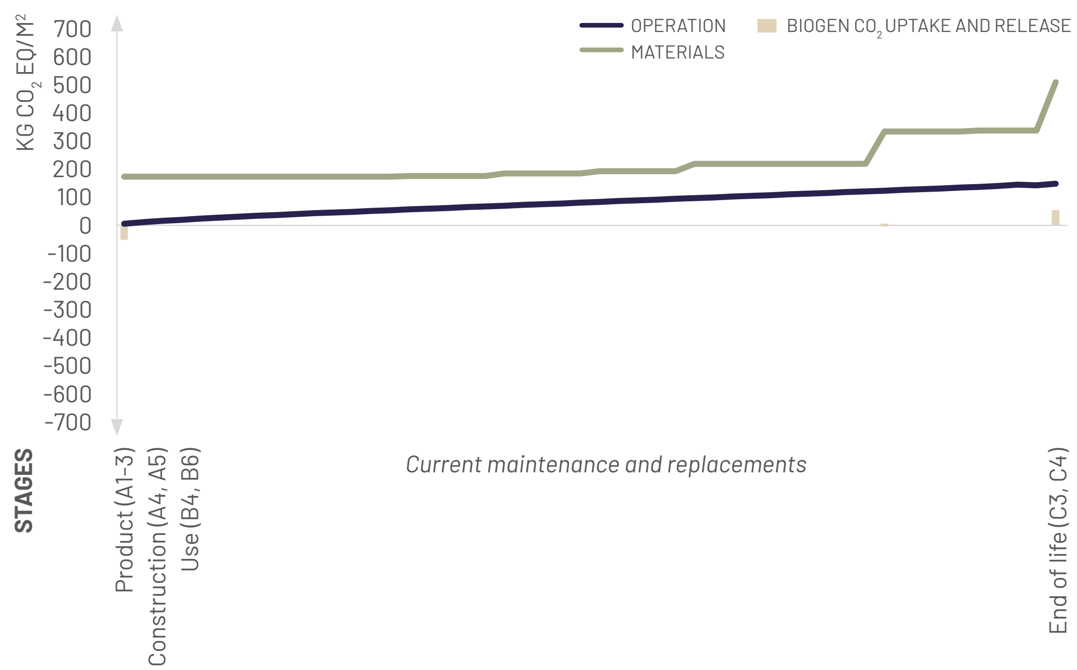


Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

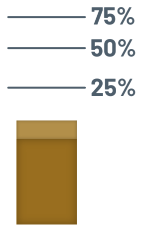
DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

RESULT IN **HIGH IMPACT**	Sedum roof EPS insulation in grade deck Photovoltaic modules on roof Concrete in grade deck and foundations Bituminous felt roofing One-storey building, resulting in a large area for climate envelope, grade deck, and foundations
RESULT IN **LOW IMPACT**	


Photo Sophia Lydolph / EcoCocon Denmark

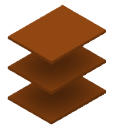
DESCRIPTION

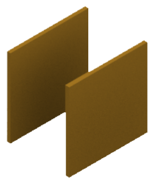
Skolen for Livet (School for Life) was built to realise a vision about a sustainable school building. The school is built with supporting structures of prefabricated straw bale panels. Other than that, the building also features ventilation windows, clay-plastered interior walls, and 75% a sedum roof.



Mat.: 4,4
Tech. inst.: 0,9
Operation: -
stated in KG CO_2 EQ/M²/YEAR

Location	Stege, Denmark
Year	2018
No. of units	1
Category	School
Architect	Ønskeøen
Landscape	-
Engineer	-
Client	Skolen for Livet
Contractor	-
Type of contract	-
Heated area	534 m²
Energy class	-
Total energy consumption	-
Energy source	-
Data basis for LCA	Architectural model
Certification	-
Project website	-


2 storeys


Sheeting

USE OF WOOD: KEY ACTORS' EXPERIENCE

No interview conducted on this building, and hence no experience was shared.


Photo Sophia Lydolph / EcoCocon Denmark

ENVIRONMENTAL IMPACT DISTRIBUTED ON BUILDING PARTS

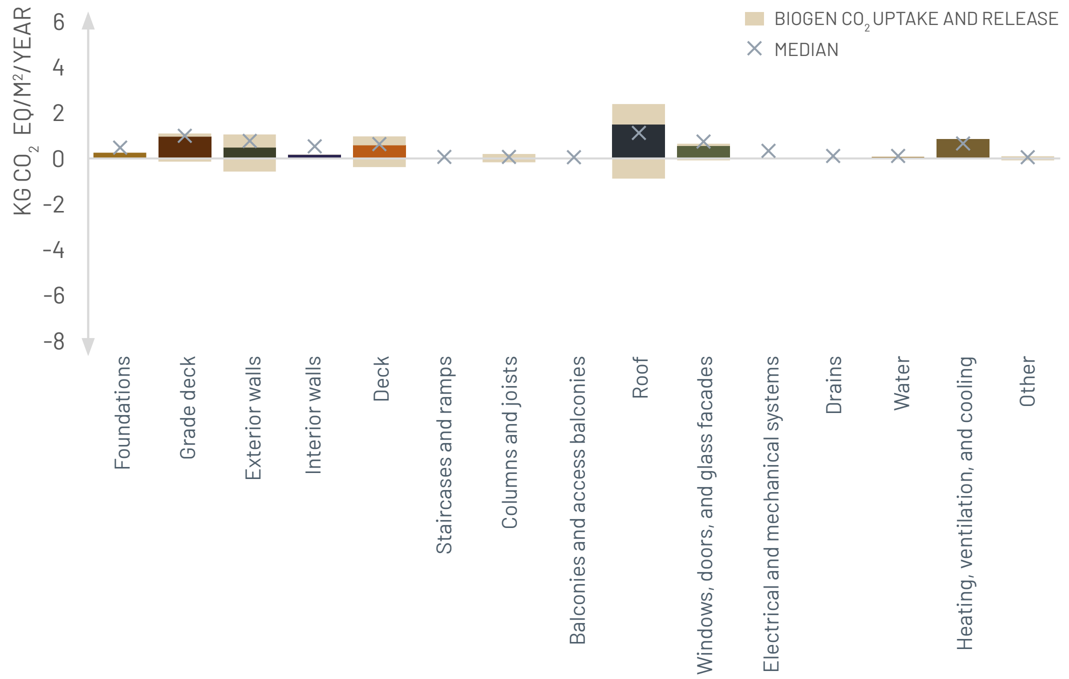


Figure 1. CO_2 accounting: building parts
The horizontal axis shows the groups of building parts, including foundations, grade decks, exterior and interior walls, decks, staircases and ramps, columns and joists, balconies and access balconies, roofs, windows, doors and glass facades, electrical and mechanical systems, drains and water, heating, ventilation, and cooling systems, etc.Please note that technical installations are based on generic values. The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year. Light brown indicates the building part's biogenic CO_2 content cf. the -1/+1 method. The crosses mark the median value for the building part in all case studies.

ENVIRONMENTAL IMPACT AND MATERIAL DISTRIBUTION

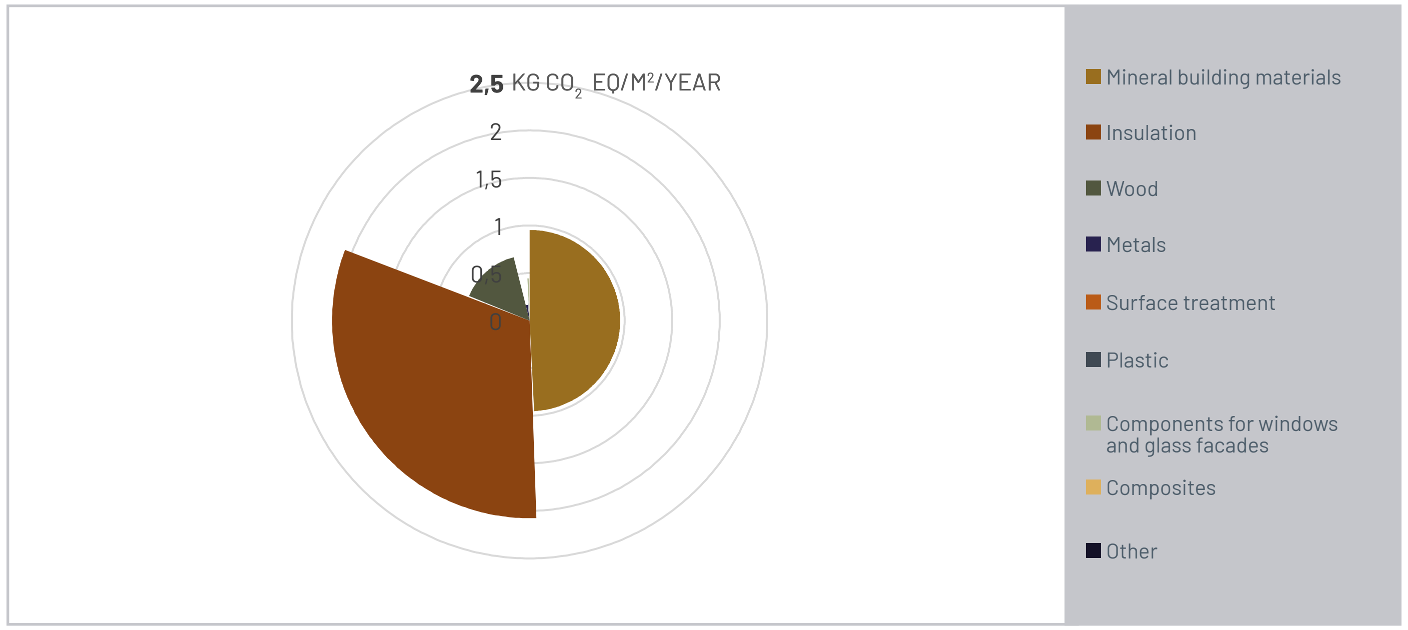


Figure 2. Material distribution and CO_2 emissions
The pie chart shows the distribution of materials measured in kg for the mineral building materials group: insulation, wood, metals, surface treatment, plastic, components for windows and glass facades, composites, and other construction-related items (%). The axis shows the emission of greenhouse gases stated in CO_2 eq/m²/year distributed on material categories. Please note the scale of the axis varies.

ENVIRONMENTAL IMPACT DISTRIBUTED OVER TIME

Figure 3. CO_2 accounting: life-cycle stages
The horizontal axis shows the distribution of life-cycle stages in the building over a 50-year period. In year 0, there are emissions from the Manufacture and Construction stages (A1–A3 and A4 and A5, respectively). Between years 1–49, there are emissions from the Use stage (B4 and B6). In year 50, there are emissions from the End-of-life stages (C3 and C4). The vertical axis shows the emission of greenhouse gases stated in CO_2 eq/m² distributed on materials and use. The biogenic CO_2 content is shown as columns corresponding to the capture and emission of biogenic CO_2 during the reference study period cf. the -1/+1 method.

DETAILS OF THE BUILDING'S ENVIRONMENTAL IMPACT

RESULT IN **HIGH IMPACT**	Wood-fibre roof insulation EPS insulation in ground deck Triple glazing in climate envelope
RESULT IN **LOW IMPACT**	Plain architecture and simple constructions Material consumption of 514.8 kg/m² is below average (average being 684.6 kg/m²)

Andersen et al., 2021
Andersen, C., Stranddorf, L. K., Wittchen, A., Rasmussen, F. N., & Birgisdóttir, H., Klimapåvirkninger fra 20 træbyggerier - LCA på 20 eksisterende træbygninger (Environmental Impact from 20 Timber Buildings - LCA of Existing Timber Buildings), 2021, BUILD 2021:27

CEN, 2012
CEN, DS/EN 15978 Sustainability of construction works – Assessment of environmental performance – Calculation method, 2012

CEN, 2013
CEN, DS/EN 15804:2012+A1 Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products, 2013

CEN, 2014
CEN, DS/EN 16449 Wood and wood-based products – Calculation of the biogenic carbon content of wood and conversion to carbon dioxide, 2014

CEN, 2019
CEN, DS/EN 15804:2012+A2:2019 Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products, 2019

IPCC, 2022
IPCC, Climate Change 2022: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. http://www.ipcc.ch.

LCAbyg, 2023
www.LCAbyg.dk

MOE, 2022
MOE, Oplæg til defaultværdier for installationer: etageboliger, kontorbyggerier, skole og daginstitutioner (Outline for Default Values for Installations: Multi-storey Housing, Offices, Schools, and Day-Care Institutions), 2022

Rasmussen et al., 2020
Rasmussen T., Rasmussen B., Andersen H., Birgisdottir H., Nielsen J., Jermiin L., Harrestrup M., Hansen T. & Cornelius T., Anvendelse af træ i byggeriet: Potentialer og barrierer (Using Wood in Construction: Potential and Barriers), 2020, BUILD 2020:25

Reduction Roadmap, 2023
www.reductionroadmap.dk

Teknologisk Institut & Sweco, 2022
Teknologisk Institut & Sweco, Outline for Default Values for Installations: Single-Family Dwellings, Terraced Housing, 2022

Trafik-, Bygge- og Boligstyrelsen & COWI, 2020
Danish Transport, Construction, and Housing Authority & COWI, Opdaterede emissionsfaktorer for elektricitet og fjernvarme (Updated Emission Factors for Electricity and District Heating), 2020

Videncenter om Bygningers Klimapåvirkning, 2022
Videncenter om Bygningers Klimapåvirkninger, LCA ifølge klimakravene: Introduktion til LCA i henhold til klimakravene i bygningsreglementet (Centre for Knowledge on Environmental Impact, LCA in Compliance with Environmental Requirements: Introduction to LCA in Accordance with the Building Regulations)

Wittchen & Rasmussen, 2021
Wittchen, A. & Rasmussen, T., Erfaringer fra 20 træbyggerier – Eksisterende træbyggerier (Experience from 20 Timber Construction Projects – Existing Timber Buildings), 2021, BUILD 2021:28

Zimmermann et al., 2019
Zimmermann, R. K., Kanafani, K., Rasmussen1, F. N., Birgisdóttir, H., Early Design Stage Building LCA using the LCAbyg tool: Comparing Cases for Early Stage and Detailed LCA Approaches, IOP Conf. Ser.: Earth Environ. Sci. 323 012118, 2019