Comparison of a concrete and wooden school – examinations based on carbon footprint

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1 Introduction

This report presents calculation results on carbon footprint impacts in comparable school buildings with wooden or concrete structures. The publication was prepared as part of Tampere University's CE Wood (Kiertotalous – Uusia mahdollisuuksia puurakennusteollisuudelle) research project. The aim of the CE Wood research project is to improve the competitiveness of regional wood construction companies on international markets. Within the framework of the project, Tampere University's area of responsibility is to increase know-how related to technical solutions and methods among relevant companies. The project was funded under the Botnia Atlantica programme's operations focusing on economic life.

The efforts are a continuation of the "Purkaa vai korjata" (Purkuko) research project, which was commissioned by the Ministry of the Environment and carried out by Tampere University and VTT Technical Research Centre of Finland (Huuhka, S. et al., 2021). The objective of the Purkuko research project has been to collect and produce information on the carbon footprint effects of renovation in comparison to demolition and new construction. The cases and calculations selected and prepared for the Purkuko project serve as the initial data for this case study, which focuses exclusively on comparing newly-constructed buildings.

Comparison of a concrete and wooden school – examinations based on carbon footprint

2 Method

2.1 Carbon footprint

A comparative case study examining school buildings was conducted within the scope of the CE Wood research project. For the purposes of the case study, the carbon footprint calculation was based on the Ministry of the Environment's method for assessing the carbon emissions of buildings (hereinafter "MoE method") (Ministry of the Environment, 2019). The carbon footprint calculation covers all life cycle phases: product stage, construction process stage, use stage and end of life stage (Figure 1).

The product phase material volumes were calculated using building information models (BIMs) created in ArchiCAD, and the emissions were estimated with the One Click LCA software. Correspondingly, in-service energy consumption for all compared cases was simulated based on a building information model with the IDA ICE 4.8 software, using a dynamic calculation method. The calculations for each case include the E-value kWh_E/m^2a and consumption of delivered energy kWh/a, under which district heating, district cooling and electricity consumption were specified. Energy efficiency was calculated based on standardised use in accordance with the purpose of use category 6 in Ministry of the Environment Decree 1010/2017 (Education and training buildings and daycare centres). The energy efficiency of new buildings meets the E-value limit laid down in Decree 1010/2017 (education and training buildings 100 kWh_E/m^2a; the requirement is 10% higher for solid wood buildings) and the requirements of the heat loss compliance calculation.

The actual carbon footprint calculation was conducted in the One Click LCA software using an analysis period of 50 years. The calculation takes into account in-service energy consumption as well as the carbon footprint ($kgCO_2e$) of materials used throughout the analysis period. The material emissions were selected from emission databases to correspond as well as possible with solutions commonly used in Finland.

In accordance with the MoE method, a life cycle carbon handprint was also calculated for the cases. Instead of deducting it from the carbon footprint, the carbon handprint has been presented alongside the footprint. The assessment of the carbon handprint entails the net benefits of climate impacts that would not be generated without the construction project. These can include the building's carbon stores and carbon sinks, extra renewable energy produced over the building's life span, and benefits created by virtue of reusing or recycling construction products (Ministry of the Environment, 2019, p. 30).

The method involves assumptions about the emission factors of electricity and district heating, which are expected to reduce their carbon emissions by 94% and 83%, respectively, by the year 2070. The reduction of carbon emissions was considered in ten-year periods (Ministry of the Environment, 2019, p. 46).

Tabulated values compliant with the MoE method were used in the emission calculations for phases A4 (transport to worksite), A5 (operations at a new building's construction site), B3-4 (energy consumption of repairs), C1 (operations at a deconstruction site), C2 (transport to further processing) and C3–4 (waste processing and disposal) (Ministry of the Environment, 2019, Appendix 3). Refurbishments (B5) were taken into account based on the technical life spans of various building components and Building Information File 18-10922 (Rakennustieto, 2008).

Some delineations deviating from the MoE method were used in the calculation (cf. Ministry of the Environment, 2019, p. 18). Since the aim was to focus the calculation on the building, site development measures (ground structures, supports and reinforcements, paving and area structures) were excluded from the calculation. As regards supplementary structures, surface structures and typical fixtures were left out of the calculation. These were assumed to be mostly identical in both schools since the buildings are of the same size. This means that the results are only mutually comparable.

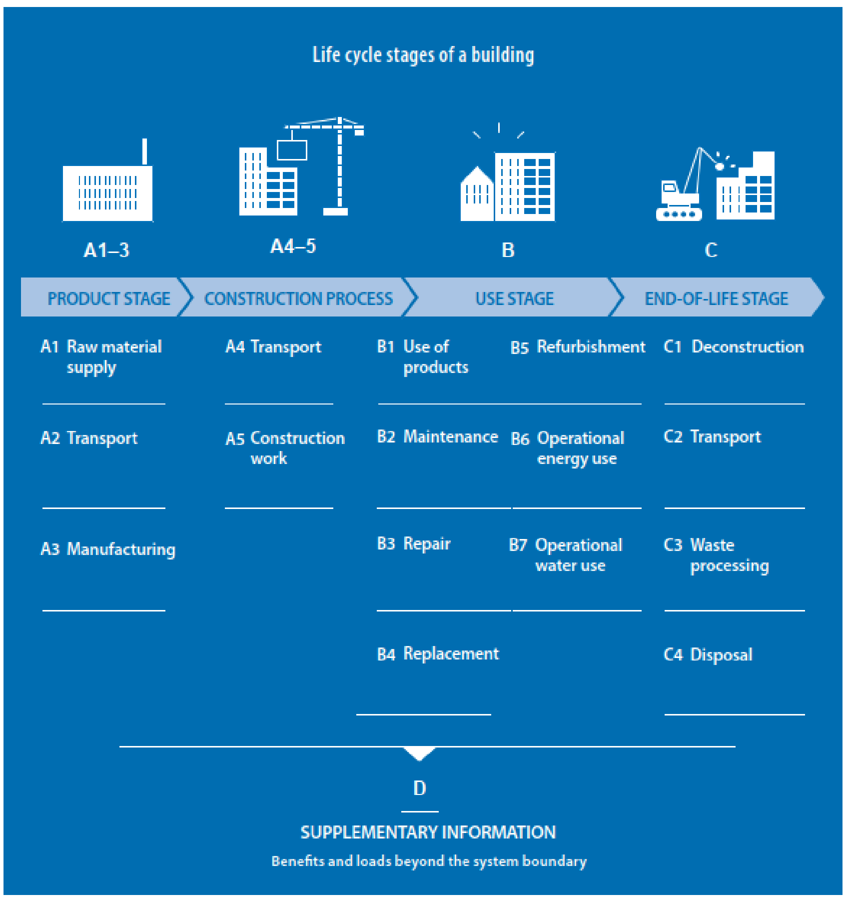

Figure 1. Building's life cycle phases (Ministry of the Environment, 2019, p.14).

Comparison of a concrete and wooden school – examinations based on carbon footprint

3 Case study: comparison of a concrete and wooden school

3.1 Case preparation

The model for the school buildings included in the case study was the new building constructed for Tesoma School in Tampere (completed in 2018, Figure 2). For the purposes of the calculation, two separate school buildings were formed based on Tesoma School's geometry: a large version and a smaller version for calculation. The building modelling and surface area calculation were simplified when preparing the calculation cases. For example, the ventilation machine rooms on the roofs and underground shafts were excluded from the building geometry. For building systems, the square-metre-based tabulated values of the MoE method were used with the net heated area (Ministry of the Environment, 2019, Appendix 2).

Figure 2. Tesoma School in Tampere. Photo Antti Lakka.

The structural types of both cases were adjusted to match typical and commonly-used structures. The concrete school structures are from the existing Tesoma School building. The wooden school structures were selected from among the CLT structure types of projects completed by Hoisko CLT (CLT Finland Oy), in cooperation with Hoisko CLT's specialists. For the wooden school, the structural types were changed to wooden structures only to the extent that this was justified and possible without modifying the original plan. The load-bearing structures, such as the exterior walls, columns, beams, intermediate floors and roof structures, were implemented as wooden, CLT or glulam structures in accordance with Table 1. As regards partition walls, plasterboard partition walls were replaced with CLT walls. Other partition walls, such as concrete load-bearing stairwells, sand lime masoned wet room walls and load-bearing walls of exterior platforms, were kept intact. This also applies to stairs, balconies and civil defence shelter structures. For example, the steel grille cladding of exit route stairs and the steel-framed glass walls in lobby areas can be regarded as essential parts of the architectural design, which is why the materials were not replaced in the wooden school. The structures, floor spans, and beam and column lines for the concrete school were taken from the existing school. In the concrete building, the wing width of the building mass varies between 15 and 20 m. Each wing has been divided into two parts with a beam and column line. In the wooden school, the span of the wooden floors has been assumed to be shorter at roughly 6–8 m, which is why load-bearing

Comparison of a concrete and wooden school – examinations based on carbon footprint

beam and column lines have been added to the building. The column size was adjusted to make it more realistic, even though an actual structural dimensioning was not conducted. In other words, the added columns and their foundations were taken into account in material calculations but not in spatial design. The spaces of the buildings were not modified, but the quantities of the construction materials used in the calculation were impacted by the structural thicknesses of the respective cases. For example, the wooden building's thinner intermediate floor results in a increased partition wall area when the floor height is maintained, and the thinner exterior walls result in a decreased outer wall area when the net heated area is maintained. More specific structural type lists are presented in Appendix 1.

Table 1. Structures used in the cases.

Building section	Concrete school	Wooden school
Frame	Precast concrete panel structure, some concrete beams and columns	CLT structure, some glulam beams and columns
Facades	Brick-tiled and painted concrete panels, some glass and steel grilles	Wood-cladded solid CLT elements, some glass and steel grilles
Roof	Wooden load-bearing structures, rubberised bitumen membrane coating	Wooden load-bearing structures, rubberised bitumen membrane coating
Ceiling	Hollow-core slabs, mineral wool insulation	Glulam beams, wood fibre insulation
Intermediate floors	Hollow-core slabs	CLT floor slabs
Walls in contact with soil	Concrete panels, exterior water insulation	Concrete panels, exterior water insulation
Base floor	In-situ cast concrete slab in soil contact and with heat insulation under it	In-situ cast concrete slab in soil contact and with heat insulation under it
Partition walls	Steel-framed, masoned and concrete partition walls	CLT partition walls, masoned and concrete partition walls
Building systems	Typical building systems, no sprinklers	Typical building systems, sprinklers

Both versions use the reference values specified in Decree 1010/2017 and the standardised use of the relevant category. In heat loss equalisation, compliance was achieved thanks to an air tightness that is

Comparison of a concrete and wooden school – examinations based on carbon footprint

higher than the reference value (2 for both versions). The cold bridges were found to be identical in both buildings. Table 2 presents the most essential initial data used in energy calculation. The extents of the building versions are listed in Tables 3 and 6.

Two separate comparisons were prepared from the results. The first comparison examines the emissions of a small concrete school compared to a wooden school of the same size. The second comparison features a school that is four times the size of the building in the first comparison. More detailed initial data for the cases is provided in Chapters 3.2. and 3.3.

Table 2. Initial data for energy calculation.

Initial data for energy calculation			
Name and description	Unit	Concrete school	Wooden school
Structure properties			
Air tightnessq50)		2	2
U-values of structures			
Exterior wall	W/(m²K)	0.19	0.39
Exterior wall, basement	W/(m²K)	0.17	0.17
Ceiling	W/(m²K)	0.09	0.097
Base floor	W/(m²K)	0.16	0.16
Doors	W/(m²K)	1.00	1.00
Windows	W/(m²K)	1.00	1.00
Window properties			
U-value of glass	W/(m²K)	0.90	0.90
U-value of frame	W/(m²K)	2.00	2.00
Frame area fraction		0.10	0.10
g-value of windows		0.54	0.54
Equipment, ventilation			
Annual efficiency of air supply unit's heat recovery	%	55	55
Supply air temperature set point	°C	18	18
Specific fan power/SFP	kW/m³/s	1.8	1.8
Minimum temperature of exhaust air	°C	3	3
Standard air flow, education building	dm³/(s m²)	3	3
Type of heating		District heating	District heating

3.2 Comparison 1: small concrete school compared to a wooden school of the same size

The first pair for comparison includes a small concrete-framed school building and wooden-framed school building of the same size (Figure 3). For the first pair, a smaller version of Tesoma School's geometry was prepared using a single L-shaped wing. In accordance with the MoE method, the net heated area (2,412 m^2) was used as the reference area.

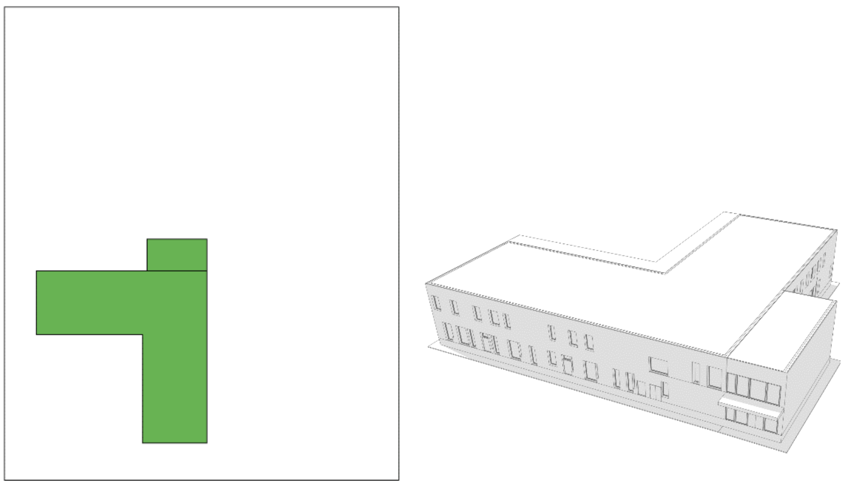

Figure 3. Illustrations of the buildings being compared: building footprint and perspective drawing.

Table 3. Extent details for comparison 1.

Extent details			
Name and description	Unit	Concrete school, small	Wooden school, small
Net heated area	m²	2,412	2,412
Floor area	m²	2,597	2,550
Volume	m3	10,655	10,483
Geometry		As per drawings	As per drawings
Floors	pcs	2	2

Comparison of a concrete and wooden school – examinations based on carbon footprint

3.2.1 Carbon footprint

The results of the carbon footprint calculation are formed by the itemised results of the energy calculation and the results of the life cycle carbon footprint calculation. The results also separate the carbon handprint, which in this comparison is formed by the reuse of materials and the organic carbon bound to construction materials. In wood-based products, concentration of organic carbon has been estimated to be 50% of the dry weight, in accordance with the MoE method.

The results of the energy calculation (Table 4) serve as inputs for the calculation of the life cycle carbon footprint.

Table 4 and Figure 4 indicate that the energy efficiency (E-value) of the small wooden school is lower than that of the small concrete school. The wooden school's E-value and consumption of delivered energy are 5% and 8% higher, respectively, than for the concrete school. This is primarily due to the lower U-values of the wooden building's exterior walls.

Table 4. Energy calculation results for comparison pair 1.

In-service energy			
Name and description	Unit	Concrete school, small	Wooden school, small
E-value	$kWh_E/(m^2a)$	98	103
E-value, concrete vs. wood	%	100%	105%
District heating, heating and domestic hot water	kWh/a	203,327	229,456
District cooling	kWh/a	21,857	22,942
District heating total	kWh/a	225,184	252,398
Electricity	kWh/a	106,024	105,996
Delivered energy total	kWh/a	331,208	358,394
Delivered energy / m² /a	kWh/m²/a	137	149
Electricity's share of delivered energy	%	32%	30%
Delivered energy, concrete vs. wood	%	100%	108%

The results of the carbon footprint calculation are presented in Table 5 and Figure 4. Despite the better energy efficiency, the total carbon footprint of the small concrete school over a 50-year analysis period is about 10% higher than of the wooden school.

Comparison of a concrete and wooden school – examinations based on carbon footprint

Table 5. Carbon footprint calculation results for comparison pair 1.

Carbon footprint			
Name and description	Unit	Concrete school, small	Wooden school, small
Carbon footprint kg CO_2e /m² /a	kg CO_2e /m²/a	16.96	15.30
Carbon handprint kg CO_2e /m² /a	kg CO_2e /m²/a	-3.90	-12.42
Carbon footprint kg CO_2e /m² for the analysis period	kg CO_2e /m²	848	765
Carbon handprint kg CO_2e for the analysis period	kg CO_2e	2,046,000	1,845,000
Carbon footprint kg CO_2e concrete vs. wood	%	100%	90%

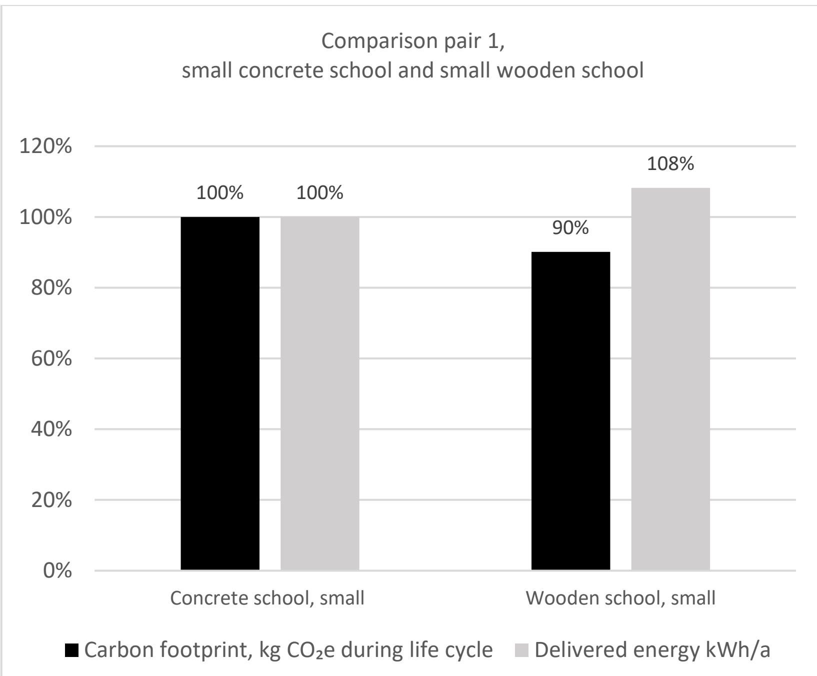

Figure 4. Results for comparison pair 1.

When examining emissions across the analysis period as a function of time, it is found that the emission levels of the concrete school and wooden school are furthest apart at the start of the analysis period, and that the gap decreases towards the end of the period (Figure 5). The difference between the product and construction phases (A1–A5) of the small wooden school and small concrete school is about 36%. Despite the better energy efficiency of the concrete school, the graphs do not intersect during the analysis period

Comparison of a concrete and wooden school – examinations based on carbon footprint

(50 years), meaning that the wooden school remains at lower carbon levels through the entire analysis period. Of the small wooden school's emissions, only about 30% are generated by the product and construction process stages, 66% by the use stage and 4% by the end of life stage.

Of the small concrete school's carbon footprint, 41% is formed by the product and construction process stage, 55% by the use stage and 4% by the end of life stage. The small wooden school's carbon handprint is substantially larger than that of the small concrete school. The carbon handprint is presented with a minus symbol in Table 5 and Figure 7.

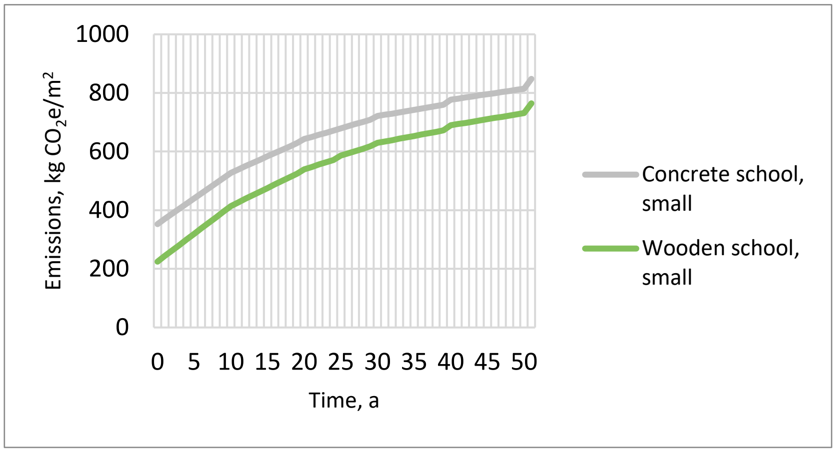

Figure 5. Carbon footprint as a function of time: small concrete school and small wooden school.

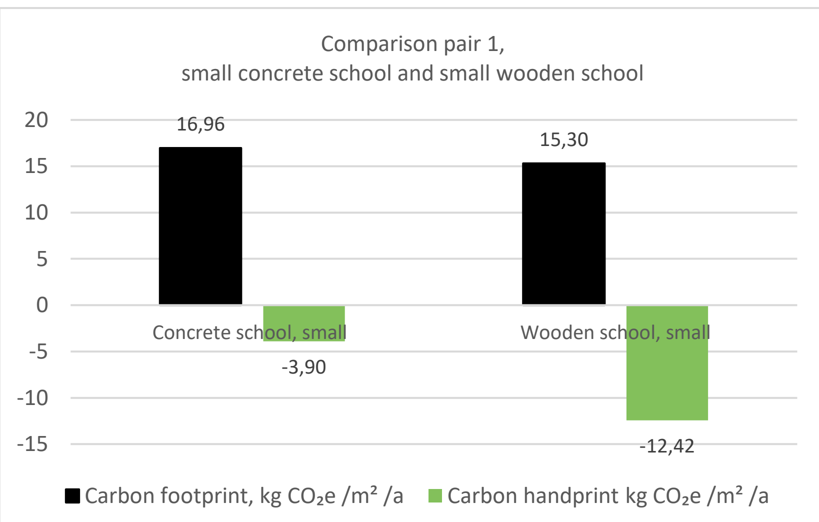

Figure 6. Carbon footprint and carbon handprint, comparison pair 1.

Comparison of a concrete and wooden school – examinations based on carbon footprint

3.3 Comparison 2: Large concrete school and same-sized wooden school

The second comparison pair focuses on a building four times the size of those included in the first pair, with a net heated area of 9,648 m2. The comparison pair was formed based on the same example building as the first comparison pair, and the structures are also the same as those of the first pair (Tables 1 and 2). The extent details are provided in Table 6.

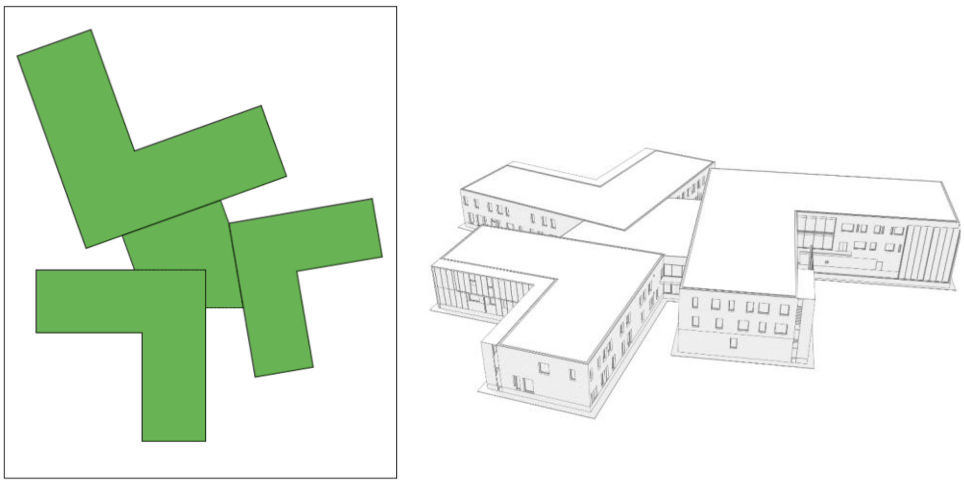

Figure 7. Illustrations of the buildings being compared: building footprint and perspective drawing. Comparison pair 2.

Table 6. Extent details for comparison pair 2.

Extent details			
Name and description	Unit	Concrete school, large	Wooden school, large
Net heated area	m²	9,648	9,648
Floor area	m²	10,284	10,117
Volume	m3	41,746	41,137
Geometry		As per drawings	As per drawings
Floors	pcs	3	3

Comparison of a concrete and wooden school – examinations based on carbon footprint

3.3.1 Carbon footprint

The results of the carbon footprint calculation are derived from the results of the energy calculation and the carbon footprint calculation for the entire analysis period, as is the case with comparison pair 1. The energy calculation results are presented in table 7. The E-value difference of the compared buildings is similar to that of comparison pair 1. The E-value of the large wooden school is 4% higher than that of the large concrete school, and the consumption of delivered energy is 7% higher for the wooden school than for the concrete school. Compared to the first pair, it appears to be easier to achieve a better E-value with a larger building.

Table 7. Energy calculation results for comparison pair 2.

In-service energy			
Name and description	Unit	Concrete school, large	Wooden school, large
E-value	$kWh_E/(m^2a)$	95	99
E-value, concrete vs. wood	%	100%	104%
District heating, heating and domestic hot water	kWh/a	777,866	865,116
District cooling	kWh/a	43,200	46,504
District heating total	kWh/a	821,066	911,620
Electricity	kWh/a	423,142	911,620
Delivered energy total	kWh/a	1,244,208	1,334,642
Delivered energy / m² /a	kWh/m²/a	129	138
Electricity's share of delivered energy	%	34%	32%
Delivered energy, concrete vs. wood	%	100%	107%

The results of the carbon footprint calculation are presented in Table 8 and Figure 8. The large wooden school's total carbon footprint for the 50-year analysis period is about 10% lower than that of the large concrete school.

In this comparison, 37% of the concrete school's life cycle emissions come from materials. In the concrete school's product stage, over 60% of the material emissions come from the concrete frame and about 4% from the mineral wool insulation, with other materials remaining below 3%, respectively. For the large wooden school, materials account for about 23% of the whole, with the largest 30% share being attributable to concrete, 12% to CLT and 5% to sand lime bricks in wet room partition walls.

Comparison of a concrete and wooden school – examinations based on carbon footprint

Table 8. Carbon footprint calculation results for comparison pair 2.

Carbon footprint			
Name and description	Unit	Concrete school, large	Wooden school, large
Carbon footprint kg CO_2e /m² /a	kg CO_2e /m²/a	15.74	14.00
Carbon handprint kg CO_2e /m² /a	kg CO_2e /m²/a	-2.98	-11.46
Carbon footprint kg CO_2e /m² for the analysis period	kg CO_2e /m²	787	700
Carbon handprint kg CO_2e for the analysis period	kg CO_2e	7,593,000	6,753,000
Carbon footprint kg CO_2e concrete vs. wood	%	100%	89%

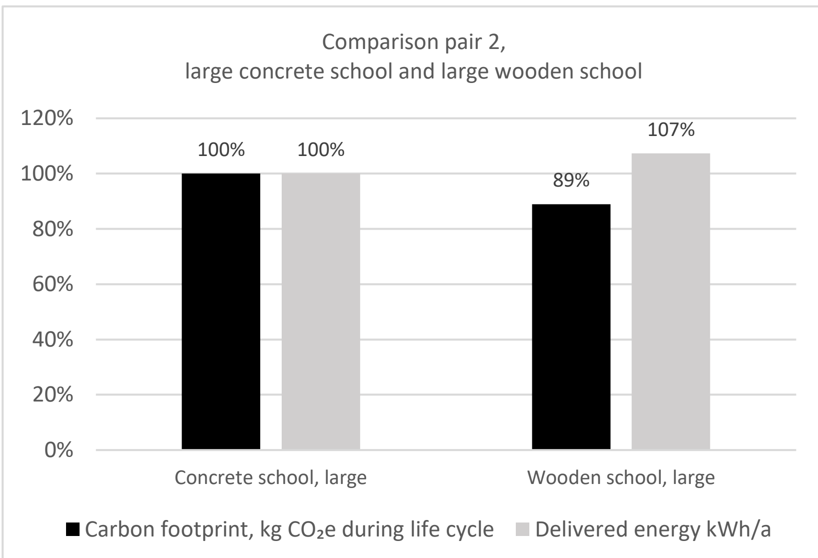

Figure 8. *Carbon footprint and delivered energy for comparison pair 2, large concrete school and large wooden school.*

As was the case with comparison 1, emission levels of the concrete school and wooden school are furthest apart at the start of the analysis period, and that the gap decreases towards the end of the period (Figure 9). The gap between the product and construction process stages of the large wooden school and large concrete school is 39%. Of the large wooden school's emissions, only about 28% are generated by the product and construction process stages, about 67% by the use stage and 5% by the end of life stage. Of the large concrete school's carbon footprint, 41% is formed by the product and construction process stages, 55% by the use stage and 4% by the end of life stage. The large wooden school's carbon handprint

Comparison of a concrete and wooden school – examinations based on carbon footprint

is substantially larger than that of the large concrete school. The carbon handprint is presented with a minus symbol in Table 8 and Figure 10.

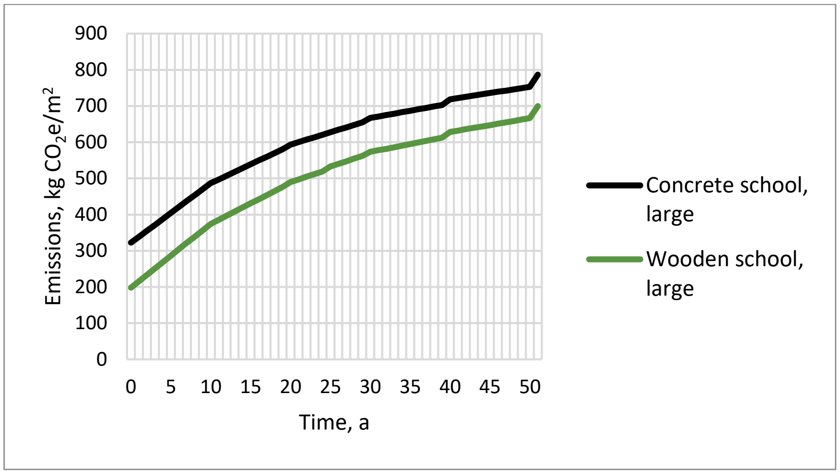

Figure 9. Carbon footprint as a function of time: large concrete school and large wooden school

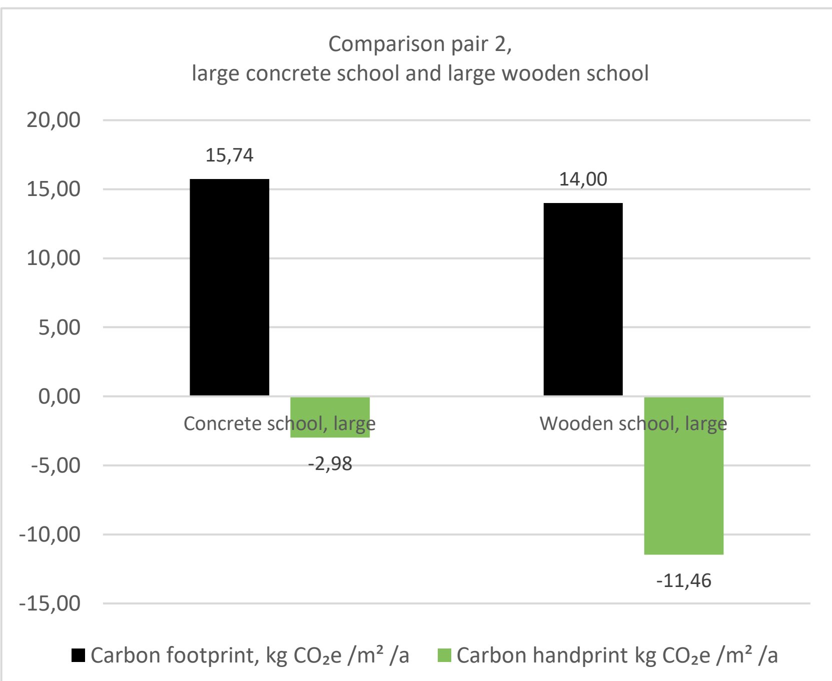

Figure 10. Carbon footprint and carbon handprint, comparison pair 2.

Comparison of a concrete and wooden school – examinations based on carbon footprint

3.4 Considerations and analyses using various insulation solutions

Energy efficiency is extremely important for the formation of the carbon footprint, despite the fact that the MoE calculation method assumes the emissions from electricity and district heating to decrease gradually over the course of the analysis period. Three separate additional analyses were carried out on the cases. These involved adding heat insulation in the ceiling, exterior walls, and exterior walls and ceiling. The relevant calculation results are presented in Figure 11.

For the wooden school's exterior walls, a solid-wood structure was selected, which has a U-value that is significantly lower than that of the concrete building (0.39 W/m²K). The ceiling's U-value was also slightly weaker (0.097 W/m²K) than for the concrete-structured school. In order to get the U-value of the wooden school's ceiling to match that of the concrete building (0.09 W/m²K), 20 mm of wood fibre insulation was added to the ceiling in additional analysis 1. On an annual level, this would only reduce the consumption of delivered energy by 0.1%. The added material would increase the carbon footprint slightly during the analysis period. Even if the annual decrease in energy consumption were to be taken into account for the entire 50-year period, this would only reduce the large wooden building's carbon footprint by 0.1%. This would not change the carbon footprint gap between the large wooden school and large concrete school (11%).

The second additional analysis was conducted by adding 50 mm of windproofing mineral wool in the wooden school's exterior walls, which brought the structure's U-value to 0.27 W/m²K. This would reduce the wooden school's calculated consumption of delivered energy by over 3% a year. Adding material, in turn, would increase the building's carbon footprint by 0.6% for the analysis period. Taking the annual decrease in energy consumption into account for the entire 50-year period, this would only reduce the large wooden building's carbon footprint by about 2%. This would increase the carbon footprint gap between the large wooden school and large concrete school to 13%.

The third additional comparison was conducted by adding 20 mm of wood fibre insulation in the ceiling, in the same way as in additional analysis 1, and a 25 mm windproofing board and 100 mm of wood fibre insulation in the exterior walls. These structures achieved roughly the same U-values as the concrete school: 0.19 W/m²K for the exterior walls and 0.09 W/m²K for the ceiling. This would reduce the wooden school's calculated consumption of delivered energy by about 8% a year. When the addition of material and annual energy consumption are considered for the entire analysis period, the large wooden school's carbon footprint would decrease by 3.5%. This would increase the carbon footprint gap between the large wooden school and large concrete school to 14% in favour of the wooden school.

Comparison of a concrete and wooden school – examinations based on carbon footprint

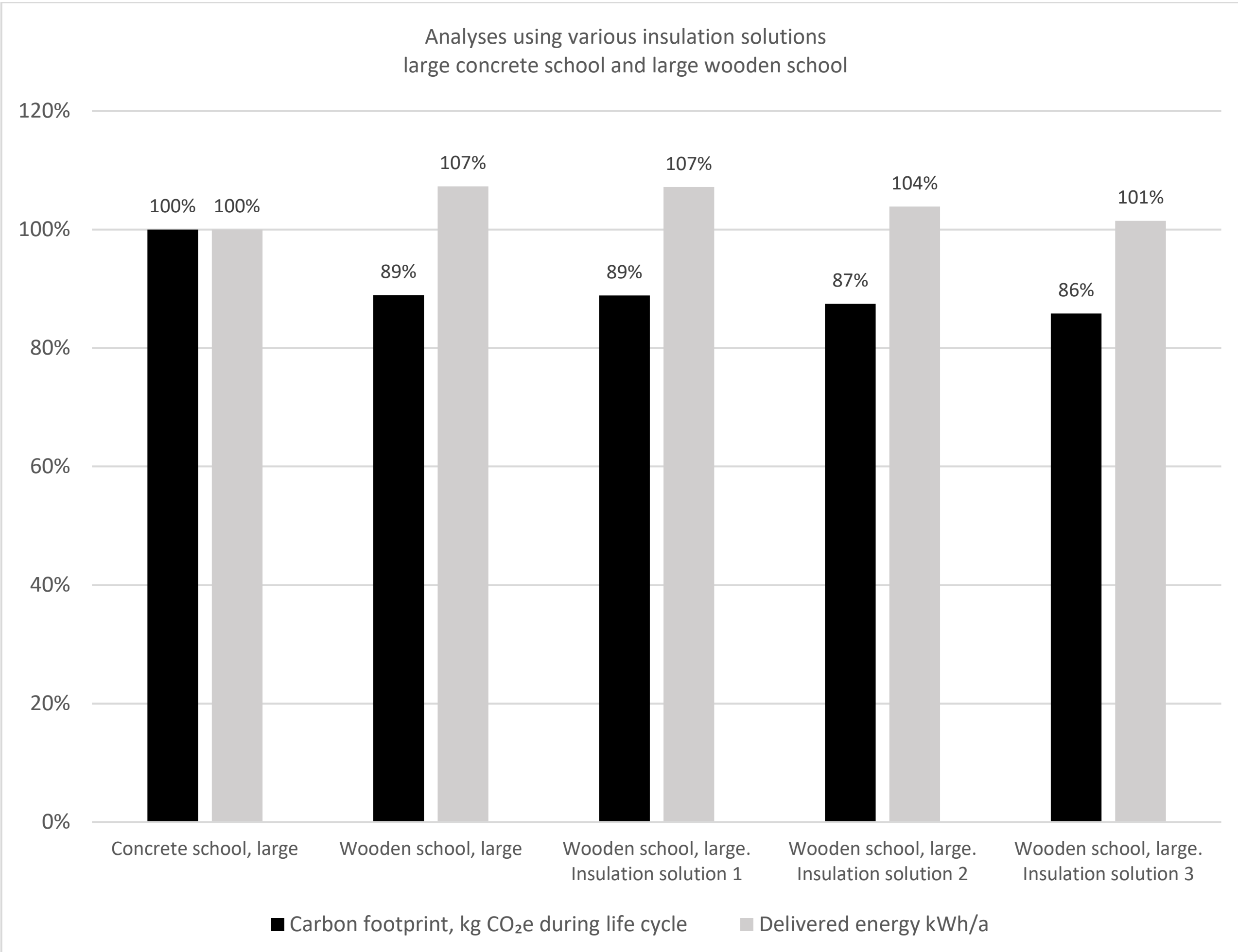

Figure 11, Analyses with various insulation solutions 1–3, large concrete school and large wooden school

There are hundreds of individual factors affecting the energy efficiency of a building. When considering impacts of the building geometry and alignment, it is safe to say that the number of variables is virtually endless. Small details, such as cold bridges between building sections or the annual efficiency of the air supply unit's heat recovery, gain significance in the carbon footprint analysis when the annual energy consumption has 50 years of time to impact the carbon footprint. Material selections can also be used to influence the results. In this comparison, components such as the concrete outdoor platforms and steel grilles could have been made from wood, which would have further reduced the carbon footprint. Similarly, materials with lower emissions and solutions that improve energy efficiency could be used in the concrete school.

Comparison of a concrete and wooden school – examinations based on carbon footprint

4 Summary and conclusions

As regards the concrete school, energy consumption during the analysis period (50 years) constitutes slightly more than half of the carbon footprint, and materials and construction slightly less than half, while demolition accounts for the remainder. For the wooden school, energy consumption during the analysis period accounts for roughly two-thirds of the carbon footprint (usage 66% for the large school), materials and construction for one-third (29% before use), and demolition for the remainder (after use 5%).

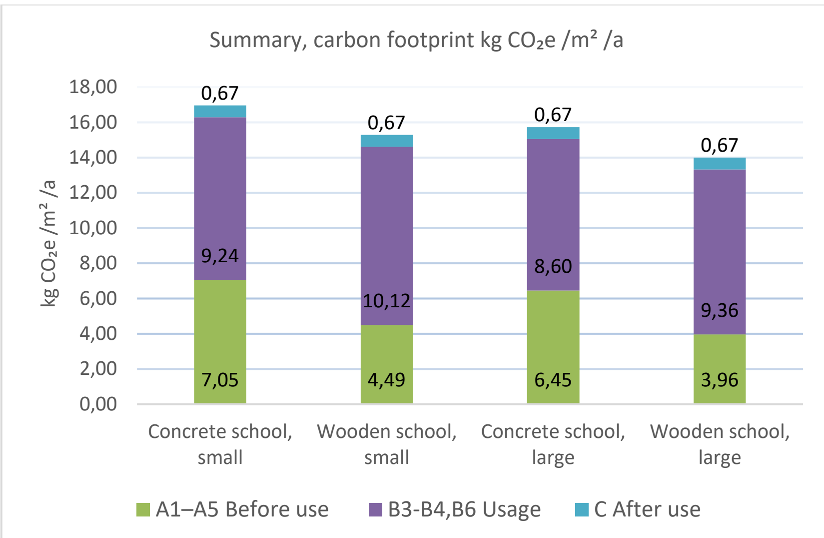

Figure 12. Carbon footprint division between life cycle phases

For the concrete school, concrete, which accounts for over 60% of the total, is the construction material that has the biggest impact on the carbon footprint. Mineral wool insulation is second in terms of carbon footprint impact (4%). Other materials are all below 3%, respectively. For the wooden school, too, concrete is the construction material with the most substantial impact on the carbon footprint at about 30% of the total. The second highest source of emissions is CLT (12%) and the third highest is sand lime bricks (5%). Based on the two comparable cases examined in this study, it can be concluded that the wooden school is a better option than the concrete school from the perspective of carbon footprint. The wooden school's carbon footprint is about 10% smaller than that of the concrete school, and its carbon handprint is significantly larger. The per-square-metre carbon emissions of the small and large wooden school are lower than those of the concrete school, even though the concrete school is more energy-efficient. However, energy efficiency has a significant impact on the results. In terms of the carbon footprint per square metre, the larger building is better than the small one, if the construction materials and other variables are kept the same.

Comparison of a concrete and wooden school – examinations based on carbon footprint

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6 Appendices

6.1 Appendix 1. Structural types

Concrete school

US1	U-value 0.19 W/(m²K)
35 mm	Brick tile
65 mm	Concrete
220 mm	Mineral wool
180 mm	Load-bearing structure, concrete
500 mm	

US2 (glass wall)	U-value 0.17 W/(m²K)
20 mm	Aluminium panel
110 mm	Steel column, EPS insulation
20 mm	Fibre cement board
150 mm	

US3	U-value 0.19 W/(m²K)
	Paint
80 mm	Concrete
220 mm	Mineral wool
180 mm	Concrete
480 mm	

Wooden school

US1	U-value 0.39 W/(m²K)
28 mm	Wood cladding
22 mm	Ventilation gap
22 mm	Cross furring
280 mm	Load-bearing structure, CLT
352 mm	

US1_insulation solution 2	U-value 0.27 W/(m²K)
28 mm	Wood cladding
22 mm	Ventilation gap
22 mm	Cross furring
50 mm	Windproofing mineral wool
280 mm	Load-bearing structure, CLT
402 mm	

US1_insulation solution 3	U-value 0.19 W/(m²K)
28 mm	Wood cladding
22 mm	Ventilation gap
22 mm	Cross furring
25 mm	Windproofing board
100 mm	Wood fibre insulation
280 mm	Load-bearing structure, CLT
477 mm	

US2 (glass wall)	U-value 0.17 W/(m²K)
as with the concrete building	

US3	U-value 0.39 W/(m²K)
as wooden school's US1	

Comparison of a concrete and wooden school – examinations based on carbon footprint

Concrete school

US4 (plinth)	U-value 0.17 W/(m^{2}K)
	Bitumen membrane
80 mm	Concrete
220 mm	EPS insulation
220 mm	Concrete
521 mm	
US5 (civil defence)	
	Paint
80 mm	Concrete
220 mm	Mineral wool
300 mm	Concrete
600 mm	
YP1	U-value 0.09 W/(m^{2}K)
7 mm	Waterproofing rubberised bitumen membrane
23 mm	Tongue and groove boards 23 mm
150 mm	Roof trusses k900
200 mm	Ventilated air space
450 mm	Mineral wool
0.5 mm	Vapour barrier bitumen membrane
320 mm	Hollow-core slab
1,155 mm	

Wooden school

US4 (plinth)	U-value 0.17 W/(m^{2}K)
as with the concrete building	
US5 (civil defence)	
as with the concrete building	
YP1	U-value 0.097 W/(m^{2}K)
7 mm	Waterproofing rubberised bitumen membrane
23 mm	Tongue and groove boards 23 mm
50 mm	Battens
110 mm	Ventilated air space
40 mm	Windproofing mineral wool
480 mm	Glulam beams k900 and wood fibre insulation
0.2 mm	Vapour barrier plastic
44 mm	Cross furring
13 mm	Plasterboard
719 mm	
YP1_ insulation solution 1 and 3	U-value 0.09 W/(m^{2}K)
7 mm	Waterproofing rubberised bitumen membrane
23 mm	Tongue and groove boards 23 mm
50 mm	Battens
110 mm	Ventilated air space
40 mm	Windproofing mineral wool
500 mm	Glulam beams k900 and wood fibre insulation
0.2 mm	Vapour barrier plastic
44 mm	Cross furring
13 mm	Plasterboard
7,399 mm	

Comparison of a concrete and wooden school – examinations based on carbon footprint

Concrete school		Wooden school	
AP1	U-value 0.16 W/(m²K)	AP1	U-value 0.16 W/(m²K)
15 mm	Putty	as with the concrete building	
80 mm	Concrete slab		
150 mm	EPS insulation		
	Filter fabric		
300 mm	Sand		
300 mm	Gravel		
AP2 (civil defence)		AP2 (civil defence)	
15 mm	Putty	as with the concrete building	
70 mm	Concrete slab		
200 mm	Concrete slab		
150 mm	EPS insulation		
	Filter fabric		
300 mm	Sand		
300 mm	Gravel		
VP1		VP1	
5 mm	Vinyl flooring	5 mm	Vinyl flooring
15 mm	Putty	15 mm	Putty
70 mm	Concrete slab	260 mm	CLT floor slab
370 mm	Hollow-core slab		
VP2, civil defence		VP2, civil defence	
5 mm	Vinyl flooring	as with the concrete building	
15 mm	Putty		
80 mm	Concrete floor slab		
50 mm	EPS insulation		
1,550 mm	Crushed stone		
400 mm	Concrete		
VP3, wet rooms		VP3, wet rooms	
	Tiling	as with the concrete building	
	Waterproofing		
40 mm	Putty and sloped cast		
	Like VP1		
VS1		VS1	
13 mm	Plasterboard		
95 mm	Steel frame, mineral wool	120 mm	CLT partition wall
13 mm	Plasterboard		
121 mm			
VS2, wet rooms		VS2, wet rooms	
	Putty	as with the concrete building	

Comparison of a concrete and wooden school – examinations based on carbon footprint

130 mm	Sand lime brick		
	Putty		
VS3, load-bearing		VS3, load-bearing	
200 mm	Concrete	as with the concrete building	
VS4, civil defence		VS4, civil defence	
300 mm	Concrete	as with the concrete building	
Concrete school		**Wooden school**	
Column 1		Column 1	
500x500 mm	Concrete columns	190x360 mm	Glulam columns
380x380 mm	Concrete columns		
Column 2 and 3		Column 2 and 3	
	Steel columns	as with the concrete building	
Beam 1		Beam 1	
200x500 mm	Concrete beam	190x495 mm	Glulam beam
Window 1	U-value 1.0 W/(m²K)	Window 1	
	Triple-glazed MSE window	as with the concrete building	
Window 2	U-value 1.0 W/(m²K)	Window 2	
	Triple-glazed MEK glass wall	as with the concrete building	
Interior window 1		Interior window 1	
	Two-glazed interior window	as with the concrete building	
Exterior door 1	U-value 1.0 W/(m²K)	Exterior door 1	
	Heat-insulated wooden door	as with the concrete building	
Interior door 1		Interior door 1	
	Wooden door	as with the concrete building	
Balcony slabs and outdoor platforms		Balcony slabs and outdoor platforms	
15 mm	Putty	as with the concrete building	
50 mm	Concrete slab		
6.9 mm	Bitumen membrane		
200 mm	Load-bearing concrete slab		
20 mm	Plastering		
Heating		Heating	
	Heat distribution network and centre	as with the concrete building	

Comparison of a concrete and wooden school – examinations based on carbon footprint

Water and sewerage		Water and sewerage
	Water piping system	as with the concrete building
Ventilation		Ventilation
	Ventilation system	as with the concrete building
Electricity		Electricity
	Electrical installations and cabling	as with the concrete building
Sprinklers		Sprinklers
	No sprinklers	Sprinklers in wooden school