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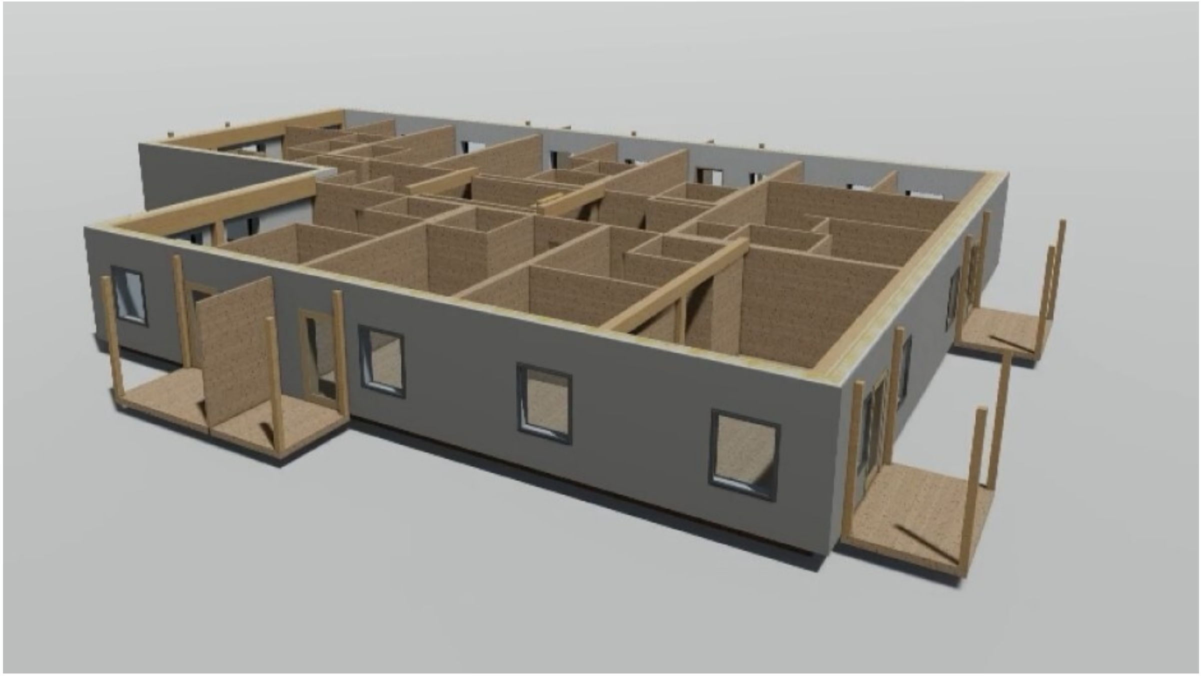

COMBIENT PURE

COMPARISON CALCULATIONS OF LOW-CARBON CONSTRUCTION – MULTI-STOREY APARTMENT BUILDING

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COMPARISON CALCULATIONS OF LOW-CARBON CONSTRUCTION – MULTI-STOREY APARTMENT BUILDING

Project	**Emission comparison calculation of low-carbon construction – multi-story apartment building**
Recipient	**Combient Pure, NCC & Stora Enso**
Document type	**Carbon footprint calculation report**
Version	**13 May 2022**
Prepared by	**Henna Näsänen**
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 a multi-story apartment building constructed from prefabricated concrete in Espoo and a modification of said project with the use of CLT concrete-wood elements. In addition, the carbon footprint of a multi-story building designed with a wooden structure from the beginning was calculated. This solution also had a concrete-structured first floor, but the solution is in the report referred to as a wood-structured solution to distinguish between the different design cases. This report discusses the calculated climatic impacts of all three design solutions (building of reinforced concrete, wooden building (conversion) and wooden building (optimized)). The surface area, scoping procedure and structural parts covered by the carbon footprinting of the concrete-structured and both wood-structured multi-story apartment buildings were the same to enable comparison.

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 apartment building, proportioned to the heated net area and assessment period, were 12.37 kg CO_2e/sq. m./a. The carbon footprint of the wood-structured apartment building (conversion) for the same period equaled 9.81 kg CO_2e/sq. m./a. The carbon footprint of the building site in the alternative solutions was 0.16 kg CO_2e/sq. m./a proportioned to the plot area and assessment period, but the calculation was made considering only a selected part of the structural elements included in the footprinting of the building site, and these were assumed to remain unchanged regardless of the design solution.

1.1 Basic information on assessed building

The basic data on the assessed building in the reviewed cases are gathered in Table 1. The concrete building is a typical building of reinforced concrete of which the exterior walls are concrete sandwich panels, the intermediate floors and roof decks built from hollow-core slabs, and the ground floor is a reinforced concrete slab on grade, load-bearing walls of reinforced concrete. The framing structures of the wooden multi-story building (conversion) are CLT slab structures, the first floor is similar to that of the concrete multi-story building. The framing structures of the optimized wooden multi-story building have a CLT slab structure, exterior walls of wood, and the first floor is similar to that of the concrete multi-story building. All cases had geothermal heating.

Table 1. Basic data on assessed building.

Name of building project	
Building ID code	-
Address	-
Building type	Multi-story apartment building
Year of completion	2022
Gross area	
Floor area	2500 sq. m.
Heated net area	3008 sq. m.
Number of floors	6
Number of basement floors	1
Service life of framing structures	Concrete building:100 years Wooden building (conversion & optimized): assumed 100 years
Main framing material	Concrete building: reinforced concrete Wooden building (conversion & optimized): CLT (concrete-structured within 1st floor)
Type of heating	Geothermal heat
Foundations	Strip foundation
Façade	Concrete building: Sandwich panels of concrete Wooden building, conversion: CLT + Plastering base Wooden building, optimized: Wood framing + Plastering base
Energy class	A
Estimated consumption of purchased energy	Electricity: 187 MWh
Plot area	3789 building-site sq. m.
Assessment prepared by	
Name	Henna Näsänen
Education	M.Sc. (Eng.)
Date of preparation of climate survey	28 March 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, only the ground floor and foundations were included of the plot structures in this review.

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.

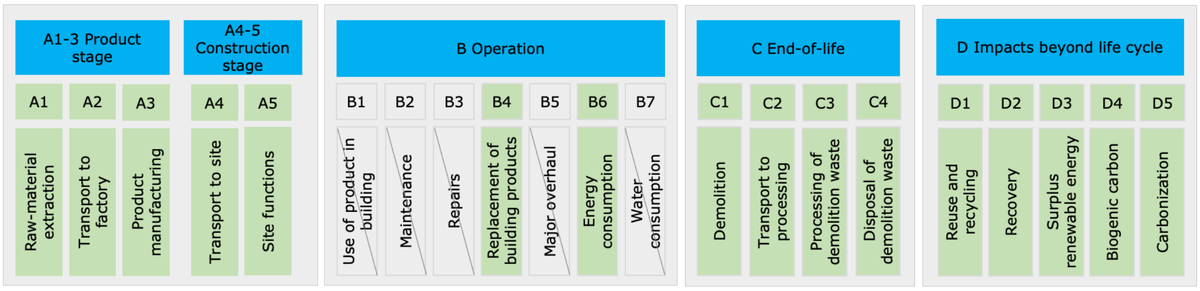

Figure 1. Life cycle phases of a building.

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 a combined model, structural types and NCC's estimated quantities of reinforcement and steel for the concrete multi-story building. The material flows of the wooden multi-story building (conversion) are based on preliminary structural types and a building information model. The material flows of the optimized wooden multi-story building are based on structural types and a preliminary building information model.
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, Stora Enso sawn timber and rock wool partition insulation Paroc).
2. As the secondary source of information – and in the estimated case, as the main source, since the exact product selections were not known – 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 46 kg CO_2e/sq. m. which is the value applicable to a multi-story residential building 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 7 kg CO_2e/sq. m. for a multi-story residential 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: combustion of plastic
    - Standard fittings, doors: combustion of wood
    - 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 multi-story building (conversion and optimized). The assessment of multi-story apartment 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, and the impact of excluded parts on the overall situation was insignificant. The scoping procedure of the calculation excluded the plot structures, the roof-mounted ventilation chamber, 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 multi-story building	Wooden multi-story building, conversion	Wooden multi-story building, optimized
Plot structures	111 Ground elements	-			
	112 Soil stabilization and reinforcement elements	-			
	113 Paved and green areas	-			
	115 Site constructions	-			
Load-bearing members	121 Foundations	x	Concrete basements	Kept the same	Kept the same
	122 Ground floors	x	Slab on grade	Kept the same	Kept the same
	1231 Civil defense shelters	x	Civil defense shelter of reinforced concrete	Civil defense shelter of reinforced concrete	Kept the same
	1232 Bearing walls	x	Reinforced concrete	CLT	CLT
	1233 Columns	x	Concrete columns	-	Glulam columns
	1234 Beams	x	Delta - and concrete beams	-	Glulam beams
	1235 Intermediate floors	x	Hollow-core slab, staircases massive slab	CLT slab	CLT slab
	1236 Roofing decks	x	Hollow-core slab	CLT slab	CLT slab
	1237 Structural frame stairs	x	Concrete stairs	CLT	CLT
	1241 External walls	x	Sandwich panel	1st floor similar to concrete building, other floors CLT slab.	Wood frame (non-bearing), 1st floor similar to concrete building
	1242 Windows	x	Wood-aluminum windows	Kept the same	Kept the same
	1243 External doors	x	Metallic external doors	Kept the same	Kept the same
	1250 External decks	x	Concrete balcony slabs and side panels	Balcony slabs and side panels of CLT slab	CLT slab and glulam columns
	1260 Roofs	x	Bitumen roof covering	Kept the same	Saddleback roof
Light-weight structures	131 Internal dividers	x	Steel-framed partitions, wet rooms of calcium silicate block	Kept the same	CLT
	132 Space surfaces (floors, ceilings, walls)	X (floors, walls)	Suspended ceilings and ceiling surface materials not considered in assessment.	Kept the same	Kept the same
	1331 Standard fittings	x	Kitchen equipment, cupboards	Kept the same	Kept the same
	134 Ducts and fireplaces	x	Concrete flues	Kept the same	Wooden flues
	135 Box units	x	Concrete bathroom module	Kept the same	Kept the same
Building service technology	Heating, water supply, sewerage, air-conditioning, cooling and electrical systems	x	Assessment for building services made based on surface area		Kept the same
	2511 Lifts	x	Assessed based on number of lifts	Kept the same	Kept the same

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

3.1 Concrete-structured multi-story building

The total life-cycle footprint of the concrete-structured multi-story building stood at 1,860 t CO_2e with the period of assessment of 50 years including the structural parts listed in Table 4. Table 4 presents the life-cycle climatic impacts of the concrete-structured multi-story building considering the climatic impacts specified separately for the building and the building site. The climatic impacts of the building and the building site 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 for the part of the building, and, applicable to the building site, to the building site surface area and period of assessment.

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.

	Building kg CO_2e/sq. m./a*	Building site kg CO_2e/sq. m./a**
A. Before operation	7.52	0.14
B. During operation	4.36	0.00
C. After operation	0.49	0.01
Carbon footprint total	**12.37**	**0.16**
D1 & D2 re-use, recycling and use as energy	*Could not be determined*	*Could not be determined*
D3. Surplus renewable energy	-	-
D4. Carbon storage effect	0	0
D5. Carbonization	*Could not be determined*	*Could not be determined*
Carbon handprint total	**0**	**0**

*Emissions of building are proportioned to heated net area of building (3008 sq. m.) and assessment period (50 years)

** Emissions of building site are proportioned to building site area (3789 sq. m.) and assessment period (50 years)

Table 5 and Figure 2 indicate the life-cycle climatic impacts of the concrete-structured multi-story building 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 concrete-structured multi-story building, i.e., the carbon footprint.

	Before use A1-A5	During use B4 +B6	After use C	Carbon footprint kg CO_2e/m²/a	Carbon footprint t CO2e
1210 Foundations*	0.04			0.05	9
1211 Foundations: Footings*	0.10		0.01	0.11	21
Carbon footprint of building site, total	**0.14**		**0.01**	**0.16**	**30**

Carbon footprint of building, total, t CO2e	**27**		**3**		
1220 Ground floors	0.05	0.00	0.00	0.05	8
1231 Framing: Civil defense shelters	0.37	0.00	0.03	0.39	59
1232 Framing: load-bearing walls	0.52	0.00	0.05	0.57	86
1233 Framing: Columns	0.01	0.00	0.00	0.01	2
1234 Framing: Beams	0.02	0.00	0.00	0.02	3
1235 Framing: Intermediate floors	1.38	0.00	0.10	1.48	222
1236 Framing: Roof decks	0.12	0.00	0.01	0.13	19
1237 Framing: Structural frame stairs	0.02	0.00	0.00	0.02	3
1241 Façades: Exterior walls	0.96	0.00	0.07	1.03	155
1242 Façades: Windows	0.34	0.00	0.01	0.35	52
1243 Façades: External doors	0.03	0.00	0.00	0.03	5
1250 External decks	0.19	0.00	0.02	0.20	31
1260 Roofing decks	0.23	0.02	0.00	0.25	37
1311 Partition walls: Partition walls	0.09	0.00	0.00	0.09	13
1315 Internal doors	0.04	0.00	0.00	0.04	7
1321 Surface structures: Floor coverings	0.12	0.13	0.00	0.25	38
1325 Surface structures: Walls.	0.01	0.01	0.00	0.02	3
1351 Box elements: Bathroom	0.23	0.09	0.01	0.33	50
1355 Box elements: Flue and duct components	0.23	0.00	0.02	0.25	38
1331 Standard fittings	0.16	0.14	0.01	0.3	46
Building service technology	0.89	0.25	0.02	1.15	172
2511. Lifts	0.06	0.06	0.00	0.11	17
A4 Transportation to building site (table value)	0.54			0.54	81
A5 Site functions (multi-story ap. building)	0.92			0.92	138
C1 Demolition (multi-story ap. buildings)			0.14	0.14	21
Electrical energy consumption		3.67		3.67	552
Building's carbon footprint, total, $kgCO_2e$/sq. m./a	**7.52**	**4.36**	**0.49**	**12.37**	**1 861**
Building's carbon footprint, total, t CO_2e	**1131**	**656**	**74**		
Share of total carbon footprint	**61%**	**35%**	**4%**		

*Climatic impacts proportioned to the building site area and heated net area.

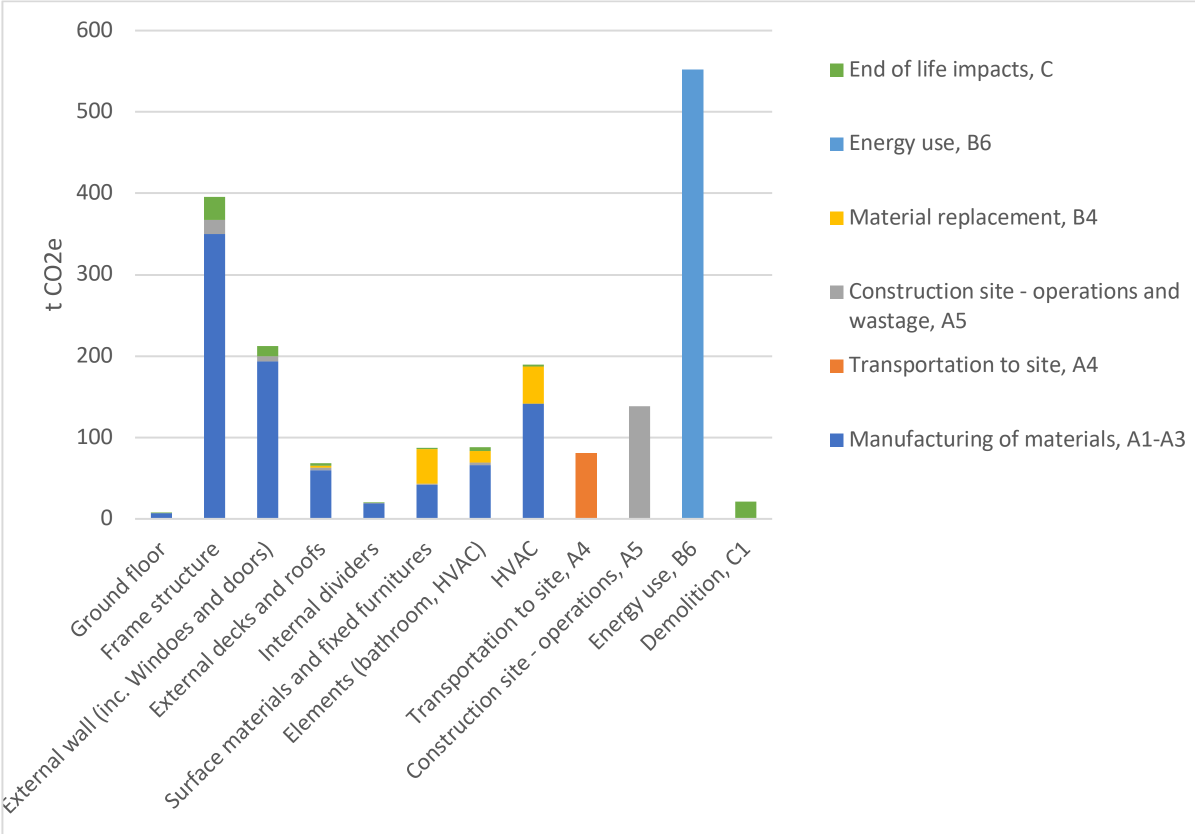

Figure 2. Life-cycle climatic impacts of the concrete-structured multi-story building (does not include emissions of the building site).

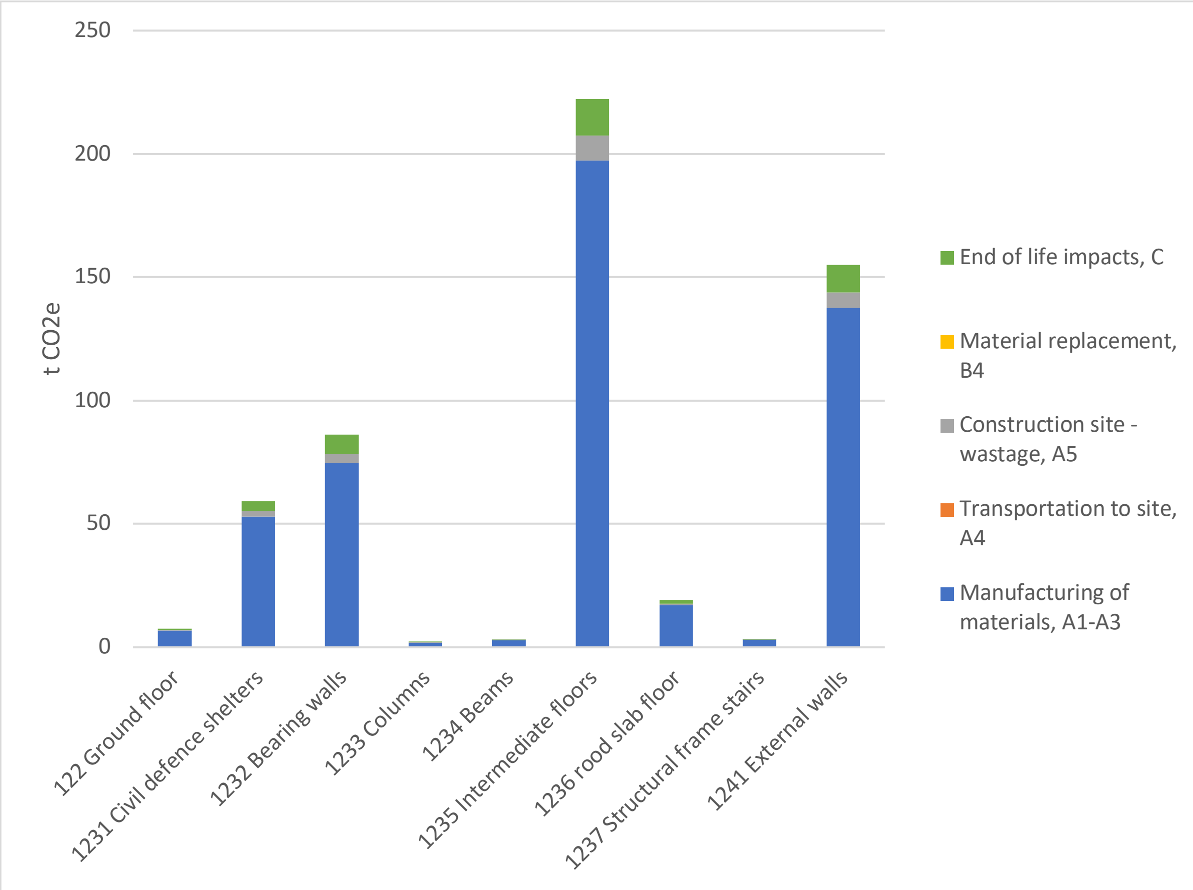

Figure 3. Climatic impacts of the framing structures of the concrete-structured multi-story building in different life stages.

3.1.1 Interpretation of the results – concrete-structured multi-story building

The assessment shows that a significant part (47%) of the life-cycle climatic impacts is caused by the manufacturing of building materials for the concrete-structured multi-story building. The biggest impact in the manufacturing emissions is attributable to the building's framing (22% of the life-cycle climatic impacts), exterior walls (12%), and building service technology (10%). The carbon-intensive concrete and steel products used raises the emissions for the part of the framing and the exterior wall structures. The emissions of the building service technology are as well increased due to the carbon-intensive manufacturing of steel products used in it.

Emissions of the operation stage correspond to totally 35% of the life-cycle climatic impacts. A considerable share of emissions in the operation stage consists of energy consumption (30%). The emissions of the operation stage 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 proportioned to the emissions of the energy consumption remains low (about 6%).

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 calculation of the site functions of a new building project carried out based on the values of the construction emission database is surprisingly high – over 7%.

3.2 Wood-structured multi-story building, conversion

The life-cycle climatic impacts of the wooden multi-story building (conversion) are presented separately for the building and the building site in Table 6. Figure 4 contains a breakdown of the climatic impacts from a converted wooden multi-story building by the structure, system and use of energy. Table 5 gives a more detailed listing of the life-cycle climatic impacts of framing structures. Table 8 presents the distribution of the climatic impacts by the Building 2000 Project Classification for the building parts that differ from those of the concrete-structured multi-story building.

Table 6. Results of 50 years' assessment on the climatic impacts of the wood-structured multi-story building (conversion).

	Building kgCO2e/sq. m./a*	Building site kgCO2e/sq. m./a**
A. Before operation	5.69	0.14
B. During operation	4.36	
C. After operation	0.38	0.01
Carbon footprint, total	**10.43**	**0.16**
D1 & D2 re-use, recycling and use as energy	*Could not be determined*	*Could not be determined*
D3. Surplus renewable energy	-	-
D4. Carbon storage effect	-4.76	0
D5. Carbonization	*Could not be determined*	*Could not be determined*
Carbon handprint total	-4.76	0

*Emissions of building are proportioned to heated net area of building (3008 sq. m.) and assessment period (50 years)

** Emissions of building site are proportioned to building site area (3789 sq. m.) and assessment period (50 years)

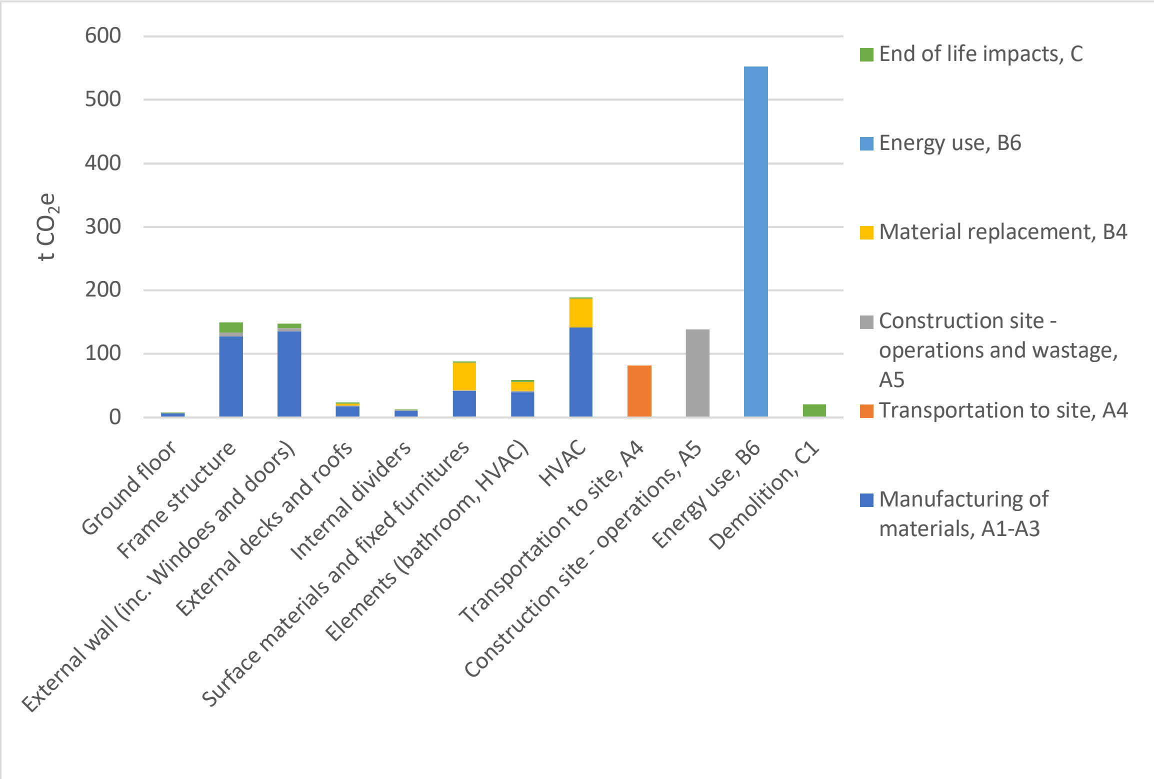

Figure 4. Life-cycle climatic impacts of the wood-structured multi-story building (conversion; does not include emissions of the building site).

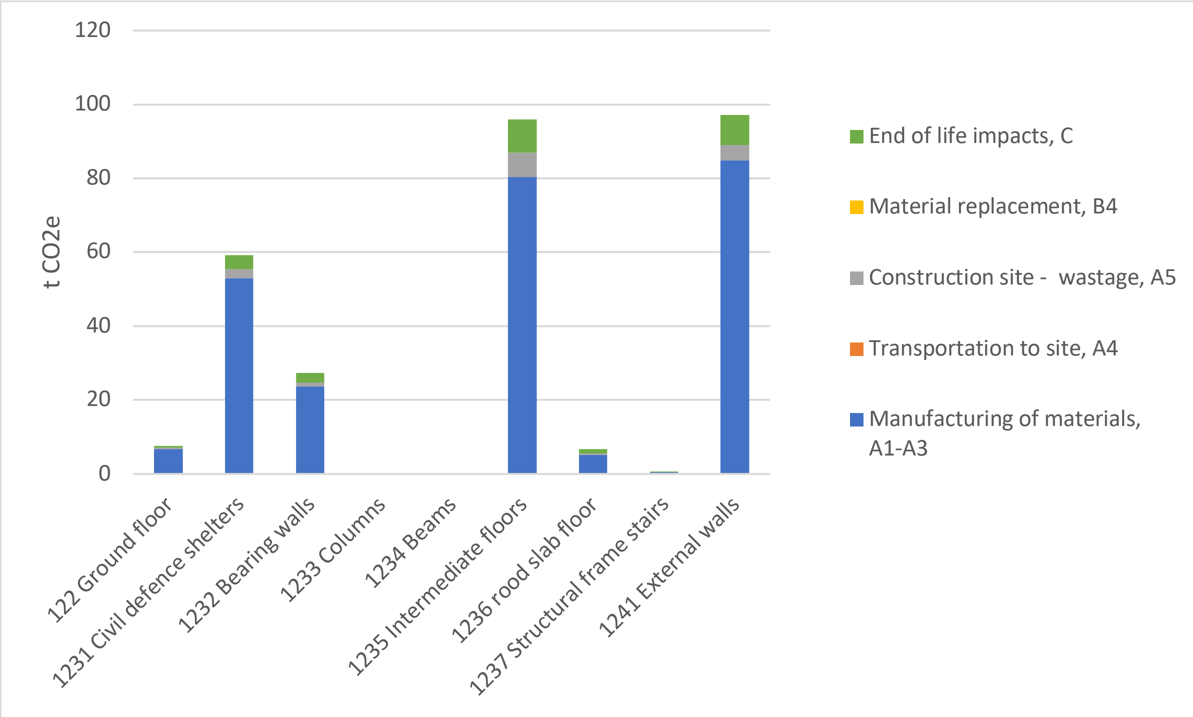

Figure 5. Climatic impacts of the framing structures of the wood-structured multi-story building (conversion) at different life stages.

3.2.1 Interpretation of the results – wood-structured multi-story building, conversion

The carbon footprint of the wood-structured multi-story building was reduced from that of the concrete-structured multi-story building owing to the use of a less carbon-intensive material, i.e., wood. The highest emission reduction potential was reached by replacing the hollow-core slabs of the intermediate floors with the CLT-structured intermediate floors. This gives a 7% reduction of the carbon footprint from that of the concrete-structured multi-story building. In addition, replacing the load-bearing walls and exterior walls with CLT allows cutting the emissions considerably from those of the whole-life carbon footprint of the concrete-structured multi-story building (a 6% reduction from the whole-life carbon footprint of the concrete-structured multi-story building). Replacing the roofing deck, balcony slabs and balcony side panels with CLT also reduces the emissions from those of the concrete-structured multi-story building, but the reduction is not as significant as that achieved with the use of the above-mentioned structures. The emissions from energy consumptions are assumed to remain the same in both buildings. The overall life-cycle climatic impacts of the wood-structured multi-story building are 16% less than those of the concrete-structured multi-story building.

3.3 Wooden multi-story building, optimized

The life-cycle climatic impacts of the optimized wooden multi-story building are presented separately for the building and the building site in Table 7. Figure 6 contains a breakdown of the climatic impacts from the optimized wooden multi-story building by the structure, system and use of energy. Table 7 gives a more detailed description of the life-cycle climatic impacts of framing structures.

Table 7. Results of 50 years' assessment on the life-cycle climatic impacts of the wooden multi-story building (optimized).

	Building $kgCO_2e/m^2/a$*	Building site $kgCO_2e/m^2/a$**
A. Before operation	5.08	0.14
B. During operation	4.37	0.00
C. After operation	0.35	0.01
Carbon footprint, total	**9.81**	**0.16**
D1 & D2 re-use, recycling and use as energy	Could not be determined	*Could not be determined*
D3. Surplus renewable energy	-	-
D4. Carbon storage effect	-3.84	0
D5. Carbonization	*Could not be determined*	*Could not be determined*
Carbon handprint total	-3.84	0

*Emissions of building are proportioned to heated net area of building (3008 sq. m.) and assessment period (50 years)

** Emissions of building site are proportioned to building site area (3789 sq. m.) and assessment period (50 years)

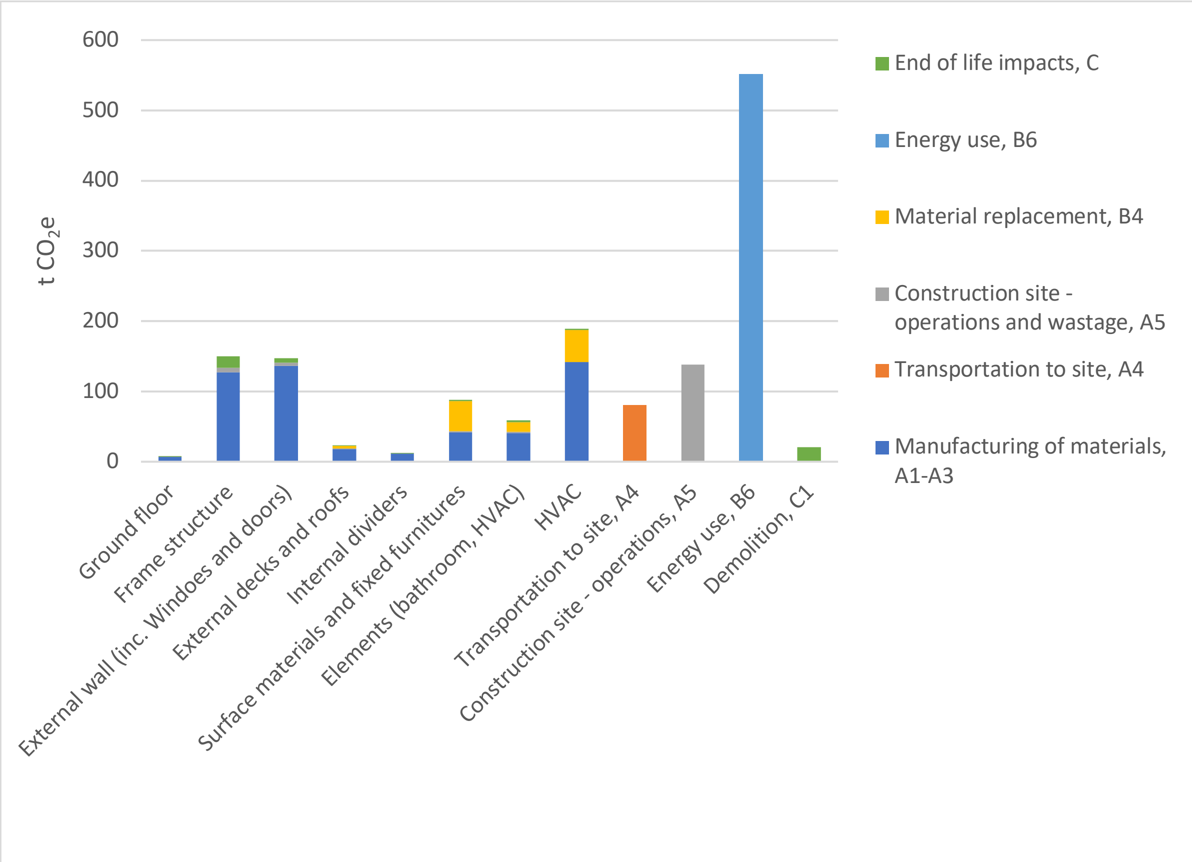

Figure 6. Life-cycle climatic impacts of the wooden multi-story building (optimized; does not include emissions of the building site).

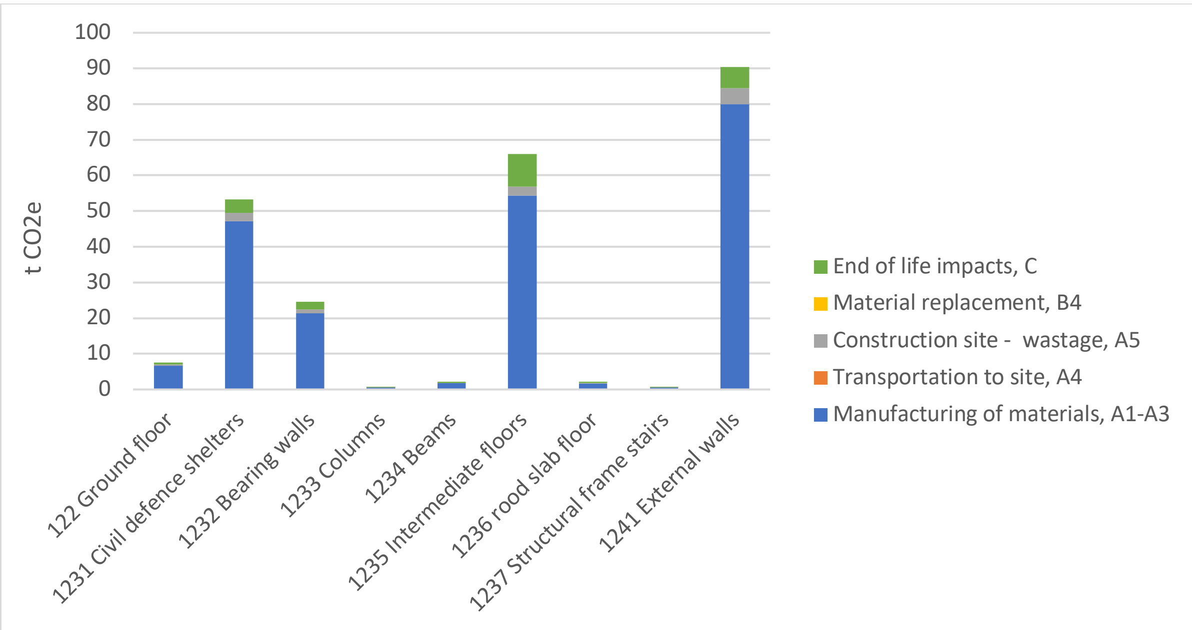

Figure 7. Climatic impacts of the wooden multi-story building (optimized) in differfent life stages.

3.3.1 Interpretation of the results – wood-structured multi-story building, optimized

The carbon footprinting of the optimized wood-structured multi-story building was carried out based on a project that had been originally designed as a wood-structured building. The carbon footprint of the wood-structured multi-story building was reduced from that of the concrete-structured multi-story building owing to the use of a less carbon-intensive material, i.e., wood. A considerable emission reduction potential was reached based on the carbon footprinting of the wooden multi-story building and the concrete-structured multi-story building when the hollow-core slabs of the intermediate floors were replaced with the CLT-structured intermediate floors. (An 8% reduction of the carbon footprint from that of the concrete-structured multi-story building). An additional 3% reduction of the building’s carbon footprint can be reached by replacing the concrete structures of the (non-load-bearing) external walls with wooden structures. With CLT-structured load-bearing walls, a 3% reduction can be achieved from the life-cycle carbon footprint of concrete-structured multi-story apartment building. The roofing deck and roof structures also reduce the emissions, their impact is 2% less than the emissions of the concrete-structured multi-story building. It should be noted that the partition division of the wood-structured multi-story building did not fully correspond to the one used in the concrete-structured multi-story building. The emissions from energy consumption were assumed to remain unchanged in both the concrete- and wood-structured multi-story apartment buildings. However, the energy emissions of the wood-structured multi-story building can depart from those of the concrete-structured multi-story building depending, i. a., due to the better U value of the exterior wall in the wood-structured multi-story building as compared to that in the concrete-structured multi-story building. The overall life-cycle climatic impacts of the wood-structured multi-story building are 21% less than those of the concrete-structured multi-story building.

The intermediate floor solution of the optimized wooden multi-story building gives a 2% reduction from the carbon footprint of the converted wooden multi-story building. Both of the calculated projects used CLT as the load-bearing structure for the intermediate floors, but the cement-based poured levelling on the intermediate floors of the converted wooden multi-story building is thicker than the Plaanovalu type of levelling of the optimized wooden multi-story building. The converted wooden multi-story building also contains a 100 mm gravel course which is absent from the intermediate floor stuctures of the optimized wood-structured multi-story building. Apart from the intermediate floor structure, an additional reduction from the carbon footprint of the converted wood-structured multi-story building is brought by the roofing deck structure of the wood-structured multi-story building (about 1% reduction). The load-bearing roof decking structure is CLT (240 mm), and LECA is used instead of rock wool in the roof structure. The CLT-structured bearing- and non-bearing walls of the optimized wooden multi-story building allow cutting down the carbon footprint by one per cent from that of the converted wooden multi-story building. Both projects have load-bearing partitions of CLT, but the scope of the bearing- and non-bearing partition is distributed differently in each project, and the number of non-bearing walls in the optimized wood-structured multi-story building is smaller than that of the converted wood-structured multi-story building. The overall carbon footprint of the optimized wood-structured multi-story building is 6% smaller than that of the converted wood-structured multi-story building.

3.4 Summary of the results of carbon footprinting of the different building types – multi-story apartment building

Figure 8 describes the whole-life carbon footprint of the concrete-d and wood-structured (converted and optimized) multi-story apartment buildings. The carbon footprint of a wooden multi-story building (converted) is 16%, and of the optimized multi-story building 21%, smaller than the life-cycle carbon footprint of the concrete-structured multi-story building. When assessing only those emissions which are created before the operation stage, the carbon footprint of the converted wood-structured multi-story building is 24%, and of the optimized multi-story building 32%, smaller than the emissions created by the concrete-structured multi-story building before the operation stage.

Concrete-structured multi-story building
Wood-structured multi-story building, conversion
Wood-structured multi-story building, optimized

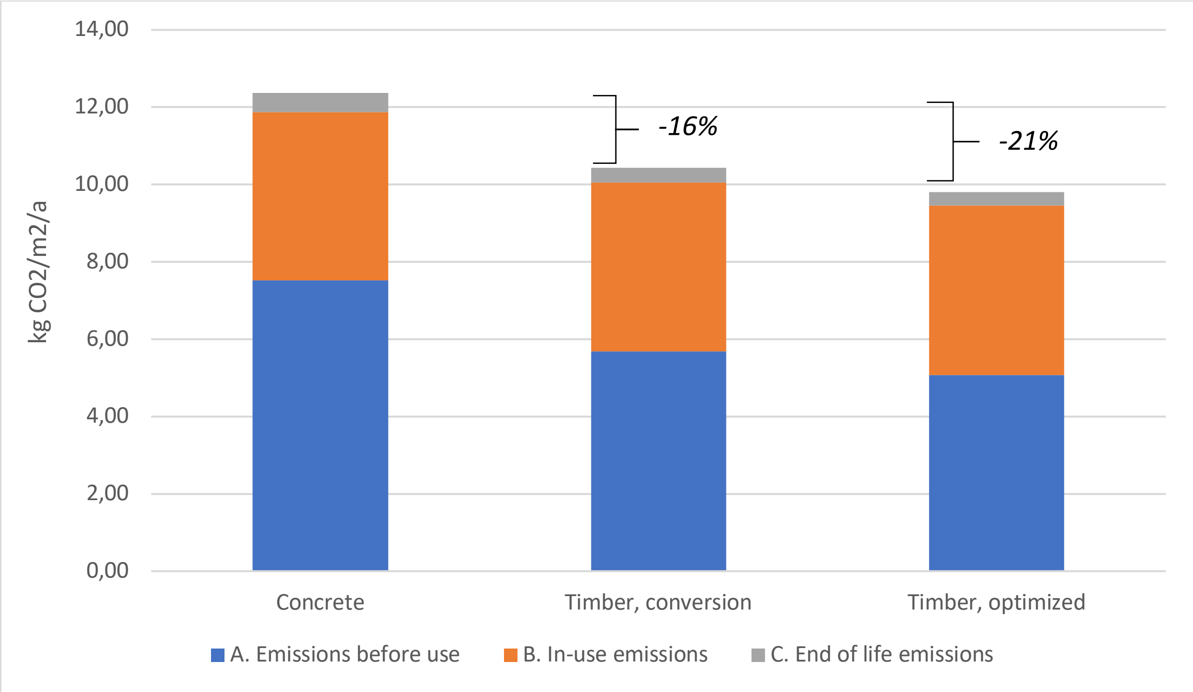

Figure 8. Carbon footprint of concrete- and wood-structured multi-story apartment buildings in different life stages (does not include carbon footprint of the building site).

Table 8 comprises a more detailed description of how the carbon footprint of the differing structures is formed, following the itemization as per the Building 2000 Project Classification. The carbon footprint of the converted wood-structured multi-story building was assessed based on a project which was modified from a concrete-structured multi-story building into a CLT structured multi-story apartment building. The optimized wood-structured multi-story building was originally designed with a wooden structure, and its structures differ from those of the converted wood-structured multi-story building and the concrete-structured multi-story building. Such structural differences occurred i. a. in the intermediate floor- and roof decking structures, in the partition- and exterior wall structures as well as in the wood-structured flues of the optimized wood-structured multi-story building.

Table 8. Results of carbon footprinting of the concrete-structured, converted and optimized wood-structured multi-story buildings and the percentage difference between the carbon footprints of wood- and concrete-structured multi-story buildings.

Building2000 - classification	Concrete multi-story building	Wooden multi-story building, conversion	Difference %	Wooden multi-story building, optimized	Difference %
1220 Ground floors	8	8		8	
1231 Framing: Civil defense shelters	59	59		59	
1232 Framing: load-bearing walls	86	27	-68%	25	-71%
1233 Framing: Columns	2		-100%	1	-69%
1234 Framing: Beams	3		-100%	2	-25%
1235 Framing: Intermediate floors	222	96	-57%	66	-70%
1236 Framing: Roof decks	19	7	-65%	2	-89%
1237 Framing: Structural frame stairs	3	1	-82%	1	-77%
1241 Façades: Exterior walls	155	97	-37%	90	-42%
1242 Façades: Windows	52	52		52	
1243 Façades: External doors	5	5		5	
1250 External decks	31	3	-89%	3	-89%
1260 Roofing decks	37	37		20	-46%
1311 Partition walls: Partition walls	13	13		5	-63%
1315 Internal doors	7	7		7	
1321 Surface structures: Floor coverings	38	38		40	4%
1325 Surface structures: Walls.	3	3		2	-23%
1351 Box elements: Bathroom	50	50		50	
1355 Box elements: Flue and duct components	38	38		9	-77%
1331 Standard fittings	46	46		46	
Building service technology	172	172		172	
2511. Lifts	17	17		17	
A4 Transportation to building site (table value)	81	81		81	
A5 Site functions (multi-story ap. building)	138	138		138	
C1 Demolition (multi-story ap. buildings)	21	21		21	
Electrical energy consumption	552	552		552	
Carbon footprint of building	**1861**	**1569**		**1475**	
kg CO2e/m2/a	**12,37**	**10.43**		**9.81**	
% difference		**-16%**		**-21%**	

APPENDIX 1 – ENVIRONMENTAL DECLARATIONS USED

The life-cycle climatic impacts of the concrete-, converted and optimized wood-structured multi-story buildings were estimated using the construction emission database factors, except for the materials in Tables 9, 10 and 11, 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 multi-story building.

EPDs used in calculation of concrete-structured multi-story building	EPD	EPD number
Petra – hollow-core slab brackets	Steel brackets, for hollow core slab, 7850 kg/m3, linear mass 15.3-41.8 kg/m, PETRA® Green (Peikko)	RTS_106_21
Steel – delta beam	Slim-floor composite steel beam, DELTABEAM (Peikko, Lahti and Kralova nad Vahom plants)	RTS EPD 10
Partitions – steel framed walls	Galvanized steel joists for drywall, Steel type: X51D+ Z 100 g/m2, steel sheet: 0.5 mm, Gypsteel ELPR, ELR, GK, GKC, SLIM, SK, SKP, SKF, SKE, SKT, ATR, XR. (Lundell)	NEPD-1904-8332-EN
Partitions – Paroc Sonus	Stone wool insulation, 36 mm, 29.5 kg/m3, 1.06 kg/m2 (for R=1 Km2/W), Lambda=0.036 W/(m.K), eXtra (Paroc)	NEPD-2392-1128-EN

Table 10. Environmental declarations used in the assessment of the climatic impacts of the wood-structured multi-story building (conversion).

EPDs used in the calculation of wood-structured multi-story building (conversion)	EPD	EPD number
Sawn timber	EPD Classic Sawn by Stora Enso	S-P-02150
CLT structures	Galvanized steel joists for drywall, Steel type: X51D+ Z 100 g/m2, steel sheet: 0.5 mm, Gypsteel ELPR, ELR, GK, GKC, SLIM, SK, SKP, SKF, SKE, SKT, ATR, XR. (Lundell)	NEPD-1904-8332-EN
Partition – steel framed walls	Galvanized steel joists for drywall, Steel type: X51D+ Z 100 g/m2, steel sheet: 0.5 mm, Gypsteel ELPR, ELR, GK, GKC, SLIM, SK, SKP, SKF, SKE, SKT, ATR, XR. (Lundell)	NEPD-1904-8332-EN

Partitions – Paroc Sonus	Stone wool insulation, 36 mm, 29.5 kg/m3, 1.06 kg/m2 (for R=1 Km2/W), Lambda=0.036 W/(m.K), eXtra (Paroc)	NEPD-2392-1128-EN

Table 111. Environmental declarations used in the assessment of the climatic impacts of the wood-structured multi-story building (optimized).

EPDs used in the calculation of wood-structured multi-story building (optimized)	EPD	EPD number
Sawn timber	EPD Classic Sawn by Stora Enso	S-P-02150
CLT structures	EPD CLT (Cross Laminated Timber)	S-P-02033
LVL frame	EPD LVL (Stora Enso)	S-P-01730
Partitions – acoustic spring frame	EPD Gyproc Steel Profiles and Accessories, ver. 2	S-P-00782, ver.2
External wall insulation	EPD ISOVER RKL-31 Facade 50 mm	
Balcony water proofing Protan G	EPD Protan G 1.5 Protan AS	NEPD-1747-723-NO