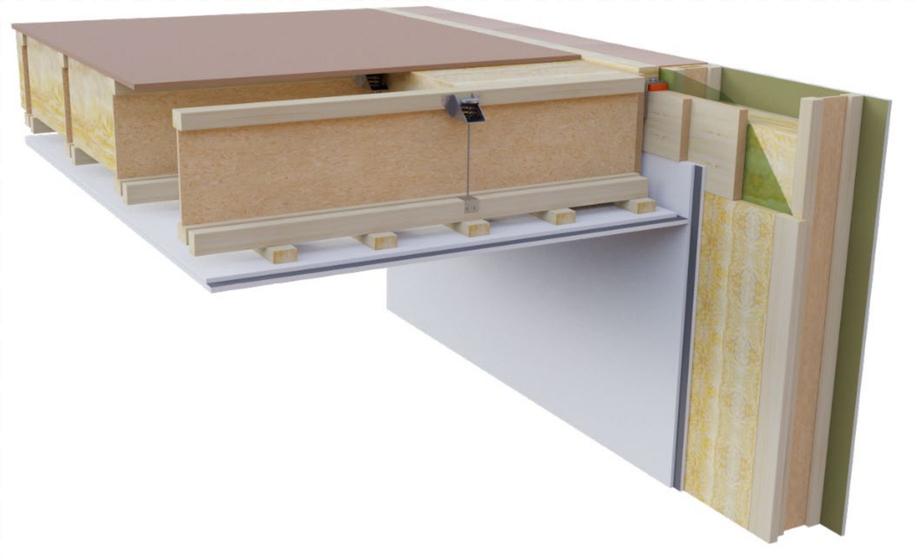

Nr C 558
October

The Blå Jungfrun reference building constructed with wood-based I-joist elements and cellulose insulation

– a climate declaration for the whole building from a life cycle perspective

On behalf of Norrlands Trähus and Masonite Beams

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Summary

Climate impact comparison between different building system's is of wide general interest. All building components from the bottom up including the drainage layer should be included in calculations – the entire life cycle of the building as well. Many studies do not take all building resources nor the entire life cycle into consideration, quite often some aspects are lacking, and this hinders balanced comparison.

In order to compare the climate impact of different building system s throughout their life cycles, IVL and KTH have carried out five different building system calculations for the same six-storey apartment building (Erlandsson et al. 2018). These calculations used the Blå Jungfrun (Blue Maiden) architectural design plans as basis for comparison and therefore referred to as a reference building. The case study buildings have the same heated surface area. In addition to Boverket's minimum performance requirements according to the building regulations (BBR) has improved performance been required for energy use and sound classification. These LCA calculations on five building systems were then supplemented with an additional analysis of a building system consisting of pillar decks with steel columns, hollow core floor slabs and lightweight curtain walls (Erlandsson & Malmqvist 2018). All these six studies and the new one included in this report are here comparable in terms of method choice, scope of inventory and data gaps, enabling a comprehensive analysis of the differences between various building systems.

This study adds another comparable building system in consonance with the Blå Jungfrun reference building, one that utilizes I-joist beams and prefabricated elements of wood-based materials. The examination indicates that this building system has a lower climate impact than the building systems analysed to date, with a climate impact during the construction phase of 176 kg CO_2/m^2 A_{temp}. This is a result on a par with the climate impact of a standard detached house. The current building system with cellulose insulation, similar to solid construction with cross-laminated timber (CLT), sequesters a larger proportion of biogenic carbon measured in carbon dioxide (CO_2) than is contributed to climate impact under the construction phase, measured in carbon dioxide equivalents (CO_2e).

In regard to the climate impact of the construction site, standard data templates have been used in a similar fashion as in previous analyses of the Blå Jungfrun reference building (Erlandsson et al. 2018). The calculation includes a large number of resources for all the selected building components to be included in forthcoming mandatory climate declarations. For building components that lie outside this system boundary, i.e., internal surface layers and room completion as well as all installations, standard data templates have been applied. The data for building components outside Boverket's proposed system limit for mandatory climate declarations makes up just over a third of the total climate impact caused by all construction products under the construction phase. This leads us to conclude that when we make environmental improvements in the future, there will be an increased interest in analysing building components outside the statutory system boundary – this is essential if we are to achieve further climate improvements and aspire to climate-neutral building practices.

Background

Climate impact comparison between different building system's is of wide general interest. The aim of this study is to identify improvements that can be applied to each building system and to help us understand which stages under a building's life cycle have the greatest impact on the climate.

IVL has together with KTH performed a detailed life cycle assessment (LCA) of an apartment building built under the Blå Jungfrun (Blue Maiden) passive house project in Stockholm (Liljenström et al. 2015). Ideally, environmental accounting should cover all building components from the bottom up, including the drainage layer – as well as the entire life cycle of the building. Many studies do not take all building resources or the entire life cycle of the building into consideration. Some aspects are often lacking, and this hinders balanced comparison. The original apartment building in the Blå Jungfrun neighbourhood was constructed with a concrete frame. Since then, a number of improvement proposals for construction solutions that utilize concrete have been analysed (Erlandsson 2017).

To compare the climate impact of different building systems throughout their life cycles, IVL and KTH carried out five different building system calculations for the same six-storey apartment building (Erlandsson et al. 2018). These calculations used the same architectural design plans for the Blå Jungfrun project as basis for comparison. All different building systems have the same heated surface area as Blå Jungfrun, why the buildings external size varies a bit instead. In addition to the minimum requirements set by the National Board of Housing, Building and Planning (Boverket's building regulations BBR), there are higher functional requirements for energy use and sound classification in the reference building in order to reflect what is actual build on the market. These LCA calculations from 2018 were then supplemented with an analysis of a building system consisting of pillar decks with steel columns, hollow core floor slabs and I-joist unfolding walls (Erlandsson & Malmqvist 2018). All these six studies and the new one included in this report are here comparable in terms of method choice, scope of inventory and data gaps (also called degree of coverage), enabling a comprehensive analysis of the differences between various building systems.

This report adds another construction platform with a 'wood-resource efficient' building concept, compared to a wood joist system or a solid wood construction utilizing cross-laminated timber (CLT). The building in question utilizes cellulose insulation, which increases the proportion of renewable material compared to previous wood-based concepts that primarily use mineral wool.

Goals, objectives and boundaries

The aim of this report is to perform LCA calculations for the Blå Jungfrun reference building targeting a system based on I-joist beams and prefabricated wood-based elements. The goal is to analyse differences in climate impact contributions generated by this system and compare them with previous analyses carried out by IVL and KTH. This result will allow a comparative assertion on climate impact assessment based upon identical design, floor plans and function, where the only difference lies in the choice of building system. Above all, it is of interest to compare the climate impact of resource-efficient systems based on I-joist beams with other wood-based alternatives. Our vision is to contribute to an increased understanding of how to utilize wood when building multifamily houses.

The project has been carried out on behalf of Norrlands Trähus AB and Masonite Beams AB. IVL has played a consultant role together with Åkej AB. The calculations have been based on the provided design documentation that has been supplemented with any missing elements of design and their building components, to ensure that all construction resources are included that can be summarised as a 'bill of resources'. Specific LCA data has been obtained for the building components included in the forthcoming mandatory climate declaration that will apply from January 2022. For installations, surface layers and other furnishings as well as construction site climate impact, standard data templates set forth in Erlandsson et al (2018) have been used.

The reference building

An apartment building in the Blå Jungfrun district was chosen to act as reference object due to its typical design and layout. It is a six-story building, including the entrance level. It houses 22 apartments, there are two elevators and a total heated area of 2198 m² A_{temp}. There is a dedicated technology room on the attic floor.

Figure 1 House 3 in the Blå Jungfrun residential development in Stockholm – the reference building for the respective building system s. Drawings: Reflex Arkitekter AB.

The reference building satisfies the FEBY energy requirements (2008) for passive houses as well as sound class B, which means that the technical functional requirements are higher than those required by the building code (BBR) and aim to reflect better that which actually is built on the market. The original construction of Blå Jungfrun has verified that the energy requirements have been met, i.e., an energy requirement of 41 kWh per m² Atemp and year, with purchased district heating and 12 kWh per m2 Atemp per year property electricity. The energy use of the different building systems under analysis is based on calculations concerning their energy performance. The heated are of the reference building No 3 is 2198 m² and is one of 6 almost equal buildings in the same block.

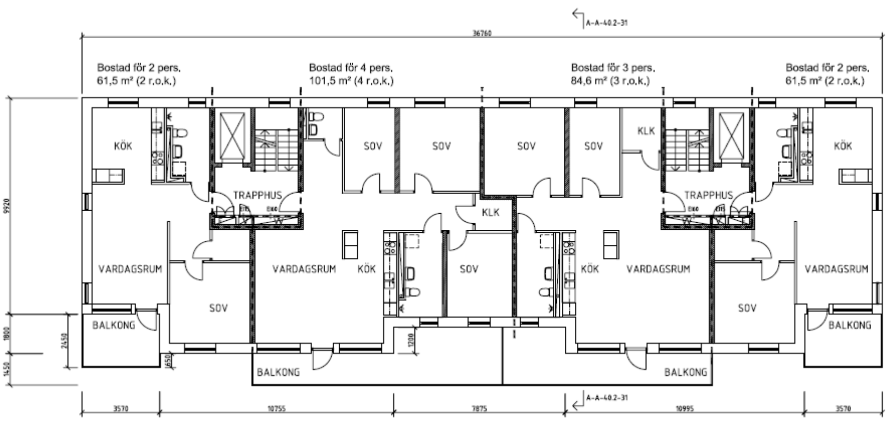


Figure 2 Reference building floor plans, floors 2-6. House no. 3, Blå Jungfrun. Source: Svenska Bostäder

The original reference building was constructed in cased concrete, which is the most common frame material used in apartment buildings in Sweden. The choice of façade material has little or nothing to do with the choice of frame material, so plaster, which is common for this type However, the details of the balcony solutions differ to allow usage with the specific system of construction in Sweden, is used in all the building scenarios. The exact design of the plaster cladding differs slightly between the different building system s, as it has been adapted to suit the chosen building solution.

All analysed building systems have been designed for the reference house in accordance with the floor plans and type drawings of the original, i.e., an identical number of apartments, floor plans, window and balcony layouts, etc., However, the details of the balcony solutions differ to allow usage with the specific system. In all cases, the facades are plastered, the roof is covered with bitumen waterproofing membrane with one bottom and one top layer and the foundation is a ground bearing concrete slab. The building has no basement garage and parking facilities are located on the ground floor.

Previous outcomes

This segment assesses the climate impact of the six most recently projected solutions proposed for the Blå Jungfrun reference building, published in Erlandsson et al. (2018) and Erlandsson & Malmqvist (2018). For detailed information about these platforms, please refer to these publications. The various platforms analysed are shown in Figure 3.

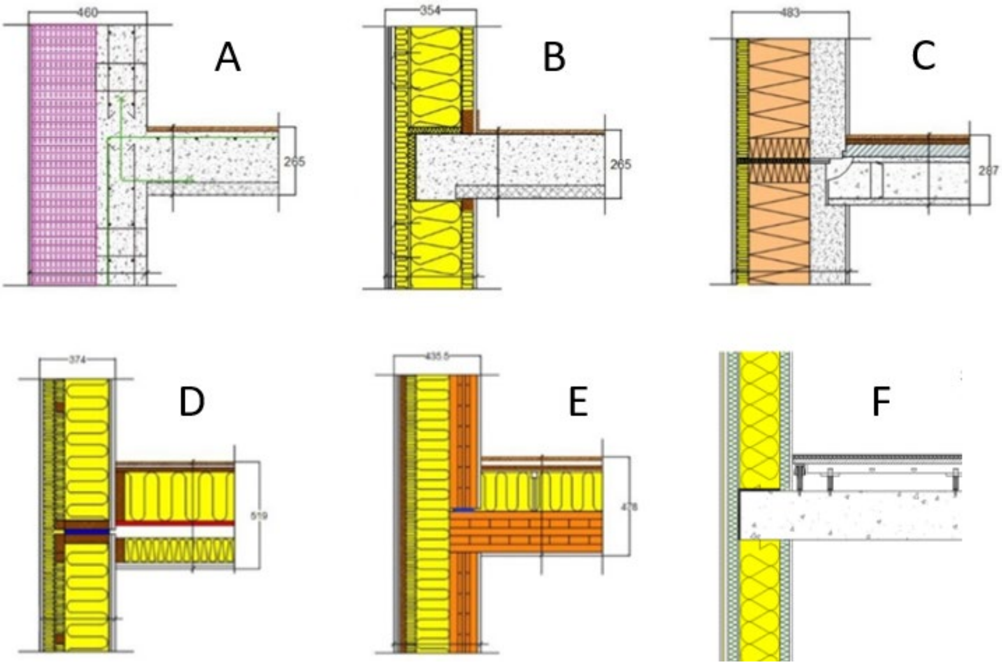


Figure 3 **Detail of the exterior wall/slab connections in A) cast-in-place concrete with load-bearing outer wall, B) cast-in-place concrete and lightweight curtain wall, C) prefabricated concrete with load-bearing outer wall, D) volume elements of wood, E) CLT F) Pillar deck, concrete prefab and steel pillars / beams, light gauge curtain wall.**

Historically, the largest contribution to climate change caused by buildings comes from heating. However, due to ever higher demands for low-energy use and better energy mix, these emissions have fallen significantly, and are likely to decrease even further in the future. Today the construction and manufacture of building materials accounts for an increasing share and the climate impact from heating is less than half, when calculated over an analysis period of 50 years, see Table 1. This suggests that we should focus more on climate-smart material choices. Calculations to date imply that well-known technology will take us some of the way, but research leading to new innovative solutions is also needed if the built environment is to be climate neutral.

Table 1 LCA results for climate impact of the various building system s over 50 years (kg CO_2e/m^2 A_{temp}) References: Erlandsson et. al. 2018, Erlandsson & Malmqvist 2018

Building system	A1-3 Product stage	A4 Transport	A5 Construction and installation process	B1) Carbonation	B2 Maintenance and replacement 50 years	B6) Operating energy	C1-4 Final stage	Total lifecycle A-C	A1-5 Construction phases
A) Cast-in-place concrete with permanent formwork, load-bearing outer wall	279	11	42	-4	17	188	18	550	332
B) Cast-in-place concrete, lightweight unfolding wall	234	11	45	-3	17	188	14	506	290
C) Prefab concrete, load-bearing concrete outer wall	214	24	34	-3	18	188	6	486	272
D) Timber volume elements	176	18	32	-1	24	188	10	447	226
E) CLT in frame and outer wall	167	19	37	-1	22	188	8	441	223
F) Pillar deck, concrete prefab and steel pillars/beams, light gauge curtain wall	182	24	39	-2	18	188	6	455	245

Table 1 shows that construction phase climate impact (A1-5) accounts for approximately 90% of the building's climate impact compared with phases A to C if operating energy is excluded (B6). This might provide a good motive for first and foremost a legislating on construction phase climate impact.

Methodology and calculation process

Life cycle analysis methodology is used to assess the environmental impact of a product from a life cycle perspective. A life cycle analysis (LCA) describes the environmental impact in numerical values within different environmental impact categories, such as climate impact, eutrophication, ground-level ozone and resource use. In this project, only climate impact has been calculated.

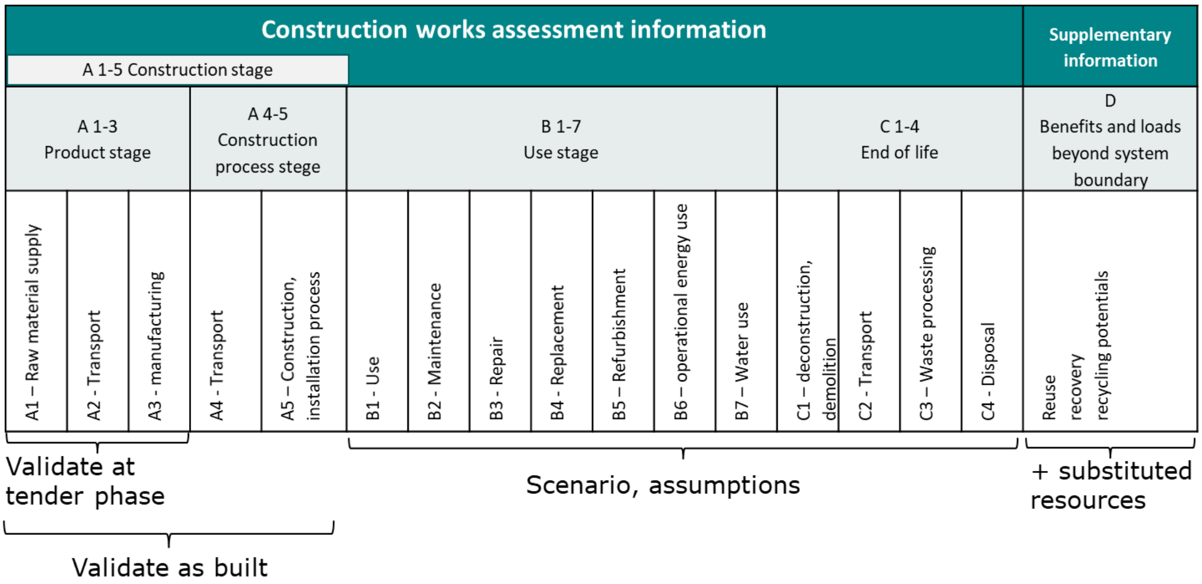


Figure 4 The life cycle of a building divided into stages and information modules (EN 15804, EN 15978). "X" indicates stages in the life cycle included in the building system calculations reported here. In the Swedish translation of, SIS has introduced the name Construction Stage for module A1-5 (SIS 2020).

If life cycle analyses are to be unambiguous, i.e., deliver the same result regardless of whoever carries them out, calculation method instructions and other specifications must be established and locked in place. Choice of methodology and clarifications made here adhere to EU Construction Products Regulation (EN 15804 and EN 15978) standards. This means, among other things, that calculations are carried out in accordance with "accounting LCA" and "modularity" principles. According to these standards, the life cycle of a building is divided into modules and the life cycle stages shown in Figure 3. Concrete carbonation is included under module B1. Biogenic carbon storage is reported as a supplementary inventory result not dealt with as an integrated impact category to global warming potential (GWP) in this project summary.

The project has calculated climate impact with the help of data from 'IVL's environmental database construction' and the LCA calculation tool 'Anavitor'. The LCA data used here for the most resources used falls under the so-called generic category and has been chosen as representative of products common on the Swedish market. However, specific data is used for the I-joist from Masonite Beams, cellulose insulation (Termoträ) and cellulose reinforced gypsum bord (Fermacell) The assumptions made in this regard and descriptions of the calculations in general and use of generic data are detailed in the project's background report (Erlandsson and Malmqvist, et al., 2018, Erlandsson et al. 2018).

LCA calculations are based on a digital model that utilizes digital design and building plans. This data consists of IFC models, in which quantities can be specified at the element level of all parts of the object under analysis. In addition, the structure of the various building elements has been specified in detail, so that these elements can be recalculated based solely on parameters, which facilitates their use in future calculations. The digital model has been supplemented with non-included resources, leveraging a resource compilation that is equally complete for all building components. This resource compilation covers drainage layers and above with the exception of installations, internal surface layers and furnishings. These components have been handled using standard data templates developed during the IVL and KTH Blå Jungfrun reference building project (Erlandsson et al. 2018). Specific data for the manufacturing of the I-joist elements is included and based on production at the Hammerdal factory (see modules A1-3), as well as the construction site's environmental impact (A5), calculated according to the standard method developed in the same project. Which means that the same data as for wood volume elements is used for the analysed system for information module A5 (see Table 2). For certain building components, e.g., balconies, stairwells and roofs, supplementary resource compilations have been developed.

The digital drawings are used as input to the Anavitor LCA calculation tool. The data consists of IFC models in which quantities can be specified at the element level of all parts of the object under analysis. In addition, the structure of the various building elements has been specified in detail, so that these elements can be recalculated based solely on parameters, facilitating their use in future climate impact calculations.

Building systems in the study

The building system under analysis here utilizes building elements comprised of I-joist wood beams manufactured by the Masonite Beams AB. This building system makes use of industrially prefabricated elements. The building elements are manufactured indoors under dry conditions at the by Norrlands Trähus AB premises at the Hammerdal factory (Strömsund municipality). The I-joist beams in the elements have a flange of planed wood and a web of particleboard or OSB board. The building system is accompanied by a handbook as support for system design, acoustic design, detailed design (construction, installations, fireproofing, etc.), as well as manufacturing design. The structure of the prefabricated elements is shown in Figure 4 and supplemented with the façade solution assumed in the calculations according to Figure 5. Figure 7 shows a section detail with fastening fittings, as well as some parts of the outer wall.

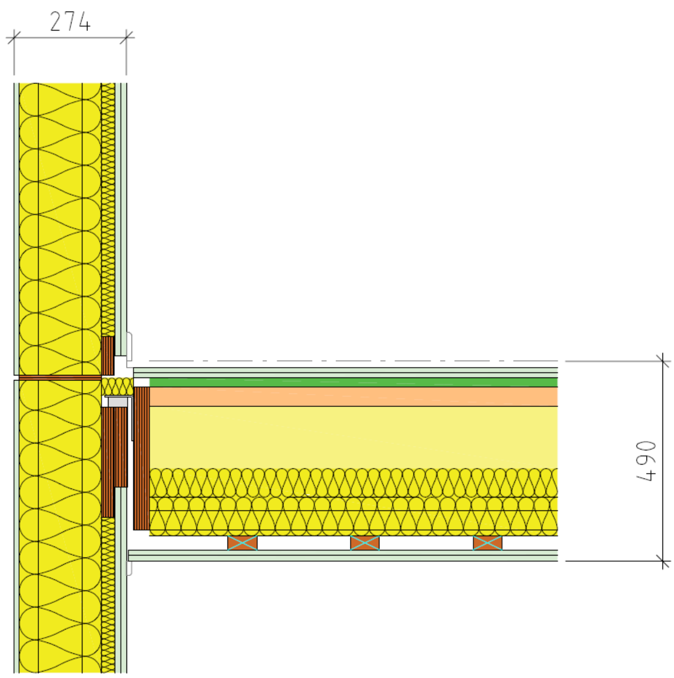
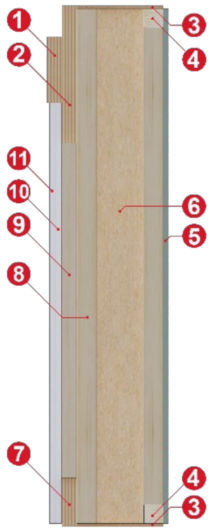
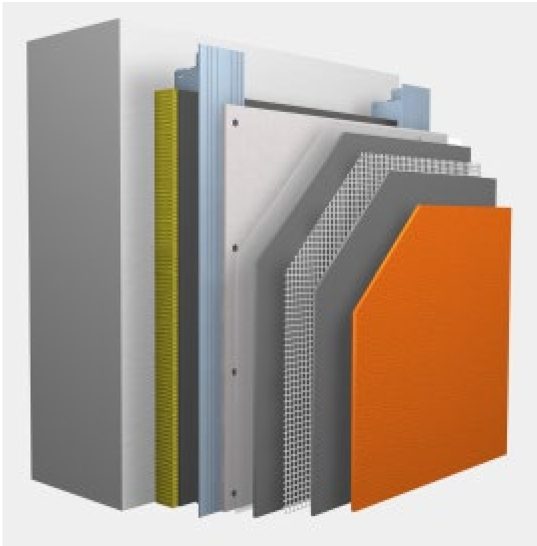


Figure 5 Overarching floor structure and outer wall. The outer gypsum fibre board is faced with an aluminium profile and an additional external plaster-bearing board which provides an aerated facade, see Figure 5 below.

The use of prefabricated building elements may impose some restrictions in terms of design and floor plans. The current building system means that certain limitations must be taken into account, e.g., a maximum of 8 floors, free spans of a maximum of 10 m, and a minimum floor thickness of 490 mm, but otherwise provides great flexibility which, among other things, allows windows to be inserted between elements in the facade.





Figur 6 Exterior wall construction up to exterior panel ; 1) LVL 33 mm, 2# LVL 33 mm, 3) hardboard 6 mm, 4) blockings 45 x 45, between Masonite studs, 5) Fermacell 12,5 mm, 6) Insulation, 7) LVL 33 mm, 8) R200, c600 + 195 mm Termoträ, 9) 34×95 c600 + 45 mm Termoträ, 10) Fermacell fire panel 15 mm, 11) Fermacell 12.5 mm.
StoVentec R ventilated facade system with joint-free plaster surface; wall membrane; anchoring, insulation, fastenings, support boards, fastening of support boards, base primer , primer, reinforcing mesh, intermediate coating, final coating.
Reference: https://www.stocorp.com/sto_systems/stoventec-render/

The I-joist beam I-profile reduces heat losses from thermal bridges by around 57% compared to solid wood. The I-joist beam system delivers an average of 15% lower u-value than conventional wooden frame constructions. Building systems with I-joist beams are intended for industrial construction use where innovative spring connections between floors and walls are used. This, together with the fact that installations have been integrated into the system, leverages a high degree of completion at the factory.

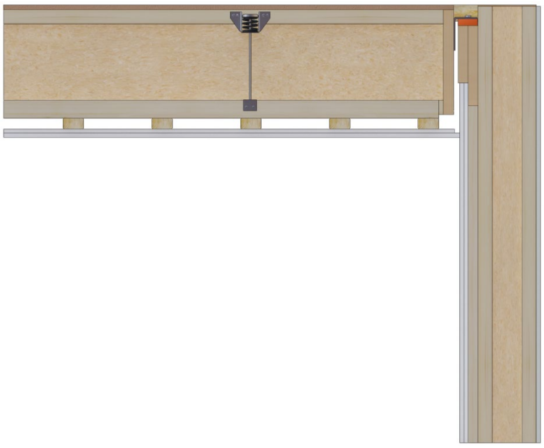


Figure 7 Sectional drawing of the system showing mounting brackets and spring connections

Sound requirements are important, and the specifications set for the reference house specify sound class B. Sound propagation in frame systems affects housing quality and in modern housing construction it is important to exercise control over the sound environment, not least when wooden building systems are concerned. When it comes to the current building system, both theoretical analyses and the results of practical tests have been made in built objects, and a test house has been used for extensive acoustic testing and noise and vibration analysis. The results good sound-insulating properties that more than satisfy the sound class B standard.

The foundation consists of a ground slab insulated with cellular plastic. All six floors of the building, exterior walls, floors and load-bearing interior walls such as stairwells, are built with wood elements. The stairs are made of glulam, which is clad with a mineral board of fibre gypsum (type Fermacell[1]), and surface layers of linoleum. Mineral fibre gypsum and fibre cement boards (instead of gypsum boards) are used throughout the reference building, as well as cellulose fibres based on mechanical pulp (type Termoträ). The cellulose fibre insulation is in the form of loose pulp and (dry) sprayed on site at the factory to a density of 48 and 40 kg/ m^3, in wall and floor cavities, respectively. The balconies consist of steel tie rods attached to the façade and balcony panels. Just as for the other buildings, systems the same resource compilation is used for installations as well as interior design and surface layers (i.e. building part No 7 and No 8).

[1] The climate impact from the Fermacell EPD has been used in the calculation, however bound biogenic carbon has been excluded, which increases its numerical value. This important adjustment brings the assessment in the EPD in line with the GWP-GHG yardstick used by both the National Board of Housing, Building and Planning (Boverket), the Swedish Transport Administration (Trafikverket) and others.

Climate impact outcomes

In this report, the climate impact of a system consisting of building elements based on I-joist beams, such as Masonite beams and cellulose insulation, has been calculated for the Blå Jungfrun reference building. These calculations facilitate direct comparison with other construction platforms previously analysed, see Figure 8 and Table 2.

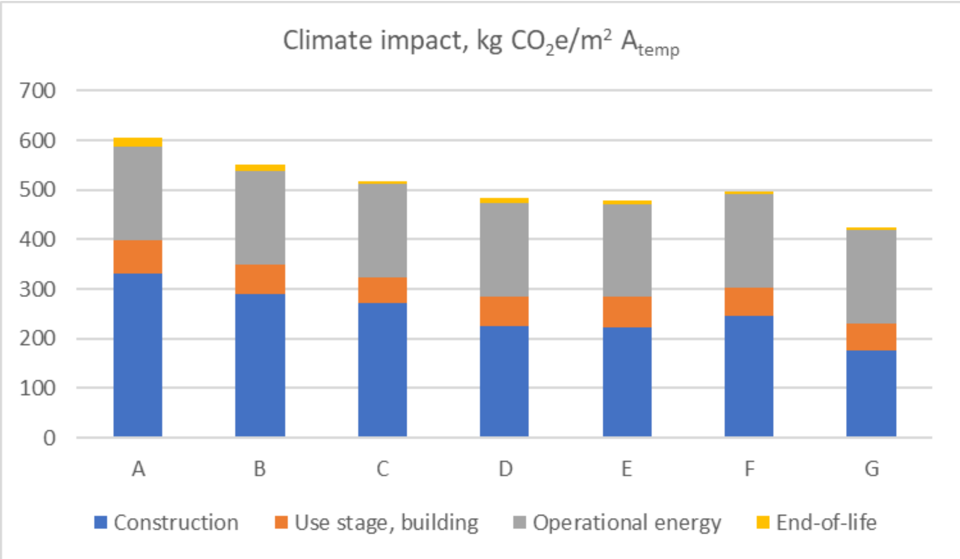


Figure 8 Climate impact GWP-GHG of various building systems applied to the Blå Jungfrun reference building and 50 years' service life and then a calculated demolition.

A) Cast-in-place concrete with permanent formwork, load-bearing outer wall
B) Cast-in-place concrete, light gauge curtain walls
C) Prefabricated concrete frame, load-bearing concrete outer wall
D) Wood volume elements
E) CLT in frame and outer wall
F) Pillar deck, concrete prefab and steel pillars/beams, light gauge curtain wall
G) Wood-based building elements with light I-joist beams

The environmental impact of the building system currently under analysis is the lowest of all the building systems studied to date. Climate impact per m² is so low for the I-joist system that it is in the range and comparable to a wooden frame single-family house with a concrete slab foundation (Erlandsson & Peterson 2015).

A potential improvement of the building system is to replace the current traditional concrete slab with a ground slab consisting of edge bars and concrete baulks, i.e., where the concrete slab has been replaced by wooden joists between load-bearing edge bars and concrete baulks. Such change will result in an improvement of about 10% of impact for the building (A1-A5.1), see Figure 9.

Table 2 would appear to suggest that solid CLT construction technology delivers bound biogenic carbon in the building, thus creating a temporary carbon sink greater than the emissions released during construction (A1-5). This also applies to systems utilizing wood-based building elements of I-joist beams analysed previously. Given that a smaller amount of wood is required for the latter system, this I-joist construction technology is more resource efficient in terms of wood raw material consumption than both CLT and wooden joist systems (c.f., the volume element included in previous analyses and referenced here).

Table 2 Compilation of GWP-GHG (kg CO_2e/m^2 Atemp) different building systems for the Blå Jungfrun reference building over 50 years, and bound biogenic carbon stored in the building (kg CO_2/m^2 Atemp).

Build system	A1-3 Product stage	A4 Transport	A5.1 Construction waste	A5.2-5.5 Construction, installation process	B1 Carbonation	B2,4 Maintenance and replacement	B6 Operating energy	C1-4 End-of-life	Total life cycle A-C	A1-5 Construction stage	Biogenic carbon dioxide bound in building materials
	kg CO_2e/m^2 Atemp										kg CO_2/m^2
A) Cast-in-place concrete with permanent formwork, load-bearing outer wall	279	11	6	36	-4	17	188	18	550	332	47
B) Cast-in-place concrete, light gauge curtain wall	234	11	14	31	-3	17	188	14	506	290	37
C) Prefabricated concrete frame, load-bearing concrete outer wall	214	24	4	30	-3	18	188	6	482	272	39
D) Wood volume elements	176	18	6	26	-1	24	188	10	447	226	160
E) CLT in frame and outer wall	167	19	6	31	-1	22	188	8	441	223	355
F) Pillar deck, concrete prefab and steel pillars/beams, light gauge curtain wall	182	24	7	30	-2	18	188	6	455	245	37
G) Wood-based building elements with I-joist light beams	138	9	3	26	-1	24	188	5	392	176	180

The climate impact accounting carried out here is restricted to the system boundary expected to apply to new building climate declarations in the future. Standard data templates are used for building components outside the proposed system boundary. This means that, apart from the construction site climate impact (B5.1-5.5), in cases where customers request an estimate of the climate impact of the whole building under the construction phase (A5), the market will probably use templates for building components when mandatory inventorying is not required. Including the climate impact of the whole building is important for systems and market arguments that aspire to the concept of climate-neutral construction, if this is the case it is essential that the whole building and all of its components is included.

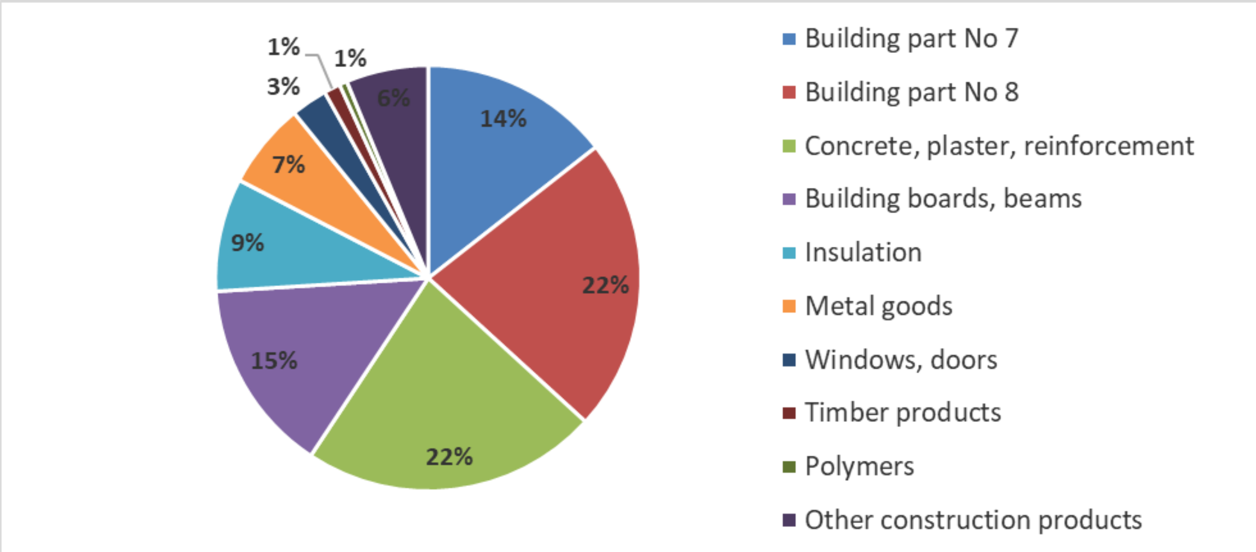


Figure 9 Relative contributions from different resources to climate impact GWP-GHG under construction phase (A1-A5.1), excluding operations at the construction site (A5.2–5.5), for building element under analysis. The standard data templates above refer to building part No 7 Internal surface layers and room completion as well as part No 8 Installations (including lifts), both of which are outside mandatory climate declaration for all new buildings in Sweden proposed system boundary (i.e. a cut-off).

The building part No 7 covering internal surface layers and room completion as well as building part No 8 Installations (including lifts) are excluded in the mandatory climate declaration for all new buildings in Sweden. If these building components outside this system boundary (i.e. building part No 7 and No 8), in respect to the new legally required climate declaration is summed and compared to the total impact A1-5, it is found that these building parts correspond to more than a third of the construction phase total climate impact. This is a result for a typically very low climate impact building system, while a building with a more polluting building frame is this not as significant cut-off.

If the authorities want to leverage environmental improvements, they should extend the range of our analysis to include components outside the statutory system boundary. At least if it is to be possible to bring about further climate improvements in the quest to embrace climate-neutral construction practices. We can also state that operating energy relative to climate impact over the 50-year analysis period increases for this type of low-climate impact building to about 50% of climate impact over the entire life cycle.

A sensitivity analysis where fibre gypsum (like Fermacell) has been replaced by standard cardboard gypsum board of equivalent quality, suggests that the climate impact per m^2 A_{temp} of the reference building will be reduced by 8 kg CO_2e/m^2 A_{temp}. As mentioned above, a modified concrete slab made of climate improved concrete can reduce the impact from the construction stage with about 10% for the case study building. The completed analysis has laid the foundation for further investigation into climate impact mitigation and adaption measures that can be applied to the current building system. The result also highlights that resource efficient use of wood makes it possible to achieve a low climate impact and still create a significant biogenic carbon sink if cellulose fibre insulation is used in combination with the wooden construction materials.

References

Liljenström C, Malmqvist T, Erlandsson M, Fredén J, Adolfsson I, Larsson G, Brogren M. Byggandets klimatpåverkan. Livscykelberäkning av klimatpåverkan och energianvändning för ett nyproducerat energieffektivt flerbostadshus i betong. IVL Svenska Miljöinstitutet, rapportnummer B2217, 2015

Erlandsson M (2017): Blå Jungfrun version 2017 med nya cement. IVL Svenska Miljöinstitutet rapport C250, juni 2017.

Erlandsson M, Peterson D: Klimatpåverkan för byggnader med olika energiprestanda. Underlagsrapport till kontrollstation 2015. För Energimyndigheten och Boverket. IVL Svenska Miljöinstitutet, rapport nr U5176, 27 maj 2015, första version daterad 10 maj 2015.

Erlandsson, M och Malmqvist, T., Francart, N, Kellner, J. (2018). Minskad klimatpåverkan från flerbostadshus – LCA av fem byggsystem. Underlagsrapport. Stockholm: Sveriges Byggindustrier, IVL Svenska Miljöinstitutet, rapport C350, oktober 2018.

Erlandsson, M och Malmqvist, T., (2018): Olika byggsystem av betong och trä där mix av material inklusive stål ger klimatfördelar. Bygg & teknik 7/18, 2018 (även publicerad som IVL rapport C355).

Erlandsson, M., Sandberg, E., Eek, H., Wall, M., Ruud, S., Wahlström, Å. (2008) Kravspecifikation för passivhus i Sverige — Energieffektiva byggnader. Version 2008:1. Forum för energieffektiva byggnader (FEBY). Energimyndigheten och Västra Götalandsregionen. IVL rapport nr A1548, LTH rapport EBD-R--08/21, augusti 2008.

SIS (2020): Livscykelskeden och moduler i EN 15804 och EN 15978. Hållbarhet hos byggnadsverk SIS/TK 209. https://www.sis.se/en/standardutveckling/tksidor/tk200299/sistk209/

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