Comparison of different measures for reducing the carbon footprint of the building sector – a rental house case study

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Abstract. This paper compares and estimates cost-optimal means to increase the potential of reducing the carbon footprint of future rental houses. As a case study we present a comparison between four rental apartment houses, where one house has achieved the Nordic Swan ecolabel. The carbon footprints of these buildings have been calculated for the building lifetime. According to the results, the effects of single measures are quite small in reducing the carbon footprint, but larger effects can be obtained by combining several measures together. It is essential to minimize the amount of used materials by paying attention to material efficiency under both design and construction phase. The paper also discusses the role of the voluntary ecolabelling of buildings as a tool to reduce the carbon footprint of the building sector.

1. Introduction

The built environment of a typical European country accounts for approximately 40 % of the total energy consumption, 30 % of the total emissions and 50 % of the resource use. Lowering the energy and resource use of the built environment has a key role when aiming to reduce the country-specific carbon emissions. It is therefore important both to estimate and to decrease the carbon footprint of buildings.

The life-cycle carbon footprint of a single building describes how much greenhouse gas emissions the building emits to the atmosphere during its lifetime. Main factors affecting the carbon footprint are the energy consumption of the building, the type of energy consumed and the used building materials. The most important factor is still the energy consumption, but with the increased utilization of renewable energy and better energy-efficiency of the building systems, the proportional importance of the building materials on the total carbon footprint is steadily growing.

The Finnish Ministry of the Environment is promoting low-carbon construction with several measures. The ministry has compiled recommendations for purchase criteria of public construction projects, which enable cities and communities to construct buildings with a lower carbon footprint. In line with European standards, the Ministry of the Environment is introducing a method to calculate embodied energy and CO₂ emissions of building materials during the whole life cycle. The ministry is also developing low-carbon evaluation tools and updating building regulations to support low-carbon construction. At the end of 2018 the ministry launched a common request for the opinion about a draft for the assessment method to estimate the carbon footprint of a building [1]. There may be a voluntary piloting phase before setting the boundary values by 2025.
One example of voluntary climate-conscious actions is environmental certification of buildings. The official ecolabel of the Nordic countries, the Nordic Swan includes criteria for both new and renovated buildings. The criteria have requirements for the entire building process, from cutting of trees to recycling of waste. The criteria have both direct and indirect impacts on the climate and the carbon footprint due to e.g. requirements for a tighter energy efficiency demand than the building regulations, a demand-controlled lighting diminishing the electricity consumption and over 70 % construction site waste recycling target. There are also circular economy requirements, e.g. of the window and door materials aluminium must contain at least 40 %, PVC-material at least 30 % and steel at least 20 % of recycled material. The criteria have also requirements concerning chemical load, indoor environment quality, sustainable materials and subcontractor chains.

The Nordic Swan criteria for newly constructed building types, revised in 2015, is valid for small houses, apartment buildings, buildings for pre-schools and schools/educational buildings, extensions to existing buildings and homes for the elderly [2]. Also office buildings are included in the separate criteria for renovated buildings. The Nordic Swan Ecolabel was established in 1989 by the Nordic Council of Ministers as a voluntary ecolabelling scheme for Denmark, Finland, Iceland, Norway and Sweden. Currently the Nordic Swan Ecolabel has over 60 different product groups with more than 200 different product types and more than 25.000 different products.

The criteria development process of the Nordic Swan Ecolabel is based on preliminary studies highlighting areas where the need for requirements is greatest. Development of new criteria and revision of existing criteria takes place in close contact with businesses and other stakeholders with relevant knowledge, using available literature from academic institutions and experts. The final proposal is passed by the Nordic Ecolabelling Boards and uploaded to both Nordic and national websites, together with background documents and comments from the public consultation.

The Housing Finance and Development Centre of Finland, in Finnish ARA (Asumisen rahoitus- ja kehittämiskeskus), is an agency to implement social housing policy and operates under the supervision of the Ministry of the Environment. ARA is supporting the goals of the Ministry of the Environment with a development project, where the carbon footprints of the new built houses with ARA funding are being calculated.

This paper presents the main conclusions of a ARA report [3], where the life-cycle carbon footprint was calculated for four new rental apartment houses by the Finnish consulting company Optiplan. One of these houses has achieved the Nordic Swan ecolabel. The main goal of the ARA report was to study the carbon footprint level of an ecolabelled building. The additional goal was to find out the most cost-optimal measures to reduce the carbon footprint. The report is written in Finnish.

2. Carbon footprint calculation and results

Life-cycle carbon footprint was calculated for four rental houses owned by VAV, Vantaan Asunnot Oy: Kaskelantie 1, Lipputie 14, Marsinkuja 1 and Loiskekuja 1. The houses are all located in the city of Vantaa in Southern Finland. Kaskelantie 1 has the Nordic Swan ecolabel. In Lipputie 14, also called as the Opaali house, special attention has been paid to utilize recycled material and material-effective choices. The other two houses are built with ordinary solutions. All houses had the same constructor, NCC Finland Ltd.

2.1. Calculation method and common input values
The carbon footprint was calculated using the One Click LCA calculation program. One Click LCA is a web-based cloud service for environmental and life cycle assessment calculation verified by a third actor according to EN15978.

The program includes environmental impact data of building products and materials from Finland, the Nordic countries and Europe. The tool includes emission data also from outside of Europe. The emission data of the material database is based on environmental declarations according to the standard EN-15804. The database also includes emission data for the national Finnish electricity network and the local district heating networks. The emission factors used in calculations were 0.23 kg CO2-eq./kWh for electricity and 0.20 kg CO2-eq./kWh for district heating (Vantaa Energy district heating network 2016).

The instructions of the Level(s) procedure by the European Commission [European Commission 2018] have mainly been used in the calculation, e.g. the calculation period was 60 years. All lifecycle phases have been included in the calculation.

All houses have a centralized mechanical inlet and exhaust air ventilation system with heat recovery. The houses are heated with district heating and they have no cooling system. Kaskelantie 1 has a 12 kWp solar electricity system. Following materials have been included in the calculation: foundations, outer and inner walls, facades, pillars, columns, horizontal structures, stairs and banisters, windows and doors, surface materials, building service systems including elevators and outdoor area materials including landmass, asphalt and concrete paving.

2.2. Case buildings

Kaskelantie 1. This case building from 2018 consists of two houses with eight floors each. The total number of the housing units is 127. The net floor area is 5 832 m², the gross area is 8 830 m² and the building volume is 28 250 m³. The total site area is 2 726 m². The building foundation has reinforced concrete foundation piles and footing. The slab-on-grade base floor is embedded on site. The upper floors and roof structures are made of precast hollow-core concrete slabs and the staircase landings of massive-slab elements. The bearing walls and pillars are made of reinforced concrete elements. The partition walls are mainly concrete elements or gypsum walls with metal studs. The suspended ceilings are mainly constructed of gypsum or acoustic boards. The floor coatings are laminate inside of the dwellings, floor tiles in common areas and plastic mat in technical spaces. The building has achieved the Nordic Swan ecolabel. According to the Finnish Energy Performance Certificate the electricity consumption is 137 MWh/a (15.5 kWh/m² GFA,a) and the calculated district heating energy consumption is 448 MWh/a (50.7 kWh/m² GFA,a).

![Figure 1. Kaskelantie 1 (Photo Henrik Kettunen).](image-url)
Lipputie 14. The second case building from 2015 consists of two houses with five floors each. One house has one staircase and the other house has three staircases. The total number of the housing units is 87. The net floor area is 4 274 m², the gross area is 6 224 m² and the building volume is 19 920 m³. The total site area is 2 163 m². Specific targets of the construction project were to save natural resources, reduce the carbon footprint by using recycled materials and to pay special attention on material efficiency. The necessary measures taken to fulfill these targets were to lighten partition walls, reduce the amount of concrete in structures and to utilize unprocessed wood in the facades. The building foundation has reinforced concrete palisade and footing. The base floor is mainly made of hollow-slab elements and the staircase landings of massive-slab elements. The bearing walls and pillars are made of reinforced concrete elements. The partition walls are concrete, calcareous sandstone or gypsum walls with metal wire frames. The suspended ceilings are mainly constructed of gypsum or acoustic boards. The floor coatings are mainly laminate inside of the dwellings and plastic mat in common areas and technical spaces. The facades are mostly steel framed with coating of fibre cement boards or wood. The load bearing facades are insulated concrete elements topped with plaster and the first floor of the façade facing the street has brick coating. The calculated electricity consumption is 96 MWh/a (15.4 kWh/ m² GFA,a) and the calculated district heating energy consumption is 377 MWh/a (60.5 kWh/ m² GFA,a).

![Lipputie 14](image)

Marsinkuja 1. The third case building from 2017 consists of four houses. The total number of the housing units is 147. The net floor area is 6 632 m² and the gross area is 11 675 m². The building foundation is slab-on-grade and there is no palisade. The footing is reinforced concrete embedded on site and the plinth is made of concrete elements. The base floor is mainly made of ventilated hollow-slab elements. The shelter has a slab-on-grade. The bearing walls are embedded on site or reinforced concrete elements. The intermediate and attic floors are mainly hollow-slab elements. The stairs are made of reinforced concrete elements. Most of the outer walls are concrete-sandwich elements and factory-plastered, smooth, painted or fully tinted concrete. The outer wall of the ventilation machinery space is coated with sheet metal profile. The light partition walls are mostly made of metal wire framed gypsum boards or expanded clay concrete blocks. The calculated electricity consumption is 224 MWh/a (19.1 kWh/ m² GFA,a) and the calculated district heating energy consumption is 673 MWh/a (57.6 kWh/ m² GFA,a).
Loiskekuja 1. The fourth case building from 2016 consists of three houses with six floors each. The total number of the housing units is 115. The net floor area is 5 197 m², the gross area is 8 842 m² and the building volume is 18 830 m³. The building foundation has reinforced concrete palisade and footing. The base floor is mainly made of hollow-slab elements. The intermediate and attic floors are mainly hollow-slab elements and the staircase landings massive-slab elements. The bearing walls and pillars are embedded on site or reinforced concrete elements. The light partition walls are mostly made of concrete elements, metal wire framed gypsum boards or calcareous sandstone bricks. The suspended ceilings are mainly constructed of gypsum or acoustic boards. The floor coatings are mainly laminate, floor tile and plastic mat. The facades are mostly reinforced concrete with brickwork partly coated with fibre concrete board. The calculated electricity consumption is 150 MWh/a (16.9 kWh/ m² GFA,a) and the calculated district heating energy consumption is 517 MWh/a (58.4 kWh/ m² GFA,a).

2.3. Carbon footprint calculation results

The total calculated life-cycle carbon footprint is 11 700 t CO₂e for Kaskelantie 1, 9 010 t CO₂e for Lipputie 14, 16 900 t CO₂e for Marsinkuja 1 and 14 100 t CO₂e for Loiskekuja 1. The specific life-cycle carbon footprint for each case building is presented in Table 1.
Table 1. Specific life-cycle carbon footprint, kg CO₂e/ m² GFA

|                     | Kaskelantie 1 | Lipputie 14 | Marsinkuja 1 | Loiskekuja 1 |
|---------------------|--------------|------------|-------------|-------------|
| Production phase    | 304          | 291        | 285         | 326         |
| Transport to construction site | 10           | 8          | 9           | 11          |
| Construction phase  | 42           | 57         | 50          | 40          |
| Maintenance and repair | 83         | 83         | 81          | 75          |
| Energy consumption  | 823          | 938        | 959         | 1082        |
| Water consumption   | 57           | 57         | 57          | 53          |
| Deconstruction      | 12           | 12         | 8           | 9           |
| Total               | 1 325        | 1 448      | 1 448       | 1 595       |

The construction season, weather conditions and waste sorting have an impact on the carbon footprint of the construction phase. Special attention was paid to the waste sorting at the construction site of Kaskelantie 1 because of the requirements of the Nordic Swan label. This stricter way of waste sorting lowered the carbon footprint of the construction waste, where especially the mixed waste and energy waste have significantly larger emissions than other waste types.

The renewable energy production of the solar panels at Kaskelantie 1 has been calculated to save 15.5 kg CO₂/ m² GFA during the life-cycle calculation period of 60 years. The carbon footprint of the solar panel system materials has been estimated as 2.0 kg CO₂/ m² GFA and thus the net saving is 13.5 kg CO₂/ m² GFA. The solar panels have been estimated to be replaced once during the calculation period of 60 years.

The life-cycle carbon footprint calculation excludes the domestic electricity use inside of the flats as a non-building related energy consumption, though it produces a considerable amount of emissions of the energy used in the whole building.

2.4. Additional carbon footprint calculation results

An additional carbon footprint calculation was done for Kaskelantie 1 to estimate the effect of alternative design solutions increasing the energy-efficiency (Table 2). Here both the effect of a single measure and the total effect of several measures was compared to the base case presented in the earlier chapter. According to the calculation results, the most cost-effective solutions with the 60 years calculation period were option 8) decentralized ventilation system, option 3) decentralized demand-controlled ventilation in flats and option 1) increasing the annual ventilation heat recovery efficiency rate. Carbon footprint decrease of a single measure is relatively small, but several simultaneous measures give noticeable changes.

Table 2. Effect of alternative design solutions on the base case of Kaskelantie 1

| Effect, kg CO₂e/ m² GFA | Investment, €/tnCO₂e | Lifecycle cost, €/tnCO₂e |
|-------------------------|----------------------|--------------------------|
| 1. Increasing annual ventilation heat recovery efficiency rate from 66.7 % to 78.0 % | -56 | 110 | -30 |
| 2. Decreasing the window U-value from 0.8 to 0.6 | -24 | 300 | 120 |
3. Increasing the amount of decentralized demand-controlled ventilation in flats -57 90 -50
4. Decreasing the attic floor U-value from 0.13 to 0.07 -9 1030 840
5. Decreasing the outer wall U-value from 0.17 to 0.14 -13 330 130
6. Decreasing the base floor U-value from 0.16 to 0.10 -2 1240 1050
7. Decreasing the air-tightness value from 2 to 1 m³/h,m² -17 190 10
Total effect of measures 1.-7. -161 240 40
8. Decentralized ventilation system instead of centralized

The effect of the energy source on the carbon footprint was studied by comparing district heating from the local energy company and ground source heating. The change from district heating to ground source heating decreased the carbon footprint by around 35%. However, a possible future decrease of district heating emissions was not considered in the calculation.

3. Discussion
The specific lifecycle carbon footprints for the four case buildings were between 1325–1595 kg CO₂e/m² GFA for the calculation period of 60 years. The share of the energy consumption in the lifecycle carbon footprints of the case buildings was between 823–1082 kg CO₂e/m² GFA and the share of the building materials between 384–421 kg CO₂e/m² GFA. This means that around 65% of the lifecycle carbon footprint was caused by the energy consumption and around 20% by the building materials.

The largest building material carbon footprints were caused by building service systems, horizontal structures, outer walls and foundations. The share of the building service system materials was around 25-31% of the total carbon footprint of the building materials. The amount of building service materials was estimated as a rough figure based on system specific data and building area including also elevators and solar panels. The estimated amount is probably too high considering other research results, e.g. CIBSE (2013) where the estimated share was only around 10-12% [4]. Increasing the complexity and amount of building service systems, including renewable energy production systems, increases also the carbon footprint of the building service system materials, also due to replacements during the building lifecycle. However, this increase might be compensated due increased energy-efficiency and reduced carbon footprint of the energy consumption.

Loiskekuja 1 had the largest carbon footprint due to its larger energy consumption and chosen building materials with larger emissions. Marsinkuja 1 had the lowest material carbon footprint, because no palisade was needed for the foundation of the building. The specific life-cycle carbon footprint was smallest for Kaskelantie 1, the case building with the Nordic Swan ecolabel. The main reason for this smaller carbon footprint was its better energy efficiency.

75% of the carbon footprint of the energy consumption was caused by district heating energy consumption and 25% of electricity consumption. According to the additional carbon footprint calculation results for Kaskelantie 1 the largest potential for decreasing the carbon footprint, compared to the base case, is the utilization of ground source heat instead of district heating. Here the probable development of technology and change of energy consumption emissions in the future have not been taken into account.

The most cost-effective alternative design solutions of the additional carbon footprint calculation were all related to decreasing the energy consumption of the ventilation system: the most cost-efficient single measure for reducing the carbon footprint was the implementation of decentralized ventilation.
instead of centralized ventilation. Other cost-efficient measures were decentralized demand-controlled ventilation in flats and increasing the annual ventilation heat recovery efficiency rate.

It is worth noticing that the energy emission data utilized in the lifecycle carbon footprint calculations was based on the emission values from the year 2016. Thus, the calculation did not consider the possible, foreseen reduction of the energy emissions in the future. This reduction may decrease the significance of energy-efficiency and increase the significance of the building materials in reducing the carbon footprint.

4. Conclusions

The four most important measures to minimize the carbon footprint of buildings are 1) utilization of renewable energy sources, 2) increasing the energy-efficiency, 3) increasing the material-efficiency and 4) the favour of low-emission materials.

The Finnish building regulations concerning nearly zero-energy buildings, effective since 2018, have tightened the energy-efficiency demand of buildings by around 10-15%. Even though the energy-efficiency of new buildings has been steadily increasing due to tighter building regulations and actions by building owners, the largest potential in reducing the carbon footprint of a building is still in increasing the energy efficiency of the building.

The passive, architectural solutions are the first step for minimizing the energy consumption. Ventilation system design has a large effect on the energy-efficiency of the building. Demand-controlled ventilation reduces consumption of the fan electricity, heating energy and cooling energy. The heating energy consumption can be reduced by an effective heat recovery system from the outlet air. According to Liljeström & Törnblom (2009) the annual heat recovery efficiency of decentralized ventilation units inside flats is often higher than with centralized, larger ventilation units and the annual energy costs are lower [5].

The emission factors of different energy sources have a large effect on the life-cycle carbon footprint calculation results. Therefore, real emission factors should always be used when they are available. It should also be possible to take into account if the electricity used on the construction site has been produced with renewable energy sources. One Click LCA includes also a greener electricity profile, where the production is made with 10% of solar, 30 % of water and 60 % of wind.

Even though the energy consumption currently is the most dominant factor in the lifecycle carbon footprint, the potentially decreasing carbon emissions of energy production will increase the importance of the building materials in the total lifecycle footprint, and therefore solutions for e.g. low carbon concrete and renewable and/or recyclable building materials should be developed and taken into use.

The role of circular economy solutions and minimization of building materials is increasing in new construction projects. The amount of building materials can be minimized e.g. by increasing the lifetime of the buildings and considering both the flexibility of the building use and material recycling possibilities already in the design phase.

The life-cycle carbon footprint should be considered as early as possible during the construction project for a larger impact and better cost-efficiency. The carbon footprint calculation method is a necessary step to enable the evaluation and future restriction of the life-cycle carbon footprint of a building. The calculation should guide the design of the building and enable design choices ending into a lower carbon footprint. The calculation method should also consider the existing EU standards and be in line with the future product environmental footprint (PEF) methods.

The material data in the carbon footprint calculation database should be transparent and justified and there should be a possibility to utilize own, verified emission data. This is also possible with One Click
LCA. Utilization of generic material data does not enable taking into account the utilization of recycled material, which may also reduce the carbon footprint of a building. For example, the Nordic Swan ecolabel requires that 40% of the aluminium, 30% of PVC and 20% of steel used in windows is recycled. Considering this requirement in carbon footprint calculation would require a verified environmental product declaration (EPD).

Ecolabelling is one measure for guiding the design of low-carbon buildings. Kaskelantie 1, the building with the Nordic Swan ecolabel, had the lowest lifecycle carbon footprint of all the four case buildings. Even here it would still be possible to decrease the carbon footprint caused by the energy consumption by 10% with energy-efficiency measures. The carbon footprint decrease potential for the building materials is estimated to be the same 10%. The total effect of these both 10% + 10% saving potentials would be around 15% during the whole building life cycle of 60 years. In this case the specific lifecycle carbon footprint for 60 years would be around 1100 kg CO²e/m² GFA.

According to the calculation results presented in this paper, a potential set value by the building regulations for the carbon footprint of the building materials could be around 350 kg CO²e/m² GFA without delimiting the use of concrete in building. For construction with concrete, this limit would demand specific attention to increase the material efficiency and replacing concrete structures with wood when possible. The carbon footprints of alternative building service systems should also be thoroughly inspected, e.g. plastic sewers vs. cast iron sewers, copper pipes vs. plastic pipes, centralized vs. decentralized ventilation and floor heating vs. radiator heating. It would also be important to study possible low-carbon concrete alternatives and if the carbon footprint of footing could be decreased e.g. by using steel bore piles.

The role of the building regulations is to state the minimum level for construction, whereas the role of the voluntary ecolabelling of buildings is to enhance the construction industry into continuous improvement and to speed up the technological development.

Ecolabelling can therefore act as a test bench for upcoming building regulations. Here the forerunners can first test fulfilling the requirements of the ecolabel and after this piloting period specific issues from the ecolabelling criteria can be introduced by the authorities in the obligatory building regulations. The Nordic Swan ecolabel as the third party can also follow and verify that the material choices made in the design phase have been considered in the construction phase and not replaced by other alternatives.

5. References

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