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COMBIENT PURE

COMPARISON CALCULATIONS OF LOW-CARBON CONSTRUCTION - OFFICE

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Project	**Emission comparison calculation of low-carbon construction - office**
Recipient	**Combient Pure, NCC & Stora Enso**
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Reviewed by	**Sanni Reijonen**
Description	**Climatic survey of building – Whole Life Carbon Assessment of Buildings by the Ministry of the Environment (2021 edition)**

CONTENTS

1. INTRODUCTION

NCC, Stora Enso and Combient Pure have collaborated with the aim to develop wood construction. The development work included the carbon footprinting of an office building to be constructed from prefabricated concrete and a modification of said project with the use of CLT concrete-wood elements and other low-carbon material solutions. This report discusses the calculated climatic impacts of both design solutions.

The climatic impacts were assessed by the Life Cycle Assessment (LCA) model using the Method for the Whole Life Carbon Assessment of Buildings (the 2021 edition) issued by the Ministry of the Environment of Finland. Necessary modifications were made to the scoping procedure of said method owing to the intended use of the calculation and availability of initial data. The method in question is based on the framework for sustainable buildings called Level(s) prepared by the European Commission and on standards for sustainable construction (EN 15643, EN 15978, EN 15804, EN ISO 14067 etc.).

The building's life-cycle climatic impacts were assessed using the OneClickLCA calculation software. The final result of the LCA assessment for a 50 years' period of review showed that the climatic impacts of the concrete-structured office building, proportioned to the heated net area and assessment period, were 17.43 kg CO_2e/sq. m./a. The carbon footprint of the wood-structured office building for the same period equaled 14.82 kg CO_2e/sq. m./a. As a deviation from the assessment method issued by the Ministry of the Environment, the carbon footprint attributable to the building site conditions was excluded from the assessment of the concrete- and wood-structured building.

1.1 Basic information on assessed building

The basic data on the assessed building in both of the reviewed cases are gathered in Table 1. The concrete building is a typical building of reinforced concrete of which the exterior walls in the lower part of the deep-framed building are from precast concrete elements and in the tower section from thermoframed structures. The intermediate floor and the roof structure comprise hollow-core slabs while the ground floor is a slab on grade; the building has load-bearing walls of reinforce concrete.

The exterior walls, load-bearing walls and ground floor of the wood-structured office building are similar to those of the concrete-structured office; within the lowest floors the building is identical to the concrete-structured office building. Structural differences occur on the higher floors where the columns are glulam columns, and the beams have a glulam and steel structure. The intermediate floors are built from CLT slabs and the roof from LVL elements.

It is assumed that the consumption of purchased energy is the same in both design solutions. The surface areas of the concrete- and wood-structured office are almost identical and the scope of the calculation and building parts to be included in it are the same. Both buildings have a tower section which is slightly smaller in the wood-structured office building than in the concrete-structured one due to structural reasons.

Table 1. Basic data on assessed building.

Name of building project	
Building ID code	-
Address	-
Building type	Office
Year of completion	2022
Gross area	16,600 sq. m.
Floor area	
Heated net area	15,091 sq. m.
Number of floors	11
Number of basement floors	-
Service life of framing structures	Concrete building:100 years Wooden building: 100 years
Main framing material	Concrete building: reinforced concrete Wooden building: CLT & LVL (concrete-structured within floors 1-2)
Type of heating	Geothermal heat + district heating
Foundations	Not included in assessment. Not known.
Façade	Concrete and wood: Lower part brick cladding, tower section cladding panel
Energy class	A
Estimated consumption of purchased energy	Electricity: 768 MWh District heat: 493 MWh District cooling: 102 MWh
Plot area	Building site not known
Assessment prepared by	
Name	Henna Näsänen
Education	M.Sc. (Eng.)
Date of preparation of climate survey	2 May 2022, updated 13 May 2022
Revision date of climate survey	-
Assessment input data	
Information on items calculated with table values and exact values	Presented in Table 2
Environmental declarations used	Mainly typical GWP values of construction emission database. Materials for which the product specific EPDs were used are presented in Appendix 1.
Moment of making the assessment (building permit / commissioning phase)	-
Calculation software used	OneClickLCA
Possible remarks concerning data reliability	Scope of calculation was restricted to building parts from the ground floor upwards.

2. WHOLE LIFE CARBON ASSESSMENT METHOD 2021

The scoping procedure and assumptions used in the calculation are determined in the Method for the Whole Life Carbon Assessment of Buildings (2021 edition) issued by the Ministry of the Environment of Finland. The assessment generally considers the entire building, plot structures and main building service technology except for the vegetation in the plot or temporary scaffolding and protection during construction. In deviation from the assessment method, the plot structures were excluded from the scope of this study.

2.1 Life stages and system delimitation

The assessment is made considering the whole life cycle, including the life stages presented below in Figure 1. The assessment period is 50 years.

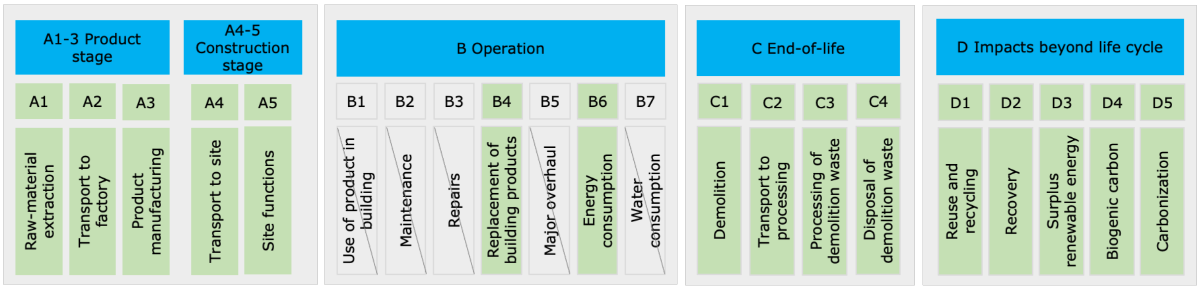

Figure 1. Life cycle phases of a building.

Product manufacturing A1-A3

The product manufacturing stage in the carbon footprint calculation consists of the emission impacts of products, materials and assemblies used in the manufacturing process. The material flows covered by the calculation are based on the building information models, preliminary structural types and NCC's estimated quantities of reinforcement and steel required for the concrete and wooden office buildings. The emission data were chosen by the following principles:

1. The primary source of information used was the environmental product declaration for materials for which the chosen material and manufacturer were known (Stora Enso CLT and Stora Enso LVL & stressed skin panels).
2. As the secondary source of information mainly served the typical GWP values (kgCO_2e/kg) of the national emission database (co2data.fi), since the exact product choices were not known.
3. In some exceptional cases where neither the primary nor the secondary information was available, the environmental information of similar products and databases was used additionally (Partition wall and thermoframed structures by Aulis Lundell, delta beams by Peikko)

The applied emission data are presented in more detail in Appendix 1.

Transportation to construction site A4

The transportation distances were not estimated separately for each product. The effect of transportation on the carbon footprint was estimated at 27 kg CO_2e/sq. m. which is a value proportioned to the building's heated net area.

Construction site functions A5

Emissions from the construction site functions are caused by the site energy consumption and auxiliary activities. The emissions were not assessed based on actual consumption, but the site effects were estimated at 78 kg CO_2e/sq. m. which is the value applicable to an office as per the national emission database. In addition, the excess and wastage percentage was included in the site activity, estimated from the material quantity as per the emission database.

Replacement of building products B4

The study included product replacements during the life cycle based on the estimated service lives of the building parts. The product service lives were estimated as per the assumed service life for the structural part. It was assumed that the products would be replaced at the end of their service life, if their service life was shorter than the building's planned service life. The emissions can be assessed in the same way as in the construction phase (phase A1-A3).

Energy consumption B6

The energy consumption for the operation period of the building was assessed according to the project's preliminary energy survey. The emissions from energy generation are calculated according to the benefit-sharing approach presented in the construction emissions database (the Finnish Environmental Institute). The energy unit emissions applied in the calculation are presented in Table 2. In the database, the energy consumed in different years have different emission unit values. In addition to the carbon dioxide emissions from combustion of fossil fuels, the database factors consider the methane and nitrogen dioxide emissions from fuel combustion as well as the carbon dioxide, methane and nitrogen dioxide emissions from the construction of power plants.

Table 2. Emission units by source of energy (Construction emission database, 02/2022).

kgCO_2e/MWh	2020	2030	2040	2050	2060	2070	2080
Electricity	153	89	59	45	34	22	15
District heat	147	114	82	54	29	21	15
District cooling	42	26	18	13	10	7	5

End of life C1-C4

The impacts of demolition (C1) were not assessed separately for each project, but they were chosen as per the national database estimate determined based on surface area amounting to 14 kg CO_2e/sq. m. for an office building. Transportation at end of life (C2) is estimated by the assumed transportation types and -distances using the emission unit data of the construction emissions database. Emissions from waste processing (C3) and disposal (C4) were based on the material-specific assessments of emission units as per the emission database waste processing and disposal processes.

Other impacts D

The assessment includes factors having such effect on the net climate benefits beyond the building's life-cycle assessment scoping procedure as would not be created, were the project not implemented. The carbon handprint is calculated as follows:

- Emissions avoided owing to building part re-use or material recycling (D1):
  - Concrete, metals, gravel and mortars: recycling benefit
  - CLT: re-use and recycling benefit
- Use of materials as recycled fuel or energy (D2):
  - EPS insulation, bitumen roof coverings, filtering fabrics: combustion of plastic

  - CLT: use as energy
- Surplus renewable energy generated in the building or its plot (D3). No surplus renewable energy is generated in this project
- Biogenic carbon or technical carbon included in long-lived building products (D4, carbon stored in wood-based materials). Only building parts and products designed as permanent structures of the building can be included in the assessment (minimum service life 100 years).
- The carbon dioxide uptake from the atmosphere through carbonization of cement-based products (D5). Carbonization was not considered in this project, since the concrete cement content and the future utilization processes were not known.

Table 3 presents the structural elements and their descriptions included in the assessment of the concrete- and wood-structured offices. The assessment of office buildings did not cover all structural parts listed in the assessment method, since the intention was to keep the accuracy and scope unchanged for both the concrete and wooden project while not all of the solutions were determined at the making of the calculations. They were also estimated as irrelevant to the comparability of the solutions. The scoping procedure of the calculation excluded the plot structures, foundations, standard fittings, doors, suspended ceilings and ceiling materials.

Table 3. Structural members reviewed in the calculation (structural members highlighted in grey are attributable to the building site footprint while the remaining ones are related to the building's carbon footprint).

Structural members reviewed in calculation (MoE edition 2021)		Included in calculation	Concrete-structured office	Wood-structured office
Plot structures	111 Ground elements	-		
	112 Soil stabilization and reinforcement elements	-		
	113 Paved and green areas	-		
	115 Site constructions	-		
Load-bearing members	121 Foundations	-		
	122 Ground floors	x	Slab on grade	Low-carbon concrete (-20% as compared to conventional concrete)
	1231 Civil defense shelters	-		
	1232 Bearing walls	x	Reinforced concrete	Low-carbon precast concrete element
	1233 Columns	x	Concrete columns	Floors 1-2 kept the same, from 3rd floor→LVL columns
	1234 Beams	x	Delta beams	Floors 1-2 kept the same (delta beam green). 3rd floor →LVL beams + WQ beams
	1235 Intermediate floors	x	Hollow-core slab	CLT slab, low-carbon hollow core slabs, low-carbon surface screed
	1236 Roofing decks	x	Hollow-core slab	LVL stressed skin panels
	1237 Structural frame stairs	x	Concrete stairs	Kept the same
	1241 External walls	x	Concrete element (lower part) Thermoframed structure (upper part)	Low-carbon concrete element in lower part
	1242 Windows	x	Wood-aluminum windows	Kept the same
	1243 External doors	-		
	1250 External decks	-		
	1260 Roofs	x	Green roof	Green roof
Light-weight structures	131 Internal dividers	x	Steel-framed partition	Kept the same
	132 Space surfaces (floors, ceilings, walls)	x (floors, walls)	Suspended ceilings and ceiling surface materials were not considered in the assessment.	Kept the same
	1331 Standard fittings	-		
	134 Ducts and fireplaces	-		

	135 Box units	-		
Building service technology	Heating, water supply, sewerage, air-conditioning, cooling and electrical systems	x	Building service technology estimated based on surface area sq. m.	
	2511 Lifts	x	Assessed based on number of lifts	Kept the same

3. BUILDING'S LIFE-CYCLE CLIMATIC IMPACTS – RESULTS

3.1 Concrete-structured office building

The total life-cycle footprint of the concrete-structured office building stood at 13,150 t CO_2e with the period of assessment of 50 years including the structural parts listed in Table 3. Table 4 presents the life-cycle climatic impacts of the concrete-structured office building considering the climatic impacts of the building only (excluding those of the building site). The building's climatic impacts are presented by the Method for the Whole Life Carbon Assessment of Buildings (the 2021 edition) issued by the Ministry of the Environment of Finland as a comparison value, i. e. proportioned to the heated net area and period of assessment.

Table 4 presents the calculated carbon footprint and the carbon handprint. The carbon footprint is calculated as the summed-up negative climatic impacts of modules A-C and describes the amount of greenhouse gas emissions generated over the building's life cycle, expressed in carbon dioxide equivalents. Instead, the carbon handprint refers to climatic benefits that can be achieved during the building's life cycle and would not be created at all, were the building project not to be realized. It is calculated by summing up the factors in module D. The carbon handprint could not be calculated in the project for all factors in the absence of sufficiently accurate initial data.

Table 4. Results of 50 years' assessment on the climatic impacts of the concrete-structured office building.

	Building **kg CO_2e/sq. m./a***
A. Before operation	9.47
B. During operation	7.38
C. After operation	0.58
Carbon footprint total	**17.43**
D1 & D2 re-use, recycling and use as energy	*Could not be determined*
D3. Surplus renewable energy	-
D4. Carbon storage effect	0
D5. Carbonization	*Could not be determined*
Carbon handprint total	0

**the results are proportioned to the heated net area of the building of 15,091 sq. m. and assessment period of 50 years.*

Table 5 and Figure 2 indicate the life-cycle climatic impacts of the concrete-structured office caused by the different structures, systems and energy forms. Figure 3 gives a more detailed listing of the climatic impacts of the ground floor, framing structures and external walls in the different life stages.

Table 5. Life-cycle climatic impacts of the office building with reinforced concrete structure, i.e., the carbon footprint.

	Before use A1-A5	During use B4 +B6	After use C	Carbon footprint kg $CO_2e/m^2/a$	Carbon footprint t CO2e
1220 Ground floors	0.09	0.00	0.01	0.09	70
1232 Framing: load-bearing walls	0.52	0.00	0.05	0.56	426
1233 Framing: Columns	0.13	0.00	0.01	0.14	103
1234 Framing: Beams	1.89	0.00	0.02	1.91	1439
1235 Framing: Intermediate floors	1.32	0.00	0.11	1.43	1080
1236 Framing: Roof decks	0.36	0.06	0.02	0.44	334
1237 Framing: Structural frame stairs	0.01	0.00	0.00	0.01	6
1241 Façades: Exterior walls	0.63	0.00	0.04	0.67	502
1242 Façades: Windows	0.57	0.00	0.01	0.58	438
1311 Partition walls: Partition walls	0.10	0.00	0.00	0.10	76
1321 Surface structures: Floor coverings	0.35	0.35	0.00	0.71	533
1325 Surface structures: Walls.	0.02	0.02	0.00	0.03	25
Building service technology	1.32	1.48	0.03	2.83	2133
2511. Lifts	0.02	0.02	0.00	0.05	34
S212. Power generation and electrical equipment	0.07	0.07	0.00	0.13	99
A4 Transportation to building site (table value)	0.54			0.54	407
A5 Site functions	1.56			1.56	1177
C1 Demolition (offices)			0.28	0.28	211
District cold consumption		0.12		0.12	91
District heat consumption		2.25		2.25	1698
Electrical energy consumption		3.01		3.01	2271
Building's carbon footprint, total, $kgCO_2e$/sq. m./a	**9.47**	**7.38**	**0.58**		
Building's carbon footprint, total, t CO_2e	**7147**	**5567**	**439**		
Share of total carbon footprint	**54%**	**42%**	**3%**		

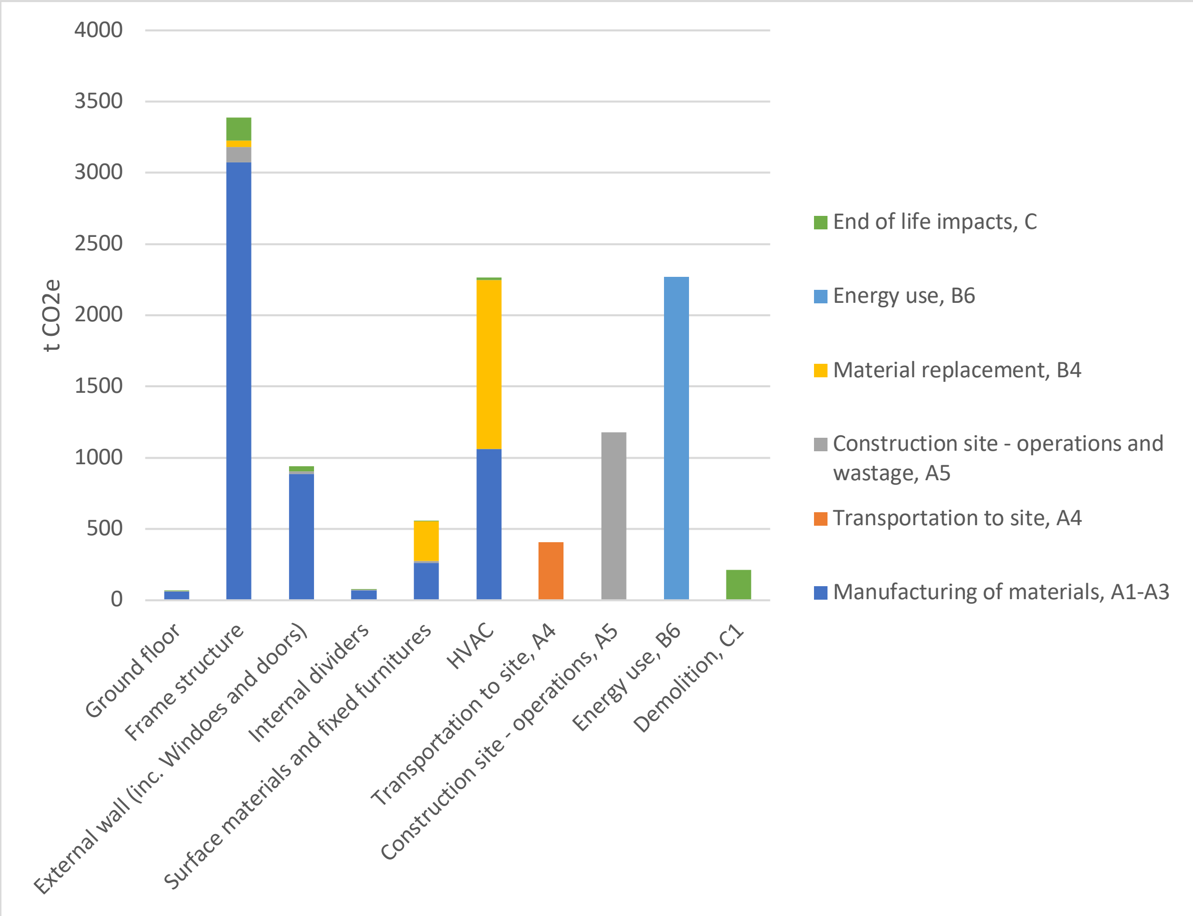

Figure 2. Life-cycle climatic impacts of the concrete-structured office building (does not include emissions of the building site).

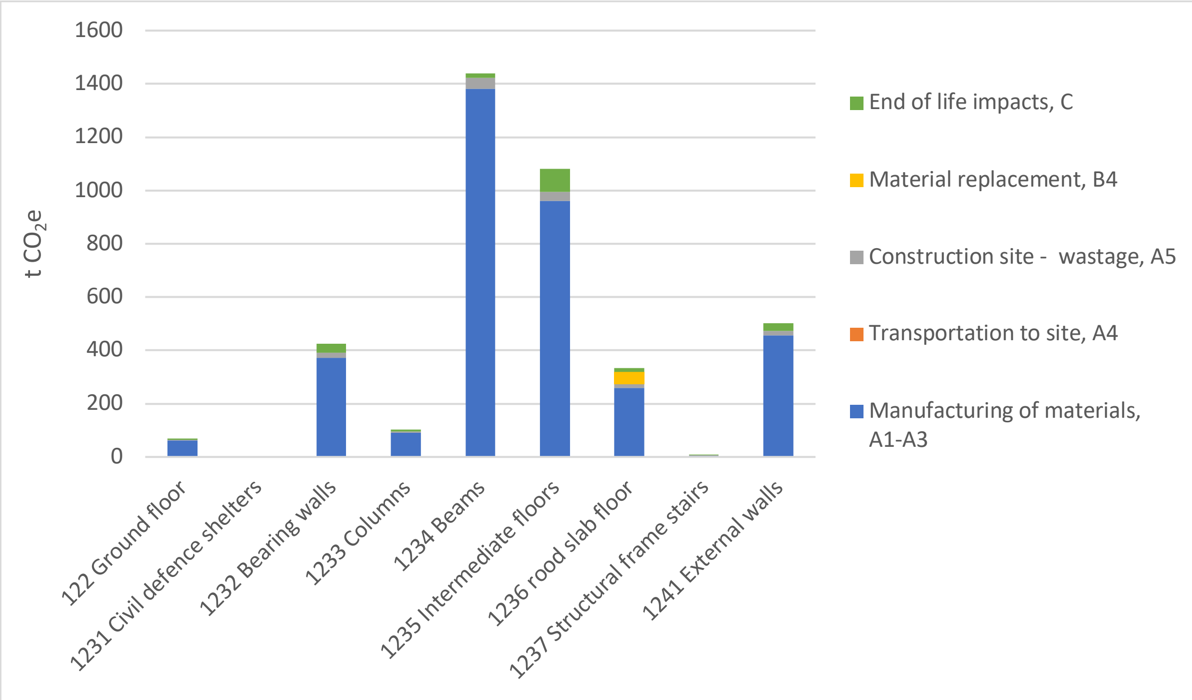

Figure 3. Climatic impacts of the concrete-structured office building in different life stages.

3.1.1 Interpretation of the results – concrete-structured office building

The assessment shows that a significant part (41%) of the life-cycle climatic impacts is caused by the manufacturing of building materials for the concrete-structured office. The biggest impact in the manufacturing emissions is attributable to the building's framing (26% of the life-cycle climatic impacts) and building service technology (17%). The use of carbon-intensive concrete and steel products in the building cause the emissions of the framing to rise. The emissions of the building service technology are as well increased due to the carbon-intensive manufacturing of steel products it uses.

Emissions from energy consumption cause a considerable share of emissions of the operation stage and 31% of the total life-cycle climatic impacts of the building. The emissions were assessed considering the decarbonization of energy production in the future. In addition, the emissions of the operation stage are caused by repairs and replacements of the components, but their share as compared to the emissions of the energy consumption are slightly lower as they amount to an 11% share of the total life-cycle climatic impacts. A significant increase in the emissions of repairs and replacements is caused by the renovation and renewal of the building service technology and – to a lesser extent – by the replacement of the flooring and walling materials.

The emissions from transportation, site functions and end-of-life emissions are low when compared to those of the above-mentioned stages. However, the share in the carbon footprint from site functions of a new building project is surprisingly high – nearly 9%.

3.2 Wood-structured office building

The calculation results for a wood-structured office building, or the life-cycle climatic impacts of the building, are presented in Table 6.

Table 6. Results of 50 years' assessment on the climatic impacts of the wood-structured office building with comparison values of the Ministry of the Environment.

	Building kgCO2e/sq. m./a*
A. Before operation	6.93
B. During operation	7.32
C. After operation	0.56
Carbon footprint, total	**14.82**
D1 & D2 re-use, recycling and use as energy	*Could not be determined*
D3. Surplus renewable energy	-
D4. Carbon storage effect	-3.75
D5. Carbonization	*Could not be determined*
Carbon handprint total	-3.75

**the results are proportioned to the heated net area of the building of 15,091 sq. m. and assessment period of 50 years.*

Table 7 includes a breakdown of the climatic impacts from structural members by the Building2000 Project Classification, the energy consumption, site functions and processes. Figure 4 lists the climatic impacts of the wooden building by the structural member, system and types of energy consumption. A more detailed specification is given in Figure 5 of the life-cycle climatic impacts of framing structures.

Table 7. Life-cycle climatic impacts of the wooden office building, i.e., the carbon footprint.

	Before use A1-A5	During use B4 +B6	After use C	Carbon footprint kg $CO_2e/m^2/a$	Carbon footprint t CO2e
1220 Ground floors	0.07		0.01	0.08	61
1232 Framing: load-bearing walls	0.34		0.05	0.39	293
1233 Framing: Columns	0.05		0.01	0.06	47
1234 Framing: Beams	0.62		0.02	0.64	484
1235 Framing: Intermediate floors	0.55		0.09	0.64	485
1236 Framing: Roof decks	0.18	0.01	0.01	0.19	145
1237 Framing: Structural frame stairs	0.01		0.00	0.01	6
1241 Façades: Exterior walls	0.59		0.04	0.63	478
1242 Façades: Windows	0.56		0.01	0.57	432
1311 Partition walls: Partition walls	0.10		0.00	0.10	76
1321 Surface structures: Floor coverings	0.34	0.35	0.00	0.70	527
1325 Surface structures: Walls.	0.02	0.02	0.00	0.03	25
Building service technology	1.32	1.48	0.03	2.83	2133
2511. Lifts	0.02	0.02	0.00	0.05	34
S212. Power generation and electrical equipment	0.07	0.07	0.00	0.13	99
A4 Transportation to building site (table value)	0.54			0.54	407
A5 Site functions	1.56			1.56	1177
C1 Demolition (offices)			0.28	0.28	211
District cold consumption		0.12		0.12	91
District heat consumption		2.25		2.25	1698
Electrical energy consumption		3.01		3.01	2271
Building's carbon footprint, total, $kgCO_2e$/sq. m./a	**6.93**	**7.32**	**0.56**		
Building's carbon footprint, total, t CO_2e	**5232**	**5525**	**423**		
Share of total carbon footprint	**47%**	**49%**	**4%**		

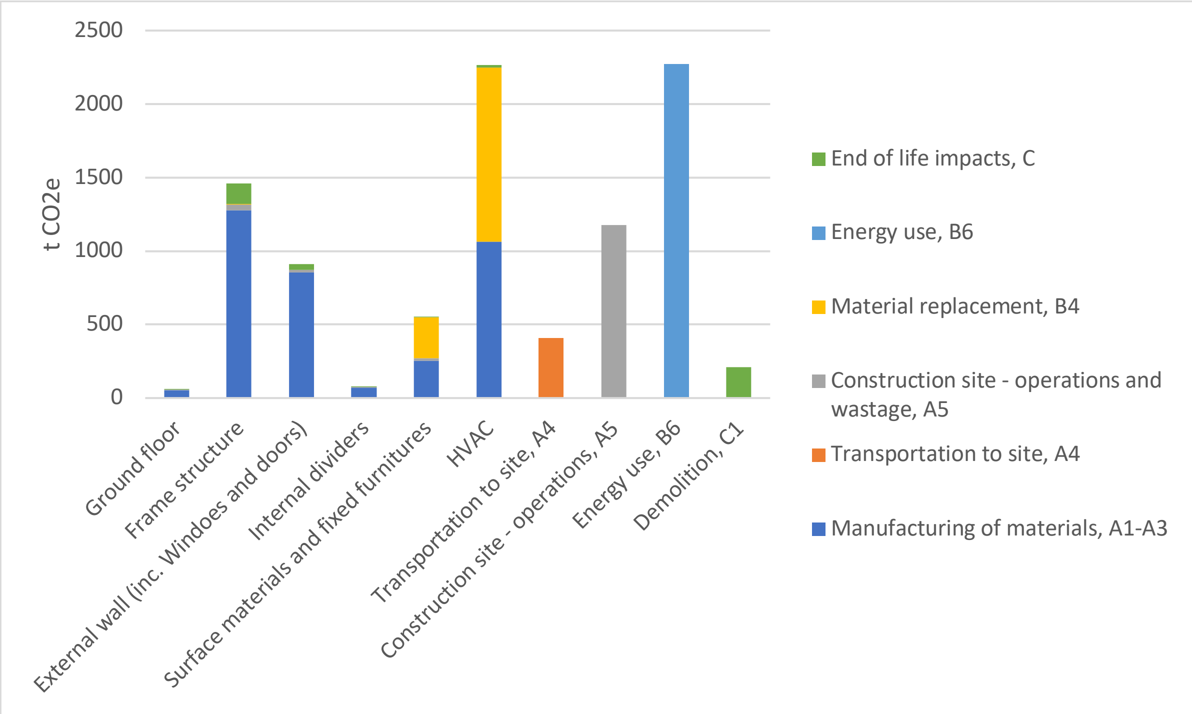

Figure 4. Life-cycle climatic impacts of the wooden office building (does not include emissions of the building site).

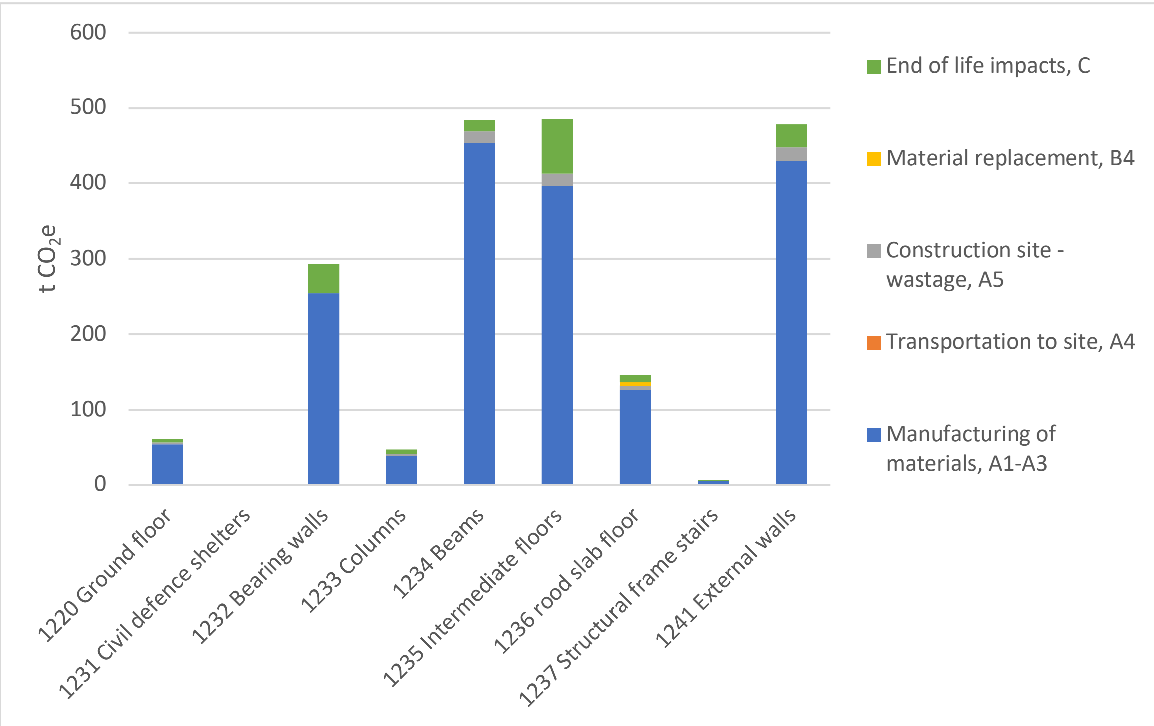

Figure 5. Climatic impacts of the wooden office building in different life stages.

3.2.1 Interpretation of the results – wood-structured office building

The carbon footprint of the wood-structured office building was reduced from that of the concrete-structured office building owing to the use of less carbon-intensive materials. The design solution uses wood, low-carbon steel beams and low-carbon concrete on the first floors, and low-carbon concrete products in the surface screeds. The biggest emission reduction potential was created by the use of a low-carbon delta beam and glulam beam whose carbon footprint is 7% less than that of the concrete-structured office. In addition, replacing the hollow-core slabs of intermediate floors with CLT-structured intermediate floors and the use of low-carbon concrete in the intermediate floor structure brought a considerable reduction of the carbon footprint (20% less emissions as compared to conventional concrete). The CLT-structured partitions and low-carbon surface screed bring a 5% reduction from the life-cycle footprint of the concrete-structured office building. Replacing the concrete columns with glulam columns allows cutting the carbon footprint of the wooden office building by just under one per cent as compared to the carbon footprint of the concrete-structured office building. Using low-carbon in-situ concrete in the ground floor structure brings a 0.1% reduction in the carbon footprint of the wood-structured office as compared to that of the concrete-structured office. The difference in size of the footprint caused by the exterior walls, windows and floor surface structures between the concrete and wooden office arises from the slightly bigger scope of the tower section in the concrete-structured office. The emissions from energy consumption are assumed to remain the same in both buildings. The overall life-cycle climatic impacts of the wood-structured office are 15% less than those of the concrete-structured office.

Figure 6 and Table 8 show the difference in the carbon footprint between the wood-structured and concrete-structured office. The table describes the difference in the carbon footprint of the structures which are different in the concrete-structured and wooden building.

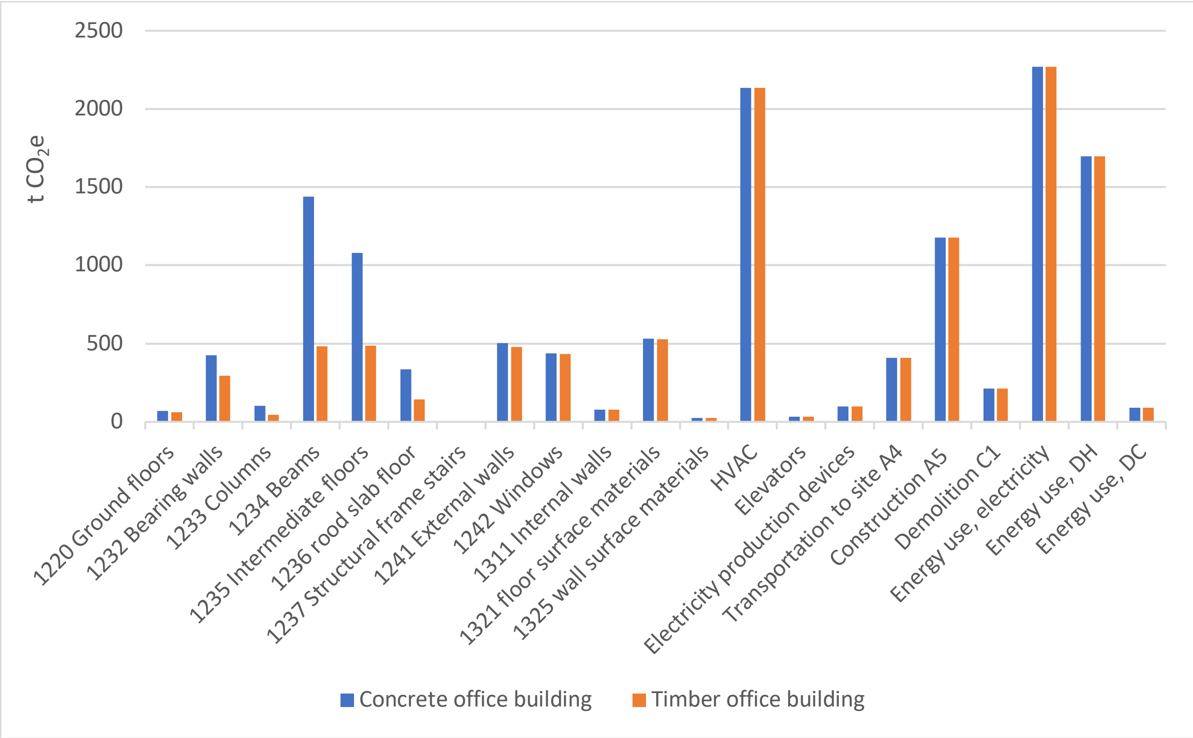

Figure 6. Life-cycle climatic impacts of concrete- and wood-structured office.

Table 8. Differences in the carbon footprints of concrete- and wood-structured office.

	Concrete-structured office building		Wood-structured office building		Difference in carbon footprint		Differ-ence in %
	$kgCO_2e/m^2/a$	tCO_2e	$kgCO_2e/m^2/a$	$t\ CO_2e$	$kgCO_2e/m^2/a$	tCO_2e	
1220 Ground floors	0.09	70	0.08	61	-0.01	-8.53	-12%
1232 Framing: Bearing walls	0.56	426	0.39	293	-0.18	-132.24	-31%
1233 Framing: Columns	0.14	103	0.06	47	-0.07	-55.94	- 55%
1234 Framing: Beams	1.91	1439	0.64	484	-1.27	-954.96	- 66%
1235 Framing: Intermediate floors	1.43	1080	0.64	485	-0.79	-595.50	-55%
1236 Framing: Roofing decks	0.44	334	0.19	145	-0.25	-188.83	- 57%
1241 Façades: External walls	0.67	502	0.63	478	-0.03	-23.83	-5%
1242 Façades: Windows	0.58	438	0.57	432	-0.01	-6.36	-1%
1321 Surface structures: Floor surfaces	0.71	533	0.70	527	-0.01	-6.16	-1%
1325 Surface structures: Wall surfaces	0.03	25	0.03	25	0.00	-0.01	0%
Unchanged structures and use of energy	10.87	8204	10.87	8204			
Total	**17.43**	**13 153**	**14.82**	**11 180**	**-2.61**	**-1972**	**-15%**

APPENDIX 1 –ENVIRONMENTAL DECLARATIONS USED

The life-cycle climatic impacts of the concrete- and wood-structured building were estimated using the construction emission database factors, except for the materials in Tables 9 and 10, which were calculated based on the product-specific EPDs.

Table 9. Environmental declarations used in the assessment of the climatic impacts of the concrete-structured office.

EPDs used in calculation of concrete-structured office	EPD	EPD number
Delta beam	EPD Deltabeam, Peikko Group Oy Deltabeam - Finland & Slovak Republic, EN 15804 Environmental product declaration, OneClickLCA Oy, 2015	RTS EPD 10
Thermoframed building	EPD Load bearing steel profile S350+Z	NEPD-1905-832-EN
Partition frames and -channels	EPD Gypsteel profiles	NEPD-1904-832-EN

Table 10. Environmental declarations used in the assessment of the climatic impacts of the wood-structured office.

EPDs used in the calculation of wood-structured office	EPD	EPD number
Delta beam	EPDDELTABEAM® Green, Painted	RTS_61_20
Thermoframed building	EPD Load bearing steel profile S350+Z	NEPD-1905-832-EN
Partition frames and -channels	EPD Gypsteel profiles	NEPD-1904-832-EN
Hollow-core slab	EPD LOW CARBON HOLLOW CORE SLAB CONSOLIS PARMA	RTS_116_21
CLT slab	EPD CLT (Cross Laminated Timber)	S-P-02033
LVL slab	EPD LVL (Laminated Veneer Lumber)	S-P-01730
LVL ribbed slab a	EPD LVL stressed skin panel	S-P-01732
Core elements of exterior walls and partition wall panels (load bearing)	EPD SOLID WALL CONSOLIS PARMA	RTS_151_21
Roofing deck insulation	EPD PAROC Stone Wool Thermal Insulation (eXtra) PAROC Building Insulation	NEPD-2392-1128-EN