Sustainability and LCA assessment for a passive house kindergarten

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Summary

This kindergarten sustainability assessment of formed part of the SUSPROC research project aimed at developing knowledge and methods for sustainable building processes. The kindergarten case study tested the evaluation of the usability and usefulness of sustainability indicators in target setting and monitoring of the building project. Assessment was conducted in conjunction with representatives of Espoo and with project designers. The study resulted in a complete life cycle inventory involving assessment of greenhouse gases, natural raw material use and energy efficiency on the building site, design options, and operation [1]. The study highlights all relevant sustainability factors that need to be considered according to the sustainability indicators presented in ISO DIS 21929 “Sustainability in building construction” [2]. The research describes the assessed environmental impacts of alternative design options, and of the different areas of the construction work. Consideration was given to all materials used and to HVAC systems, as well as to use in normal kindergarten operation, involving energy consumption, commuting and day care trips and daily waste management. Results of the study highlight the factors that need to be considered when sustainability forms the criterion in building design.

Keywords: Sustainable building, building processes, environmental impacts, sustainability indicators, LCA

1. Background and objectives

Sustainability in the building sector can be defined in many ways. According to the World Business Council for Sustainable Development (WBCSD), the key factor in the building sector is the reduction of energy use. Energy efficiency in new construction is being regulated and improved with the help of increasingly demanding building codes. On the other hand, the annual volume of new constructions is limited. To achieve a significant reduction in building energy consumption and environmental impacts, all new buildings would need to be at a better level than required by the building codes. In the Nordic countries, passive, zero and nearly zero buildings are an effective means of reducing operational energy and related emissions.

A life cycle assessment was conducted on a kindergarten design intended for Espoo, Finland with the aim of achieving an understanding of the significance of the environmental impacts of different sources over an entire building project. With one of its targets the fulfilment of the passive house criteria for Nordic countries [3], the kindergarten project provided a stern challenge. The passive house solution is an overall concept with low or almost zero energy consumption, well-insulated structures, improved air tightness and highly efficient heat recovery from ventilation. Besides the structural and operational goals, the site itself, located in the planned new area of Suurpelto in the centre of Espoo, proved particularly demanding. Soil at the site is an unfavourable blend of moraine and soft clay. This reaches to 15 m in parts, with a consequent environmental impact when preparing the land for construction. The criteria for a passive structure were discussed in the context of this case.

One powerful tool for this purpose is Life Cycle Assessment (LCA), which refers to defining the potential environmental effect of used products, functions or buildings. According to the definition [4], LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave). The LCA evaluation method was used for describing the aspects that need to be considered when the target is building sustainability and low environmental impacts. The LCI for the entire building project was made as comprehensive as possible, based on the building plans, and taking into account the dynamic building design. LCA studies concentrating on the building design phase are often limited, focusing on energy consumption and building framework materials. Simplified methods nonetheless fail to show the full picture regarding sustainable building, and the relevance of total material use remains unclear.

The functional unit in environmentally friendly building design is the building itself. The building fulfils the functionality and space requirements throughout its life span with low material and energy consumption, and thus negligible impact on environment, resources, emissions and natural biodiversity. The sustainability assessment was conducted with the help of sustainability indicators presented in ISO DIS 21929-1 “Sustainability in building construction – Sustainability indicators – Part 1”. The themes include the following aspects: access to services; aesthetic quality; land use; accessibility; emissions to air; use of non-renewable resources; fresh water consumption; waste generation; indoor conditions and air quality; safety; serviceability; adaptability; costs; and maintainability. The kindergarten case was used to test and monitor sustainability indicators.

This study brings out all relevant life cycle phases and their impacts, giving consideration to all relevant materials, appliances and HVAC systems, as well as to large site works and the building use phase. A study was made of the significance of the alternative heating options – heat produced locally by ground source heat pumps, and Espoo’s district heat production.

2. Description of the building site and building

The kindergarten was designed for building in the Suurpelto area, in Espoo, Finland. The building site was particularly demanding, requiring a large amount of infrastructure work. Foundation structures were in need of strengthening, appreciable ground work, soil exchange, stabilisations and concrete piles, as well as drainage plumbs. An architectural competition was held to obtain the best available solution. The target of the design was to take into account the principles of sustainability and the passive house criteria for Nordic countries. Figure 1 and Table 1 show details of the kindergarten solution assessed and chosen for construction.

Building location: Suurpelto, Espoo, Finland
Site area: 3,238 m^2
Useful floor area: 1,293 m^2
Gross area 1,475 m^2
Building volume 6,300 m^3
Designed to accommodate 87 children in day care and 19 staff.
Yard 1,762 m^3
Parking spaces: 7

Figure 1. View of the kindergarten design.

Table 1. Details of the kindergarten and the options studied.

Structures/systems	u-value, W/m²K	Description of implementation
Base floor: 880 m^2	0.10	Reinforced concrete slab, PU, surface concrete slab
Intermediate floor : 710 m^2		Hollow core slab
Roof :1,026 m^2	0.07 and 0.09	Hollow core slab, PU, asphalt mastics for roof covering
External wall: 1,068 m^2	0.09	Concrete, mineral wool or PU
Partition wall: 1,349 m^2		Different structures
Doors: 67 internal and 7 front doors	Front doors 0.7	Steel-structured front doors
Windows: 234 m^2		Wood / aluminum, 3 glazing
Stairs: 4 units		1 spiral steel and 3 concrete stair elements
Load-bearing structures		Steel beams, steel pillars, glued laminated beams
Yard		4 different structures, depending on subsoil condition and on the need for strengthening. A typical coating was asphalt, gravel and concrete slab pavement. The playground has green zones for different activities.
Heating and cooling		Two alternative options were compared: - Ground source heat pump for heating and cooling (designed for maximum heating capacity 100%, covers space heating, cooling and hot water. Two pumps, 12 wells 180 m each, heat storage to water) - District heating for heating and blower cooling (heating power 400 kW)
Heating system		Floor heating
Heating and primary energy		20–30 kWh/m^2 (heating demand), 130 …140 kWh/m^2 (primary energy demand) (criteria for passive house, Nordic) [3]
Air exchange rate		n_{50} = 0.6 l/h (criteria for passive house, Nordic) [3]
Ventilation		Plenum and exhaust ventilation, heat recovery rate 80%
Energy supply		District heat produced in Espoo's heat and power plants, carbon footprint 193 g CO_2 eq/kWh. Electricity production and possible changes in the production mode were covered by two alternatives: - Case 1, no influence of electricity use on electricity production method, use of annual average electricity production mix, carbon footprint 224 g CO_2/kWh - Case 2, influence in winter of electricity use on electricity production, electricity produced in separate coal condensing power plant, winter carbon footprint 966 g/CO_2 eq/kWh, other months 224 g/CO_2 eq/kWh)

3. Sustainability and Life Cycle Assessment

Ecological goals should be set for the building use phase, and for all materials used and building solutions influencing the material and energy flows and bringing about environmental impacts. The evaluation method should be appropriate, however, to achieving a reduction in environmental impacts from the building. The setting of requirements is only useful when matched by consistency of design of the executed building.

This evaluation tests sustainability indicators, verifies and monitors the sustainability targets set according to the design plan, and studies the more significant of chosen options by comparing alternative selections and improvements. The results are shown in Table 2.

Table 2. Sustainability indicators, targets and verification according to the kindergarten project.

Aspect and indicator	Design plans and target	Result and relevance
Access to services – public transport, private mode of travel, services and green areas	The area goal is reconciliation of work, family life and leisure. Residential, office and service buildings consisting of 7,000 apartments and 9,000 workplaces will be built in the Suurpelto area. The site is connected to the park. Pedestrian and cycle paths are planned. The area target is for public transport to serve 80% of transport needs.	Accessibility good according to all four indicators. Estimated average duty travels covered an area of 18 km^2; distance from the children's homes was around 1 km. The kindergarten site contains 7 parking spaces for employees. According to the LCA these journeys cause fossil raw material consumption of 132 tons/50 years, fossil energy use of 7,130 GJ/50 years and a carbon footprint of 518 tons/50 years.
Aesthetic quality – evaluated against the fulfilment of local requirements	Aesthetic quality was not set as a quality level, but described according to the chosen solutions.	The goal was for "scales", colours and materials to be chosen appropriately to match the playful kindergarten character. The architect competition was arranged to ensure good architectonic quality. This indicator is significant because the building will be centrally located and the area's first public building, giving character and providing guidelines for development.
Land use – changes in land use caused by the development of the built environment	Avoidance of land use was not the target in this case.	The land is centrally located, undeveloped and fragmented. Site development completes the Espoo area and makes use of already available infrastructure. Once completed, the area will be integrated into Espoo. Conversely, challenging land induces several environmental impacts. This is dealt with in the LCA.
Emissions to air – global warming (carbon footprint)	The target was to reduce carbon dioxide emissions by 28% over a standard building. This was considered fulfilled through the adoption of ground source heat pump and passive building structures.	LCA conducted, giving a carbon footprint in case 1 of 826 tons/50 years for GSHP and 1,230 tons/50 years for district heat. In case 2, the carbon footprint for the GSHP system was 1,650 tons/50 years and for district heat 1,750 tons/50 years.
Use of non-renewable resources – amount by type	No target was set for the use of non-renewable resources.	Non-renewable resources estimated in the LCA were ~17,100 tons/50 years. The infrastructure share of the total was 70%, while that of building structures, building services, GSHP structures and material use in building maintenance amounted to 30%.
Energy consumption	The plan is for ground source heat pumps to provide heating. A district heat comparison was also made. The criterion was passive house, Nordic.	Heating energy consumption for GSHP was 12 kWh/m^2/year, and for district heat 40 kWh/m^2/year. Electricity consumption in both cases was 38 kWh/m^2/a.

Table 2. Continue.

Aspect and indicator	Design plans and target	Result and relevance
Adaptability – flexibility, convertibility, adaptability	Adaptability was taken into extensive consideration through clear headways, with lighting, space, colour and sound world all in support of clearways.	Physical clear headway was tested during the building supervision process.
Maintainability – assessed against service life assessment	Project planning point out that the economic service life for the building is 50 years, allowing for one renovation. The designed service life for load-bearing structures is, however, 100 years.	The LCA also covered building maintenance. The carbon footprint for building structure materials was 660 tons, whereas building maintenance increased this by ~30 tons (service life 50 years).
Fresh water consumption – amount	The target for annual hot water consumption was 0.3 m^3/gross m^2 with corresponding energy consumption of 17.5 kWh/m^2.	All water fittings would be chosen according to the water saving parameters, using automatically operating taps.
Waste generation – amount by type	The kindergarten will be connected to the waste suction system, which processes mixed waste, bio waste and paper waste.	The daily bio waste amount is assumed to be 150 g/person. The carbon footprint for waste management was estimated at 130 tons CO_2 eq/50 years.
Indoor conditions and air quality – air quality and sub-aspects of indoor conditions	No special target for indoor conditions was set in project planning. It was mentioned that spaces should be functional, healthy and safe. All noisy spaces were separated from those requiring silence.	Indoor quality for heated spaces should fulfil S2 class requirements; all finishing materials should comply with the M2 class for building materials, M1 for ventilation appliances, M2 for cleanliness, and building works P2 for purity. The possibility of overheating will be simulated prior to final heating source selection.

A life cycle assessment was conducted for the soil and infrastructures, building production, the use phase (use of heating and electricity, commuting and day care trips, waste management), the production of building services, the heat production system (ground source heat pump or district heating) and building maintenance. The inspection period was 50 years. The results for carbon footprint and the consumption of non-renewable raw materials and energy are shown in Tables 3, 4 and 5.

Table 3. Carbon footprint and consumption of non-renewable raw materials and energy for the building structures.

Building structures	CO_2 eq tons/50 years	Non-renewable raw material consumption tons/50 years	Fossil energy consumption GJ/50 years
Base floor	151	2,960	1,640
Intermediate floor	93	539	789
Roof	101	282	1,376
External wall	151	595	1,904
Partition wall	69	405	568
Load-bearing structures	35	9	564
Foundation	49	273	360
Windows, doors, stairs	16	27	186
Total, building structures	664	5,090	7,386

Table 4. Carbon footprint and consumption of non-renewable raw materials and energy for the building, infrastructure, HVAC and other building installations.

	CO_2 eq ton/50 years	Non-renewable raw material consumption ton/50 years	Fossil energy consumption GJ/50 years
Infrastructures (building site + yard)	472 + 105	7,462+4436	3,540 + 790
Building structures, total	664	5,090	7,386
Electric system	10	13	15
Heat distribution system	< 1	<1	8
Sanitary engineering	5	58	131
Ventilation system	3	2	56
GSHP system, incl. wells	26	12	423
District heat system (incl. only building connections)	3	12	36
Material transport	54	14	1,309
Total (GSHP system)	1,372	17,119	14,113
Total (District heat system)	1,349	17,120	13,726

Table 5. Carbon footprint and consumption of non-renewable raw materials and energy for the building use phase, Espoo, kindergarten, service life period 50 years.

	CO_2 eq ton/50 years	Non-renewable raw material consumption ton/50 years	Fossil energy consumption GJ/50 years
Building maintenance (50 years)	32	31	451
Heating and cooling with GSHP (50 years)	826* / 1,650 **		
Heating with district heat and cooling with blower (50 years)	1,230* / 1,750 **		
Commuting (50 years)	350	85	4,960
Day care travel (50 years)	160	52	2,171
Waste management (50 years)	129	132	7,130

* Electricity production Case 1
** Electricity production Case 2

4.1 Discussion and conclusions

It is often believed that increasing energy efficiency leads automatically to a reduction in the overall carbon footprint and other emissions. In fact, more raw materials may be needed to achieve better energy efficiency, not only for insulation and better windows, but for heating systems such as ground source heat and solar panels. Advanced building systems actually increase the use of electricity, while in winter the already inadequate electricity production means the use of stand-by power plants that are less effective for heat production than CHP plants. Passive house structures can also be produced in a dozen different ways, from different materials with different service lives, different maintenance needs and different effects on the overall carbon footprint.

The LCA evaluation method was used for describing the aspects that need to be considered when the target is building sustainability and low environmental impacts. The LCI for the entire building project was made as comprehensive as possible, based on the building plans, and taking into account the dynamic building design. LCA studies concentrating on the building design phase are often limited, focusing on energy consumption and building framework materials. Simplified methods nonetheless fail to show the full picture regarding sustainable building, and the relevance of total material use remains unclear.

Total non-renewable material consumption for the kindergarten case was ~ 17,000 tons, whereas ~12,000 tons was used for infrastructure construction (this omits raw-materials used in building heating) (Table 4). The extensive infrastructure work and attendant quantity of materials are often forgotten in LCA assessments of buildings. The simplified LCA method normally only covers building structures, with site impact regarded as an inevitable consequence and outside the scope for consideration. The remarkable finding here is that the carbon footprint of soil and infrastructure construction was practically of the same magnitude as that of building structures (Figure 2).

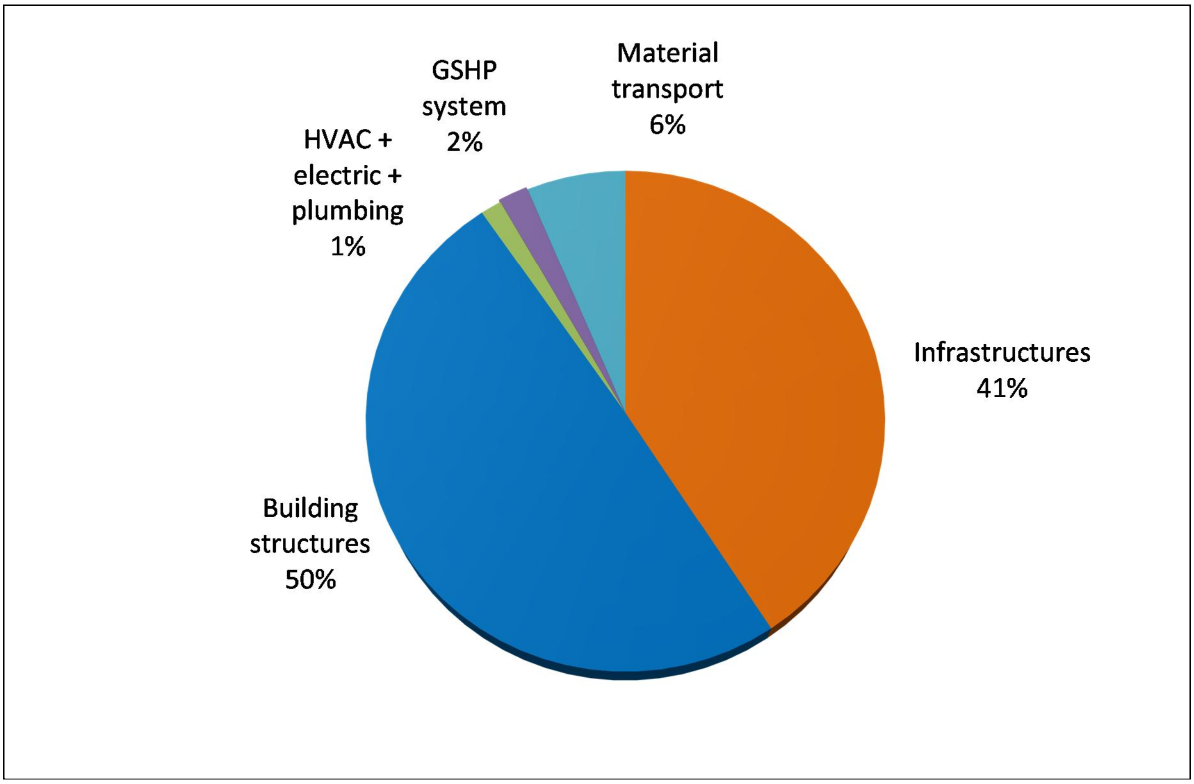

Figure 2. The carbon footprint of the total built area was ~1,370 tons.

The significance of building appliances and HVAC systems, on the other hand, was relatively low in terms of use of natural resources and carbon footprint. The disproportionate share for infrastructure derives from a particularly demanding building site in need of much strengthening, material and stabilisation. The share for building services remains as low as it does because of the massive, heavy nature of all other structures. The study also shows that the carbon footprint of a building can be significantly affected by its location and related transport.

It is claimed that building materials have a roughly 5–15% effect on energy use and emissions. The kindergarten assessment shows that over a reference period of 50 years the choice of materials (all structures) may be the cause of almost half the total carbon footprint.

From the point of view of energy efficiency, the ground source heat pump is an effective way of producing heat. On the other hand, when electricity required for the heat pump operation is produced during the winter, with the help of separate coal condensing power plants, the impact on the carbon footprint is less favourable. This kindergarten study involved two alternative electricity production scenarios. Electricity was responsible for over 55% of the total carbon footprint in Case 2, but where electricity could be produced as average production, as in Case 1, the figure drops to 38% (Figure 3).

The kindergarten evaluation tests sustainability indicators, verifies and monitors the sustainability targets set according to the design plan, and studies the more significant of chosen options by comparing alternative selections and improvements.

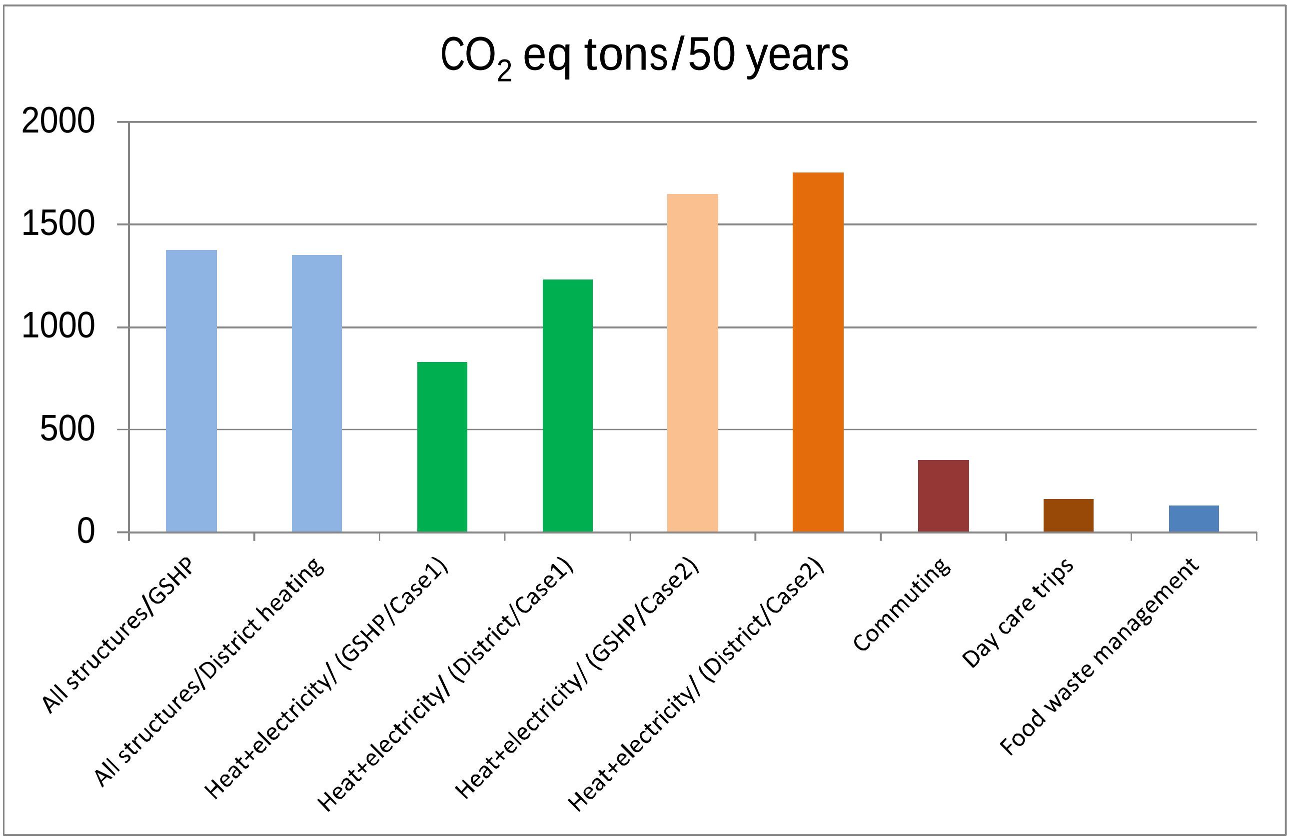

Figure 3. Carbon footprint from building materials and infrastructures.

Generally it can be said in the case of the Suurpelto kindergarten that sustainability issues were widely taken into account when targets were set. For some indicators, such as life cycle costs, energy efficiency, carbon footprint and indoor air quality, targets were comprehensive and demanding. Other indicators were expressed in more general terms. From the viewpoint of sustainable construction, target setting in relation to environmental impact is better the smaller (more ambitious) the target. However, other targets related to social and cultural aspects are linked more to user needs. The better the target setting reflects and takes into account user needs, the better the results that can be expected. Target setting is the starting point for sustainable building, but the process still requires guidance on target monitoring and updating, as well as help in recognition of user requirements.

The case study concluded that a systematic approach and sustainability indicators assist project-specific management of sustainable building and support continuous improvement. The usefulness of sustainability indicators would be considerably enhanced, however, by their improved measurability.

4.2 References

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