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Life-cycle environmental impacts of a standard house and three log house cases

A comparison of a typical Finnish house and three ecological log house designs with alternative external wall thicknesses

Antti Ruuska

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VTT
PB 1000 (Teknikvägen 4 A, Esbo)
FI-02044 VTT
Tfn +358 20 722 111, telefax +358 20 722 7001

VTT Technical Research Centre of Finland
P.O. Box 1000 (Tekniikantie 4 A, Espoo)
FI-02044 VTT, Finland
Tel. +358 20 722 111, fax +358 20 722 7001

Life-cycle environmental impacts of a standard house and three log house cases
A comparison of a typical Finnish house and three ecological log house designs with alternative external wall thicknesses

Elinkaarenaikaiset ympäristövaikutukset normitalolle ja kolmelle hirsitalolle. Perustasoisen suomalaisen normitalon ja kolmen ekologisen hirsitaloratkaisun vertailu hirsitalojen erilaisilla ulkoseinäpaksuuksilla. **Antti Ruuska.** Espoo 2013. VTT Technology 148. 61 p. + app. 1 p.

Abstract

This publication presents the calculation results for the life-cycle environmental impacts of a typical Finnish wood framed house, called 'standard house'. The calculation results are also presented for three alternative log house, with extensive use of wood and log products in structures. The log house cases vary only in their external wall log thickness.

The results take into account the emissions from material acquisition, production and transportations, as well the emissions from construction phase. The lifetime emissions are considered in terms of materials for repairs and renovations, and emissions from operational energy use over a life-cycle of 50 years. Also, the energy use for demolition and removal of demolition waste from site is included in the assessment.

The results for the material production show that the greenhouse gas emissions of log houses are 40% lower than those of the standard house. Total GHG emissions for standard house are 25 tonnes (in terms of CO_2-equ), whereas the emissions for log house scenarios are 15 tonnes.

The structures of log house cases store 3.8 to 4.2 times the carbon of the standard house in their structures. The standard house stores some 14 tonnes of carbon dioxide, whereas the figures for log houses are 53 to 58 tonnes.

According to the results, the energy content of the structures of log house cases is 2.6 to 2.9 that of the standard house. Energy content of standard house is 270 GJ, and the values for log houses vary from 720 GJ to 800 GJ.

The mass of standard house is 88 tonnes, while the total mass of log house cases varies from 70 to 74 tonnes.

When the total lifetime emissions from material-related sources are considered, the results show that the greenhouse gas emissions of log houses are some 33% lower than those of the standard house. Total emissions for standard house are 39 tonnes (in terms of CO_2-equ emissions), whereas the emissions for log house scenarios are some 26 tonnes.

The total material need over the 50-year lifetime of standard house is 106 tonnes, while the material need of log house cases vary from 81 to 85 tonnes.

The operational energy use of the log house cases of this publication is higher than that of the standard house, due to differences in space-heating energy needs. This is caused by differences in U-values of external walls. This results in a

10 to 19% higher carbon footprint of log houses, when no crediting for stored carbon or bio-energy are made. If the carbon storage is credited in the calculation of the carbon footprint, the differences between standard house and log houses diminish to a level of 0 to 10%.When both bioenergy and stored carbon are considered, the carbon footprint for standard house is 167 tonnes and for log house 200, 168 tonnes (CO_2-equ). For log houses 243 and 270, the figures are 150 tonnes (CO_2-equ), and 139 tonnes (CO_2-equ), respectively. The results show that when both bio-energy of side-streams and structures and carbon credits are taken into account, the carbon footprint of log house 200 is at the same level as the standard house. The carbon footprint of the log houses 243 and 270 are 10 and 16% lower than that of the standard house.

This publication also studies the so called total energy consumption figures, as defined in Finnish building regulations. The figure for standard house is 166 kWh/m^2, and for the log houses 184 to 194 kWh/m^2, when calculation is done as stated in regulations.

Two alternative calculations of theoretical nature are also made. Firstly, the bio-energy related to wood-based structures and their side-streams is taken into account by assuming this bio energy could be used to replace heating energy use in the building. This is done by assigning the energy in wood-based structures an energy-type factor of 0.5, as in the Finnish building regulations. The results show that with these assumptions, the total energy figure for standard house is 164 kWh/m^2. For log houses, the figures vary from 176 to 187 kWh/m^2.

Secondly, bio-energy is taken into account by assuming it to be completely emission free bio-energy, thus using a value of zero for its energy type specific factor. The results show that the total energy figure for the standard house is 159 kWh/m^2. For log houses, the figures vary from 156 to 169 kWh/m^2.

Elinkaarenaikaiset ympäristövaikutukset normitalolle ja kolmelle hirsitalolle
Perustasoisen suomalaisen normitalon ja kolmen ekologisen hirsitaloratkaisun vertailu hirsitalojen erilaisilla ulkoseinäpaksuuksilla

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Tiivistelmä

Tämä julkaisu esittelee elinkaaren aikaisten ympäristövaikutusten laskentatulokset suomalaiselle perustasoiselle ”normitalolle”. Tulokset esitetään lisäksi myös kolmelle hirsitaloratkaisulle, joissa puutuotteiden ja hirren käyttö on maksimoitu. Hirsitaloratkaisut poikkeavat toisistaan ulkoseinäpaksuuden osalta.

Tulokset huomioivat rakennusmateriaalien raaka-ainehankinnan, tuotannon ja kuljetuksen päästöt sekä rakentamisesta aiheutuvat päästöt. Elinkaarenaikaiset päästöt huomioivat korjausten ja uusimisten sekä käytönaikaisesta energiankulutuksesta aiheutuvat päästöt 50 vuoden elinkaaren aikana. Myös elinkaaren lopussa tapahtuvasta purkutyöstä aiheutuvat päästöt sekä purkujätteen kuljetuksen päästöt on huomioitu laskennassa.

Materiaalituotannosta aiheutuvat päästöt ovat hirsitaloilla noin 40 % matalammat kuin normitalolla. Tuotannon aiheuttamat kasvihuonekaasupäästöt normitalolla ovat 25 tonnia (CO_2-ekvivalenttitonnia), kun ne ovat kaikilla hirsitaloskenaarioilla 15 tonnia. Hirsitalojen rakenteet sitovat itseensä 3,8–4,2-kertaisen määrän hiiltä normitaloon verrattuna. Normitalon rakenteisiin sitoutuu noin hiiltä 14 tonnia, kun hirsitalon rakenteisiin sitoutuneen hiilen määrä on 53–58 tonnia (CO_2-ekvivalenttitonnia). Laskennan hirsitalojen rakenteiden energiasisältö on 2,6–2,9-kertainen normitaloon verrattuna. Normitalon energiasisältö on 270 GJ, kun se on hirsitaloilla 720–800 GJ. Normitalon rakenteiden massa on 88 tonnia. Hirsitalojen rakenteiden massa vaihtelee välillä 70–74 tonnia.

Koko 50 vuoden elinkaaren aikaisten materiaalipäästöjen tarkastelu osoittaa, että hirsitalojen kasvihuonekaasupäästöt ovat noin 33 % matalammat kuin normitalolla. Normitalon elinkaaren aikaiset kokonaispäästöt ovat 39 tonnia (CO_2-ekvivalenttitonnia), kun taas hirsitalojen vastaavat päästöt ovat noin 26 tonnia. Rakennusmateriaalien kokonaistarve 50 vuoden elinkaaren aikana on normitalolla 106 tonnia, hirsitalojen materiaalitarpeen vaihdellessa välillä 81–85 tonnia.

Tässä julkaisussa käytetyt käytönaikaisen energiankulutuksen arvot ovat hirsitaloilla korkeammat kuin normitalolla, mikä johtuu tilojen lämmitystarpeen erosta. Lämmitystarpeen ero syntyy erosta ulkoseinien U-arvoissa. Jos hirsitalojen sitoutunutta hiiltä tai bioenergiaa ei hyvitetä laskennassa, hirsitalojen hiilijalanjälki on 10–19 % suurempi kuin standarditalolla.

Jos hiilivarasto huomioidaan laskennassa, on hirsitalojen hiilijalanjälki minimitapauksessa samaa tasoa (270 mm paksu ulkoseinä) kuin normitalolla. Maksimi-

tapauksessa hirsitalon hiilijalanjälki on 10 % suurempi (200 mm ulkoseinäpaksuus) kuin normitalolla, kun hiilivarasto on huomioitu.

Jos sekä hiilivarasto että bioenergiatarkastelut huomioidaan laskennassa, on normitalon hiilijalanjälki ja hirsirakenteiden hiilijalanjälki samaa tasoa ohuimmalla ulkoseinäpaksuudella (200 mm hirsiseinä). Käytettäessä 243 mm tai 270 mm paksuutta hirsitalojen hiilijalanjälki on 10–16 % pienempi kuin normitalolla.

Tässä julkaisussa tarkastellaan myös kokonaisenergialukuja Suomen rakentamismääräyskokoelman mukaisilla laskenta-arvoilla. Normitalolle laskettu kokonaisenergialuku on 166 kWh/m^2 ja hirsitaloille 184–194 kWh/m^2.

Julkaisussa tehdään myös kaksi teoreettista tarkastelua. Ensiksi rakenteiden bioenergian merkitystä tarkastellaan teoreettisella tasolla, olettamalla että rakenteiden bioenergiaa voitaisiin käyttää korvaamaan tilojen lämmityksen energiatarvetta. Tämä käsitellään laskennassa käyttämällä tilojen lämmitysenergiaa korvaavalle bioenergialle rakentamismääräysten mukaista bioenergian kerrointa 0,5. Näillä laskentaoletuksilla normitalolle laskettu kokonaisenergialuku on 164 kWh/m^2 ja hirsitaloille 176–187 kWh/m^2.

Toiseksi rakenteiden bioenergia käsitellään muuten samoin kuin edellä, mutta bioenergialle käytetään määräyksistä poikkeavaa kerrointa ja sen energiamuodon kerroin oletetaan nollaksi. Näillä laskentaoletuksilla normitalon kokonaisenergialuku on 159 kWh/m^2 ja hirsitaloille 156–169 kWh/m^2.

Avainsanat Life-cycle, environmental impacts, log house, greenhouse gas emissions

Contents

1. Introduction

This publication is prepared for the Finnish Log Industry. The publication presents calculation results for the environmental impacts of a standard house and three log house cases. The results show how typical a Finnish house and three ecological log house designs with alternative external wall thicknesses compare to each other.

2. Scope of the assignment

This publication presents the calculation results for the life-cycle environmental impacts of a typical Finnish wood framed house, called ‘standard house’. The calculation results are also presented for three alternative log house, with extensive use of wood and log products in structures. The log house cases with a varying external wall log thickness.

The results take into account the emissions from material acquisition, production and transportations, as well the emissions from construction phase. The lifetime emissions are considered in terms of materials for repairs and renovations, and emissions from operational energy use. Also, the energy use for demolition and removal of demolition waste from site is included in the assessment.

Chapter three starts by presenting structures of the standard building in detail, and then presents the three alternative cases with log structures.

Chapter four shows a summary of the environmental impacts from the material production of the building. The chapter compares the structures of different cases, in terms of mass, stored carbon, greenhouse gas emissions and energy content. The results allow for a better understanding on how the cases differ from each other and what causes the differences. The results presented in chapter four are so called “cradle-to-gate” emissions, including only the emissions from the material production. In other words, the results of this chapter exclude the environmental impacts from material transportations, on-site material waste, emissions from construction work, and operational and end-of-life phases. These will be discussed in more detail in the later chapters.

Chapter five shows the environmental impacts of the material waste during the on-site construction activities, while chapter six discusses the lifetime renovation activities and their impacts.

Chapter seven summarizes the results from lifetime material-related emissions by including all the results from Chapters four to six. The totals of Chapter seven are used then in Chapter eight to calculate the emissions from material transportations. Chapter nine assesses the emissions from construction and demolition activities. Finally, Chapter ten summarizes all the previous Chapters four to nine, to present the total life-cycle emissions from material-related sources.

The lifetime total operational energy consumption and related emissions are discussed in Chapter 11, while the greenhouse gas impacts for the whole life-cycle of the buildings are assessed in Chapter 12.

Chapter 13 presents and discusses the results for all the four alternative cases.

3. Structures of the standard house

The standard house is a one-floor, two-family log house, whose structures fulfil the prevailing Finnish building standards. The building has wood-framed external walls and a felt roof with supporting wooden trusses. The base floor is a load-bearing, ground-supported cast-in-place concrete slab. The two dwelling units of the building are identical, and they are separated by a wood-framed double wall. Both of the dwellings consist of a bedroom, walk-in clothing closet, entrance hall, kitchen-living room, bathroom, sauna, outside storage room and two terraces.

3.1 Basic information, standard house

Table 1 shows the basic information for the standard house, including the total area of the building (building's footprint), heated area of the building and building volume. Figures 1 and 2 show the elevations and floor plan of the building, and Table 2 shows the bill of quantities for the building.

Table 1. Standard house, basic information.

Volume and Area information		
Area of the building	141	m^2
Net (heated) floor area	134	m^2
Building Volume	460	m^3

Figure 1 shows the elevations of the standard house. The house is a single-floor building with two apartments. Both of the apartments are identical but reversed images of each others.

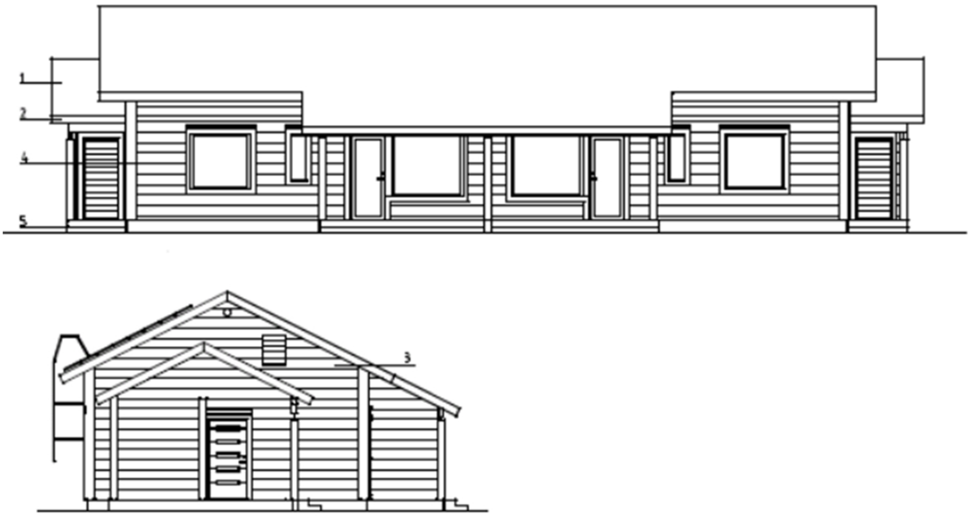

Figure 1. Elevations of the standard house.

Figure 2 shows the two layout of the two apartments in more detail by presenting the floor plan of the house.

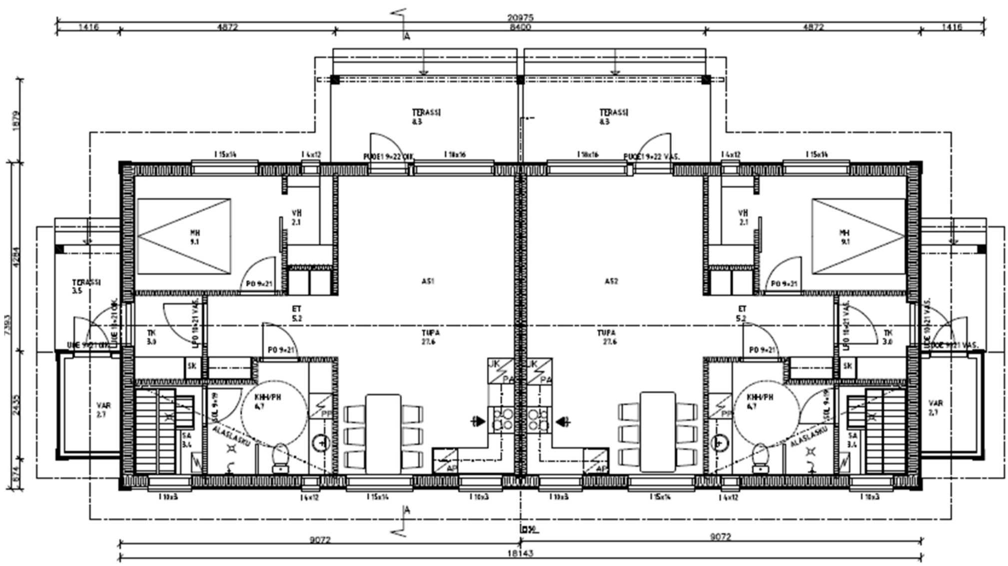

Figure 2. Floor plan of the standard house.

The bill of quantities for the standard house is presented in Table 2. The table shows the quantities for different structure types in the building. These structure types are described in more detail in the following sections.

Table 2. Bill of quantities, standard house.

Item	Quantity	Unit
Foundations		
Foundation Wall	69	m
Foundation Pillar	5	Pcs
Base Floor		
Ground-Supported Floor Slab	135	m^2
External Walls		
External Wall 1	73	m^2
External Wall 2	14	m^2
External Wall 3	23	m^2
Internal Walls		
Internal Wall 1	19	m^2
Internal Wall 2	65	m^2
Internal Wall 3	40	m^2
Roof		
Roof With Wooden Trusses	130	m^2
Others		
Wooden Windows	21	m^2
Wooden External Doors	6	Pcs
Wooden Internal Doors	8	Pcs
Wooden Terrace	24	m^2
User Inputs		
Wooden battens	160	kg
Wood cladding	310	kg
Plywood, Spruce	1200	kg

3.2 Foundations

The building has two types of foundations, the foundation wall and the foundation pillars. The foundation wall surrounds the building under the external walls. It also supports the walls of the storage rooms at the ends of the building. The total length of the foundation wall is 69 metres.

The five foundation pillars are used to support the terrace on the long edge of the building. The foundations are illustrated in Figure 3.

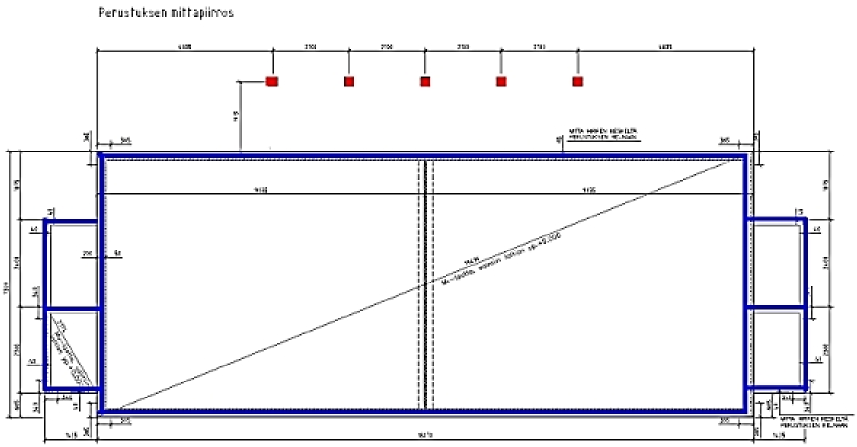

Figure 3. Foundations. The foundation pillars (5 pcs) are marked with red, the foundation wall (69 m) with blue.

3.3 Base-floor slab

The base-floor slab of the standard house is 80 mm thick, ground-supported cast-in-place concrete slab. 200 mm thick EPS-insulation is placed below the slab, with an additional 50 mm of insulation at the edges of the slab. The insulation layer is laid on top of a 200 mm thick layer of lightweight aggregate.

It is assumed that the floor surfaces of sanitary spaces are covered with 6 mm thick ceramic tiles, and that all other spaces are covered with parquet flooring. The floor slab sections of storage rooms, and under the external walls and partition walls are assumed to be untreated concrete.

A dividing wooden double wall is built on top of the floor slab. The floor slab under the dividing wall is strengthened with a 500 mm wide reinforcing strip, where the floor slab's thickness is 280 mm.

3.4 External walls

The structure of the external walls is presented in this section. The total area of external walls is 111 m^2, for the residential spaces' walls and 25 m^2 for the storage rooms' walls.

There basic structure of the external walls of the standard house is as follows:

- wooden cladding (24 mm)
- wooden battens and ventilation gap (22 mm)
- wind shield gypsum board (9 mm)
- wooden frame and mineral wool insulation (250 mm)
- water vapour barrier (0,2 mm)
- gypsum board (13 mm).

The external walls of sanitary spaces are otherwise the same, except that they have 6 mm thick ceramic tile cladding on their inner surface. The external walls of sauna have an additional 50 mm layer of insulation wool. The walls of the storage rooms are simple, wood-framed walls. These walls are uninsulated, wood-clad walls.

It should be noted that the bill of quantities of Table 2 includes a section titled "user inputs". The walls of the storage rooms are included in this section as wooden battens and wooden cladding, totalling 500 kg.

3.5 Internal walls

The height of all the internal walls is 2700 mm and they are insulated with rock wool. The wooden battens used for internal walls have a 42 x 70 mm cross section.

3.5.1 Internal wall 1

A wood-framed double wall divides the two apartments of the building. The wall consists of two separate wooden frames. Each of the wood frames is 70 mm thick, and insulated with rock wool. There is a small gap between the two wall frames. The living-space-side of the walls is clad with a double gypsum board covering, with a combined thickness of 26 mm.

3.5.2 Internal wall 2

The partition wall 2 is a wood panel covered, wood-framed wall, with 600 mm-spacing between the battens. It is used as the internal wall for all the living spaces.

The partition wall 2 is also used as the partition wall between the entrance hall and the sauna. The partition walls of sauna typically have aluminium-covered mineral wool insulation boards as heat- and moisture insulation barrier. However, the role of the insulation boards was considered only minimal in this case, so it is not taken into account in the calculations.

3.5.3 Internal wall 3

The partition wall between the living spaces and sanitary spaces is made of light-weight concrete blocks. The wall is clad with wooden panels from one side (the side of the living spaces) and gypsum board and ceramic tiling from the other.

Partition wall 3 is also used as the wall between the sanitary spaces and sauna. As explained earlier, sauna walls typically have heat insulation. However, it is not taken into account in these calculations, due to relatively small importance.

3.6 Roof structures

The standard house has a felt roof with supporting wooden trusses with the following structure:

- roof covering (felt roof)
- plywood (19 mm)
- wooden trusses
- mineral wool insulation (500 mm)
- moisture barrier layer
- wooden battens (45 mm)
- gypsum board (13 mm).

It should be noted that the previous bill of quantities of Table 2 included a section titled “user inputs”. For calculation purposes, the plywood of roof is calculated in this section. The total amount of the plywood in roof structures, in terms of its mass, equals to 1200 kg.

3.7 Other structures and materials

The other structures include internal and external doors, windows, and the structures of the terraces. List of these structures is presented in Table 2.

3.8 Calculations of the log house scenarios

The standard house was altered for calculation purposes to create three alternative log house scenarios with ecological design and different external wall thicknesses. The purpose was to create cases, where log and wood-based products are used extensively. This section presents the alterations in structures of the standard house, which were made to create the log house scenarios.

The floorplan, which is similar to that of the standard house, is presented in Figure 4.

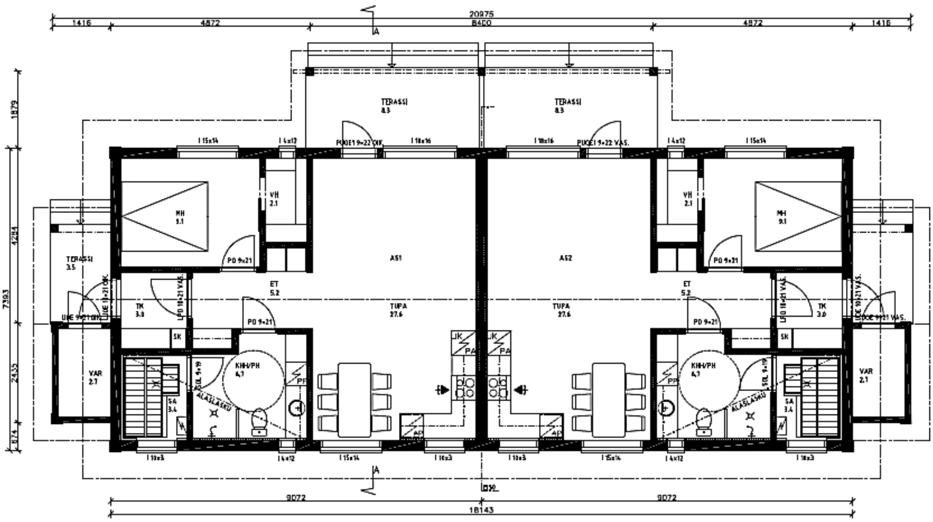

Figure 4. Floorplan of the log house cases (the width of the external wall varies between the cases).

The base-floor slab of the standard house is replaced with a ventilated bottom floor structure with similar thermal performance as the ground-supported floor of the standard house. It has the following layers:

- wooden flooring (28 mm)
- air barrier layer
- wooden frame and wood fibre insulation (350 mm)
- wind shield barrier (wood fiber board)
- crawl space below the floor
- EPS-insulation (50 mm).

The roof structure of the log houses has cellulose-based insulation, instead of the mineral-wool insulation of the standard house. Also, the ceilings are made of wood panels, instead of gypsum boards.

The internal walls of the log houses are all made of log. Internal wall 1 has a double structure with 135 mm+135 mm log, while internal walls 2 and 3 have a 135 mm log structure. The internal wall surfaces are changed from gypsum board to wood panels in the log house scenarios

The load-bearing structure of the external walls is changed from wood battens to either 200 mm, 243 mm or 270 mm thick log walls. The different scenarios are named after the thickness of the external walls, as ‘log house 200’, ‘log house 243’ and ‘log house 270’.

4. Environmental impacts of building materials

This chapter presents a summary of the environmental impacts from the material production of the building. The intent of the chapter is to compare the structures of different cases, in terms of mass, stored carbon, greenhouse gas emissions and energy content. The results allow for a better understanding on how the cases differ from each other and what causes the differences.

The results presented in this chapter four are so called “cradle-to-gate” emissions, including only the emissions from the material production, from cradle to the factory gate. In other words, the results of this chapter exclude the environmental impacts from material transportations, on-site material waste, emissions from construction work, and operational and end-of-life phases. These will be discussed in more detail in chapters five to nine.

4.1 Mass of structures

The calculations of the building for four different cases show that the mass of standard house is 88 tonnes. The log house with 200 mm walls weighs 70 tonnes, while the alternatives with 243 mm and 270 mm walls weigh 73 and 74 tonnes, respectively. (See Figure 5.)

The results show that the mass of log houses is 15 to 20% lower than that of the standard house.

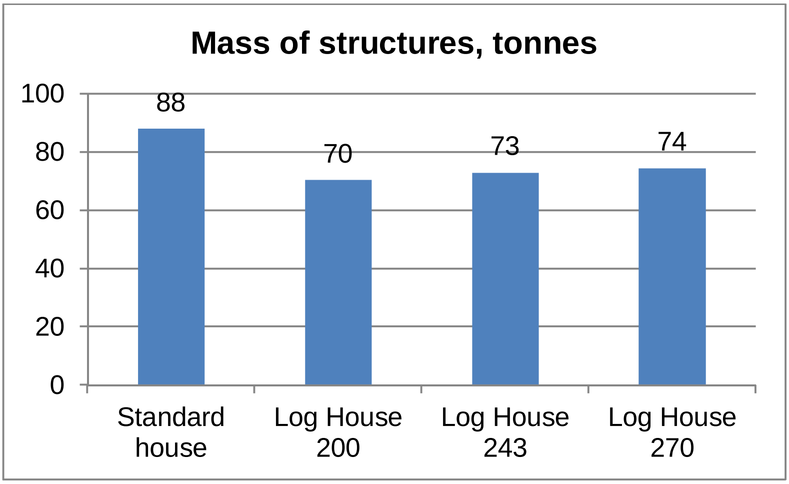

Figure 5. Mass of structures. The structures of standard house, compared to log house 200, 243 and 270.

The biggest weight difference between the standard house and the log houses is caused by the differences in the base floor slab. The base-floor and foundations of the standard house weigh some 64 tonnes, while the wooden base-floor of the log houses weighs only 34 tonnes.

The total weight difference between standard and log houses is reduced by the internal and external walls, which are heavier in the log houses. The walls weigh some 27 tonnes in the log house with 270 mm thick external walls and only 12 tonnes in the standard house.

The foundations and base-floor structures are accountable for the biggest mass share (73%) for the standard house. The roof structures and internal walls have the second biggest share (8% each), while the share of external walls (6%) and other structures remains low.

For the log houses, the case with the 270 mm external walls is used here as an example. When comparing the case to the standard house, the relative share of foundations and base floor is smaller (46%), and the share of external walls (22%) and internal walls (15%) is bigger than that of the standard house. The role of roof structures is at the same level with some 10% of the totals, with other structures accounting for a smaller share.

4.2 Stored carbon

The calculation results show that the total amount of carbon stored in the structures of standard house is 14 tonnes (in terms of CO_2-equ). The log house with 200 mm walls has 53 tonnes of stored carbon, while the alternatives with 243 mm and 270 mm walls store 56 and 58 tonnes of carbon, respectively. (See Figure 6.)

The results show that log house cases store 3.8 to 4.2 times the carbon of the standard house in their structures.

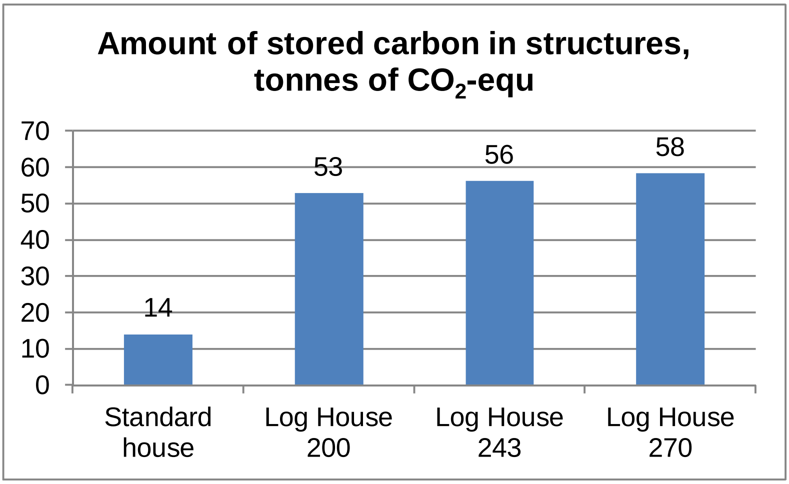

Figure 6. Amount of stored carbon in structures. The structures of standard house, compared to log house 200, 243 and 270.

The carbon stored in the standard house is stored mainly in the external walls (30%) and roof structures (30%). When looking at the log house with 270 mm walls, there are several items, such as external walls (37%), internal walls (23%), base floor (15%) and roof structures (15%), storing a large amount of carbon.

4.3 Greenhouse gas emissions

The calculations results show that the total amount of greenhouse gas emissions of standard house is 25 tonnes (in terms of CO_2-equ). The log house with 200 mm causes 15 tonnes of emissions, as do the two other log house alternatives. (See Figure 7.) This is due to the fact that between the cases, only the log thickness of external walls changes. Due to a relatively low emission factor of log (see Appendix A), the differences are not visible when rounding the results to full tonnes.

The results show that the greenhouse gas emissions from the material production of log houses are 40% lower than those of the standard house.

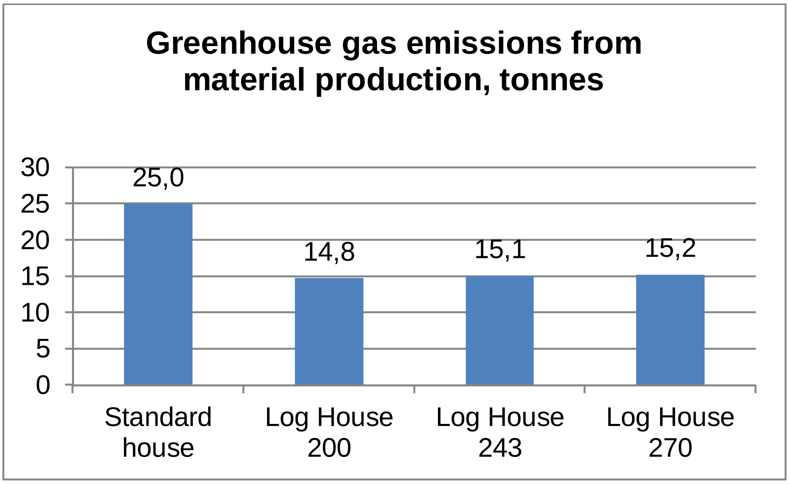

Figure 7. GHG emission from material production of structures. The structures of standard house, compared to log houses 200, 243 and 270.

The GHG emissions of the standard house are mainly from material production of foundations and base floor (50%), followed by those of roof (20%) and internal walls (12%). The share of external walls is relatively small (6%).

Also, for the log houses, the foundations and base floor are responsible for the biggest share of emissions (35%), followed by roof (20%) and external (14%) and internal walls (11%). The role of complementing structures becomes also significant in the log houses (13%). These figures shown are for the log house with 270 mm thick external walls.

4.4 Energy content of structures

The results show that the total energy content of the structures of standard house is 273 GJ. The log house with 200 mm walls has an energy content of 720 GJ, while the alternatives with 243 mm and 270 mm walls have an energy content of 771 GJ and 803 GJ, respectively. (See Figure 8.)

The results show that log house cases have 2.6 to 2.9 times the energy content of to the standard house.

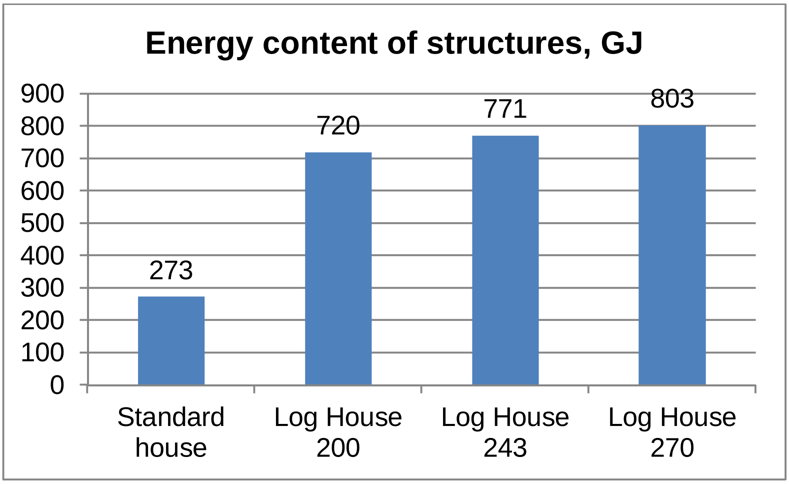

Figure 8. Energy content of structures. The structures of standard house, compared to log houses 200, 243 and 270.

The main part of the energy content for standard house is stored in the roof (28%) and the base floor structures (22%). The roles of external walls (18%) and complementing structures (12%) are also significant.

For the log houses (log house 270), the biggest part of the energy content is in the external (40%) and internal walls (26%). These are followed by roof structures (11%) and base floor (10%).

4.5 Summary of environmental impacts of building materials

Table 3 summarizes the environmental impacts of building materials in terms of mass, stored carbon, energy content and greenhouse gas emissions.

Table 3. Mass (t), stored carbon (t CO_2-equ), energy content (GJ) and greenhouse gas emissions (t CO_2-equ) of the cases, results presented for standard house, log house 200, log house 243 and log house 270.

	Mass (t)	Stored carbon dioxide (t)	Energy content (GJ)	Greenhouse gas emissions (t)
Standard house	88	14	273	25
Log house 200	70	53	720	15
Log house 243	73	56	771	15
Log house 270	74	58	803	15

The results show that the greenhouse gas emissions from the material production of log houses are 40% lower than those of the standard house. Total emissions for standard house is 25 tonnes (in terms of CO_2-equ emissions), whereas the emissions for log house scenarios are 15 tonnes.

The structures of log house cases store 3.8 to 4.2 times the carbon of the standard house in their structures. The standard house stores some 14 tonnes of carbon dioxide, whereas the figures for log houses are 53 to 58 tonnes.

According to the results, the energy content of the structures of log house cases is 2.6 to 2.9 bigger than for the standard house. Energy content of standard house is 270 GJ, and the values for log houses vary from 720 GJ to 800 GJ.

The mass of standard house is 88 tonnes, while the total mass of log house cases vary from 70 to 74 tonnes.

5. Material waste during construction phase

This chapter discusses the impact of material waste during construction phase and its impacts on the results of the previous chapter. The material waste adds to the total material needs of a building, therefore increasing the environmental impacts of building.

The on-site material waste is estimated with information provided by the contractor[1]. The waste percentages are presented in Table 4. For those materials not included in the table, a 10% waste percentage is used.

Table 4. Material wastage / losses during construction, based on information provided by the contractor, for all the items outside the table, 10% is used.

Material	Waste -%
Wood supports for felt roof	10
Wood supports for steel / ceramic roof	20
Roof covering sheeting for felt roof	10
Roof covering sheeting for steel /ceramic roof	20
Other wood parts of the roofings	20
Wind barrier board	5
Moisture barrier	20
Air barrier paper	20
Insulation materials	2
Floor coverings	6
Wooden wall coverings	8
Wooden ceiling coverings	15
Log wood panels	8
Wood for wooden frames	20
Floor beams	20
Log	0
Other materials	10

[1] Waste percentages used by the contractor, Kontiotuote Oy.

The total amounts of material waste and its environmental impacts are presented in the following Table 5. The amounts are based on the structures of the building, and waste percentages presented above in Table 4.

Table 5. Mass (t), stored carbon (t CO_2-equ), energy content (GJ) and greenhouse gas emissions (t CO_2-equ) due to material waste during construction, results presented for standard house, log house 200, log house 243 and log house 270.

	Mass (t)	Stored carbon dioxide (t)	Energy content (GJ)	Greenhouse gas emissions (t)
Standard house	7	1	24	1
Log house 200	5	2	32	1
Log house 243	5	2	32	1
Log house 270	5	2	32	1

The greenhouse gas emissions from material losses during construction phase are taken into account in the total greenhouse gas emissions for the buildings.

6. Lifetime renovation activities

This chapter discusses the impact of lifetime renovation activities. The buildings undergo maintenance, renovations and replacements over their life-cycles. These all add to the total material needs of a building, therefore increasing also its environmental impacts.

The calculation assumptions for the renovation activities are presented in the following table. The length of the life-cycle for all the cases is 50 years. It is assumed that the main components of the building frame last for the whole life-cycle without significant renovation needs.

However, the internal and external surfaces undergo renovations during the 50-year timespan. These are expected to be replaced once, after 25 years of use. Table 6 summarizes the assumptions made in the calculations. The renovations are assumed to be complete replacements, where the original structures are completely removed and re-built to match the original structures.

Table 6. Renovations over 50-years life-cycle for all the cases.

Building component	Renovations over a 50-year life-cycle
Foundations	-
Base-floor	1 time (replacement of floor surfaces)
External wall	1 time (replacement of internal and external surfaces)
Internal walls	1 time (replacement of internal wall surfaces)
Roof structures	1 time (replacement of ceiling and roofing surfaces)
Complementing structures	-

When the assumptions of the previous table are applied to the structures of the case-buildings, the total life-time material consumption for renovations can be assessed. The total mass of materials and the environmental impacts from material consumption over the lifetime of the case buildings are presented in Table 7.

Table 7. Mass (t), stored carbon (t CO_2-equ), energy content (GJ) and greenhouse gas emissions (t CO_2-equ) of the materials for lifetime renovations over 50-year life-cycle, results presented for standard house, log house 200, log house 243 and log house 270.

	Mass (t)	Stored carbon dioxide (t)	Energy content (GJ)	Greenhouse gas emissions (t)
Standard house	11	6	110	6
Log house 200	6	5	95	4
Log house 243	6	5	95	4
Log house 270	6	5	95	4

The greenhouse gas emissions from renovations are taken into account in the total greenhouse gas emissions for the buildings. It should be noted that the log houses 200, 243 and 270 have similar emissions from renovations. This is due to the fact that the cases differ only in terms of the thickness of external walls, which do not need renovations over a life-cycle of 50 years.

7. Lifetime totals for material consumption and environmental impacts

This chapter summarizes the calculation results of previous chapters by combining them into a single table. Table 8 presents the total amount of materials needed to build and maintain a building over a 50-year life-cycle (total mass of materials), including material waste during construction and renovations. It also shows the total mass of the cases (total mass of buildings), the amount of stored carbon and the energy content of the buildings' structures. Also, the total greenhouse gas emissions from the material production are shown.

Table 8. Total mass of materials(t), total mass of building (t) stored carbon (t CO_2-equ), energy content (GJ) and greenhouse gas emissions (t CO_2-equ) of the materials of the building, over a 50-year life-cycle, results presented for standard house, log house 200, log house 243 and log house 270.

	Total mass of materials (t)	Total mass of building (t)	Stored carbon dioxide (t)	Energy content (GJ)	Greenhouse gas emissions (t)
Standard house	106	88	14	273	32
Log house 200	81	70	53	720	20
Log house 243	84	73	56	771	20
Log house 270	85	74	58	803	20

It should be highlighted that the stored carbon dioxide and energy content of construction and renovation waste are not included in Table 8. They are considered as properties of construction waste, not as properties or environmental impacts of the building. However, the total amount of building materials consumption and resulting greenhouse gas emissions are included, as they are direct impacts of the building and its renovations.

8. Effects of transportation

This chapter discusses the impact of transportations of building materials and waste over the life-cycle of the building. The material transportations from the factory to building site, and the transportations of waste from the building site to landfill, cause environmental impacts which need to be included in life-cycle environmental impacts of a building.

The transportation calculations are simplified by assuming that the lifetime material balance of the building site equals zero. In other words, all the materials that are used as building materials also exit the site as waste. The building materials are transported to site with freight lorries (max load 9t), whose unit emissions are 113 g/tkm[2]. The construction and demolition waste are estimated to be taken out of site with earth-hauling trucks with emissions of 83g/tkm.[3]

As the amount of building materials and waste are equal, the amount of material transportations over the life-cycle of a building equals to the total material masses, presented in the Table 8, multiplied by two.

Since the amount of building material and waste transportations are equal, the average unit emissions for transportations can be calculated as the average of freight lorries and earth-hauling trucks. The resulting emission profile for transportations is 98 g/tkm.

The transportation distance for both materials and waste is estimated to be 50 km. Table 9 summarizes the emissions from transportations.

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[2] VTT's LIPASTO-database, http://lipasto.vtt.fi/yksikkopaastot/tavaraliikenne/tieliikenne/kajaksuuritie.htm.

[3] VTT's LIPASTO-database, http://lipasto.vtt.fi/yksikkopaastot/tavaraliikenne/tieliikenne/kamaanstie.htm.

Table 9. Greenhouse gas emissions of material and waste transportation. Emissions presented in terms of tonnes of CO_2-equ emissions. The table also shows the total mass of transported materials (t), transport distance (km), transportation units (tkm) and unit emissions for transportation (g CO_2-equ/tkm).

	Total mass of transported materials (t)	Transport distance (km)	Transportation units (tkm)	Unit emissions for transportation (g CO_2-equ /tkm)	Greenhouse gas emissions (t)
Standard house	212	50	10588	98	1,0
Log house 200	162	50	8122	98	0,8
Log house 243	167	50	8369	98	0,8
Log house 270	170	50	8524	98	0,8

The greenhouse gas emissions from transportations are taken into account in the total greenhouse gas emissions for the buildings. It should be noted that the log houses 200, 243 and 270 have similar emissions from transportations. This is due to the fact that the cases differ only in terms of the thickness of external walls, which causes only small differences in the total transport.

9. Energy for construction and demolition

The energy consumption of the site activities is collected from the building site of a similar building. The energy consumption is converted to emissions using VTT's LIPASTO-database.

The energy consumption of the demolition work is estimated to be of the same scale as for the construction work. However, the heating energy consumption of the demolition phase is estimated to be zero. The totals for both construction and demolition energy use and greenhouse gas emissions are presented in Table 10.

Table 10. Total greenhouse gas emissions from construction and demolition work. Emissions presented in terms of tonnes of CO_2-equ emissions. The table also shows the total energy use for construction work (GJ), emissions from construction work (t CO_2-equ), energy use for demolition work (GJ) and emissions from demolition work (t CO_2-equ).

Item	Energy use for construction work (GJ)	Emissions from construction work (t CO_2-equ)	Energy use for demolition work (GJ)	Emissions from demolition work (t CO_2-equ))	Total greenhouse gas emissions (t CO_2-equ)
Lifters	7,6	0,6	7,6	0,6	1,2
Tractor excavators	2,5	0,2	2,5	0,2	0,4
Other drivable machines	1,5	0,1	1,5	0,1	0,2
Chain saws	3,5	0,3	3,5	0,3	0,6
District heat	42,2	3,1	0	0	3,1
Electricity	1,2	0,1	1,2	0,1	0,2
Total	58,5	4,4	16,3	1,3	5,7

10. Total life-cycle impacts from material-related sources

This chapter summarizes the results of the previous chapters four to nine, to present the total life-cycle environmental impacts from material-related sources. These figures show the total mass and greenhouse gas emissions over the life-cycle of the building. The results are shown in Table 11.

Table 11. Mass (t), stored carbon (t CO_2-equ), energy content (GJ) and greenhouse gas emissions (t CO_2-equ) of the building over 50-year life-cycle, results presented for standard house, log house 200, log house 243 and log house 270, including environmental impacts of materials, waste, renovations, transportations, construction and demolition.

	Total mass of materials (t)	Stored carbon dioxide (t CO_2-equ)	Energy content (GJ)	Greenhouse gas emissions (t CO_2-equ)
Standard house	106	14	273	39
Log house 200	81	53	720	26
Log house 243	84	56	771	26
Log house 270	85	58	803	27

The greenhouse gas emissions presented in Table 11 show the total greenhouse gas emissions for the cases, including environmental impacts of materials, waste, renovations, transportations, construction and demolition.

When the total lifetime emissions from material-related sources is considered, the results show that the greenhouse gas emissions of log houses are some 33% lower than those of the standard house. Total emissions for standard house is 39 tonnes (in terms of CO_2-equ emissions), whereas the emissions for log house scenarios are some 26 tonnes.

The total material need over the 50-year lifetime of standard house is 106 tonnes, while the total mass of log house cases vary from 81 to 85 tonnes.

11. Lifetime operational energy consumption and related emissions

Lifetime energy consumption of all the cases is assessed based on energy calculations of each of the cases[4]. Table 12 shows the energy consumption for each of the cases. The energy consumption is divided between: space heating, hot water and electricity. The table shows the annual energy consumption per unit floor area of the building, as well as for the whole building. Also, the building-level energy consumption is shown for a 50-year life-cycle.

[4] Energy calculations provided by Kontiotuote Oy.

Table 12. Building-level life-cycle energy consumption (MWh, 50a). The table shows energy consumption for all the cases, divided between: space heating, hot water and electricity. The energy consumption per unit floor area (kWh/m^2), heated floor area (m^2) and building-level annual energy consumption (MWh, a) are also shown in the table.

	Energy consumption item	Energy consumption per unit floor are (kWh/m2)	Heated floor area (m^2)	Building-level annual energy consumption (MWh, a)	Building-level life-cycle energy consumption (MWh, 50a)
Standard house	Space heating	83	134	11	558
	Hot water	32	134	4	213
	Electricity	50	134	7	335
	Total	165	134	22	1106
Log house 200	Space heating	125	134	17	835
	Hot water	32	134	4	213
	Electricity	50	134	7	335
	Total	206	134	28	1382
Log house 243	Space heating	115	134	15	773
	Hot water	32	134	4	213
	Electricity	50	134	7	335
	Total	197	134	26	1321
Log house 270	Space heating	110	134	15	735
	Hot water	32	134	4	213
	Electricity	50	134	7	335
	Total	191	134	26	1283

Emission estimates related to energy consumption are difficult to predict into the future, as the energy production methods and energy carriers undergo constant change over time. The emission estimated used here are based on Finnish Climate and energy strategy[5], which predicts that the emissions from electricity production will fall to 78% of the level of today, by 2020, and to 16% of current level by 2030. The predictions of future district heat production estimate that the emissions of 2020 are 89% of those of today, and emissions of 2030 some 79%. These figures are used as the emission factors for 2013–2030. As the life-cycle of the assessed buildings is 50 years, the remainder of the life-cycle needs to be predicted from the previous figures. This assessment estimates that the emissions will stay at a constant level from 2030 onwards, until the end of the assessment period. The emission factors are presented in the following table. The emission calculations of later sections are based on the 50-year average-figures of the Table 13.

Table 13. Emission profiles for Finnish energy production for present moment, year 2020, year 2030, years 2030–2053 and 50-year average emissions, presented in terms of CO_2-equ emissions (kg) per produced energy unit (MWh).

	Emission factor of 2013	Emission factor of 2020	Emission factor of 2030	Emission factor of 2030–2063	Emission factor, 50 year average
Emission factor, district heat (kg CO_2-equ/MWh)	243	216	191	191	203
Emission factor, electricity (kg CO_2-equ/MWh)	230	179	36	36	92

When these emission factors are combined with the energy use information of Table 12, total emissions from energy use can be calculated. The results are shown in Table 14.

[5] Information based on data acquired on 13.4.2012 from the Finnish Ministry of Employment and Economy.

Table 14. Building-level life-cycle greenhouse gas emissions (tn CO_2-equ, 50a), divided between space heating, hot water and electricity. Table also shows building-level annual energy consumption (MWh, a), building-level life-cycle energy consumption (MWh, 50a), emission factors for energy (kg CO_2-equ/MWh) and building-level annual emissions (tn CO_2-equ, a).

	Energy consumption item	Building-level annual energy consumption (MWh, a)	Building-level life-cycle energy consumption (MWh, 50a)	Emission factors for energy use (kg CO_2-equ/MWh)	Building-level annual emissions (tn CO_2-equ, a)	Building-level life-cycle emissions (tn CO_2-equ, 50a)
Standard house	Space heating	11	558	203	2,3	113
	Hot water	4	213	203	0,9	43
	Electricity	7	335	92	0,6	31
	Total	22	1106	-	3,7	187
Log house 200	Space heating	17	835	203	3,4	170
	Hot water	4	213	203	0,9	43
	Electricity	7	335	92	0,6	31
	Total	28	1382	-	4,9	244
Log house 243	Space heating	15	773	203	3,1	157
	Hot water	4	213	203	0,9	43
	Electricity	7	335	92	0,6	31
	Total	26	1321	-	4,6	231
Log house 270	Space heating	15	735	203	3,0	149
	Hot water	4	213	203	0,9	43
	Electricity	7	335	92	0,6	31
	Total	26	1283	-	4,5	223

12. Lifetime total environmental impacts

Table 15 summarizes the results of Chapters 5–11 by showing how the environmental impacts of the cases are divided between the different life-cycle phases.

Table 15. Total mass of consumed materials (t), total mass of structures (t), stored carbon in structures (t CO_2-equ), energy content (GJ) and greenhouse gas emissions (t CO_2-equ) of the building over 50-year life-cycle, results presented for standard house, log house 200, log house 243 and log house 270, including environmental impacts of materials, waste, renovations, transportations, construction, demolition and operational energy use.

	Item	Total mass of consumed materials (t)	Total mass of structures (t)	Stored Carbon Dioxide in structures (t)	Energy Content of structures (GJ)	Greenhouse gas emissions (t)
Standard house	Building materials	88	88	14	273	25
	Material waste	7	-	-	-	1
	Renovation materials	11	-	-	-	6
	Transportations	-	-	-	-	1
	Construction and Demolition	-	-	-	-	6
	Operational energy use	-	-	-	-	187
	Total	106	88	14	273	227
Log house 200	Building materials	70	70	53	720	15
	Material waste	5	-	-	-	1
	Renovation materials	6	-	-	-	4
	Transportations	-	-	-	-	1
	Construction and Demolition	-	-	-	-	6
	Operational energy use	-	-	-	-	244
	Total	81	70	53	720	270
Log house 243	Building materials	73	73	56	771	15
	Material waste	5	-	-	-	1
	Renovation materials	6	-	-	-	4
	Transportations	-	-	-	-	1
	Construction and Demolition	-	-	-	-	6
	Operational energy use	-	-	-	-	231
	Total	84	73	56	771	258
Log house 270	Building materials	74	74	58	803	15
	Material waste	5	-	-	-	1
	Renovation materials	6	-	-	-	4
	Transportations	-	-	-	-	1
	Construction and Demolition	-	-	-	-	6
	Operational energy use	-	-	-	-	223

13. Results and analysis

This chapter analyses the results presented in the previous chapters and expands the results to cover more life-cycle aspects.

13.1 Carbon footprint and carbon storage

The carbon storage can be handled in a number of ways, depending on the selected calculation method. Some of these methods are discussed here.

ISO 14067-standard

According to the ISO 14067-standard[6], the carbon footprint of products is defined as the difference between the CO_2-equivalent emissions of a product and lifetime carbon storage. The standard defines the carbon storage as carbon, which has exited the atmosphere and is bound to the product. The standard does not award credits for the stored carbon, if the carbon storage expires after the lifetime of the product and the carbon returns to the atmosphere.

PAS (Publicly available specification) 2050

PAS (Publicly available specification) 2050 was the first widely acknowledged guide on assessment of carbon footprints[7]. It was published by the British Standards Institution (BSI) in cooperation with Carbon Trust and Defra in 2008. According to the guide, all the carbon dioxide emissions from fossil sources, and all other greenhouse gas emissions from biogenic sources need to be taken into account in calculations.

The guide instructs that part of the products carbon storage can be subtracted from the carbon footprint as credits, if at least half of the stored biogenic carbon stays out of the atmosphere over a one-year time-period. The amount of credits can be calculated with the following formula:

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[6] ISO/TS 14067:2013. Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification and communication.

[7] PAS 2050:2011. Specification for the assessment of the life cycle greenhouse gas emissions of goods and services. British Standards Institution, BSI.

$$\text{Credits} = \frac{length\ of\ storade\ (years)}{100} * Carbon\ content\ (CO2equ) \qquad (1)$$

The formula shows that if the length of the carbon storage is 50 years, half of the carbon content of the product can be subtracted from the carbon footprint as credits. If the time of the storage is 100years, the credits are equal to the whole carbon content.

prEN 16485 Standard draft

According to CEN/TC175 standard draft, prEN 16485[8] "Round and sawn timber – Environmental Product Declarations – Product category rules for wood and wood-based products for use in construction" the naturally occuring carbon storage of products can be documented as part of emission calculations.

The standard draft suggests that the timing of greenhouse gas emissions can be taken into account in calculations. The timing of the greenhouse gas emissions may have a diminishing effect on the emissions. This diminishing effect (over a 100-year study period) is calculated in a similar manner than that presented previously for PAS 2050.

ILCD Handbook

ILCD Handbook[9] gives guidelines for crediting temporary carbon storage for both biogenic and fossil carbon. Both are credited in the same manner, where the effects of temporary carbon storage are defined with the formula:

$$\text{Credits} = Carbon\ content\ (kg\ CO2equ) * \frac{length\ of\ storade\ (years)}{-0{,}01\ kg\frac{kg\ CO2equ}{kg\ CO2equ*years}} \qquad (2)$$

A closer look at the formula shows that if the time period of carbon storage is 50 years, the amount of credits equals to half of the carbon content of the product. If the time of the storage is 100 years, the credits are equal to the whole carbon content. In practise, this gives the same results as the earlier methods.
Table 16 summarizes the carbon footprint and carbon content for the different calculation scenarios. In addition to this, the table shows the amount of carbon credits with a 50% of the carbon content, and the resulting carbon footprint after these credits.

8 prEN 16485 Round and sawn timber – Environmental Product Declarations – Product category rules for wood and wood-based products for use in construction, CEN.

9 European Commission – Joint Research Centre – Institute for Environment and Sustainability: International Reference Life Cycle Data System (ILCD) Handbook – General guide for Life Cycle Assessment – Provisions and Action Steps. First edition March 2010. EUR 24378 EN. Luxembourg. Publications Office of the European Union, 2010.

Table 16. Greenhouse gas emissions (tonnes of CO_2-equ), carbon content (tonnes of CO_2-equ), carbon credit (tonnes of CO_2-equ), and carbon footprint after credits (tonnes of CO_2-equ) for all the cases.

	Greenhouse gas emissions, tonnes of CO_2-equ (t)	Carbon content of the building, tonnes of CO_2-equ (t)	Carbon credit 50% of the carbon content, tonnes of CO_2-equ (t)	Carbon footprint after 50% credit, tonnes of CO_2-equ (t)
Standard house	227	14	7	220
Log house 200	270	53	26	243
Log house 243	258	56	28	229
Log house 270	250	58	29	221

If carbon content of structures is not credited, then the carbon footprint of the different cases equals to the greenhouse gas emissions presented in Table 16. Figure 9 illustrates the carbon footprint of these cases, when the stored carbon is not credited.

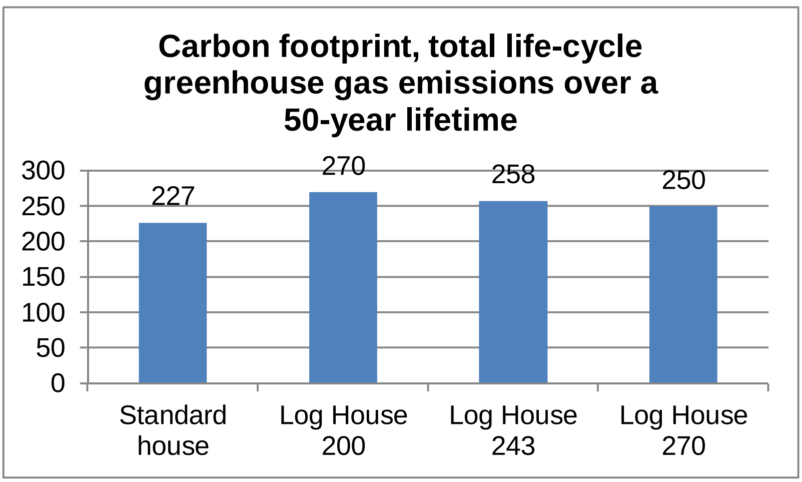

Figure 9. Comparison of carbon footprint between the cases, 50-year life-cycle, when carbon storage is not credited.

Figure 9 shows that the carbon footprint of the cases 200, 243 and 270 exceed the carbon footprint of the standard house, by 10 to 19%.

Figure 10 shows the carbon footprint of the same cases, when 50% of the stored carbon is credited in the calculations.

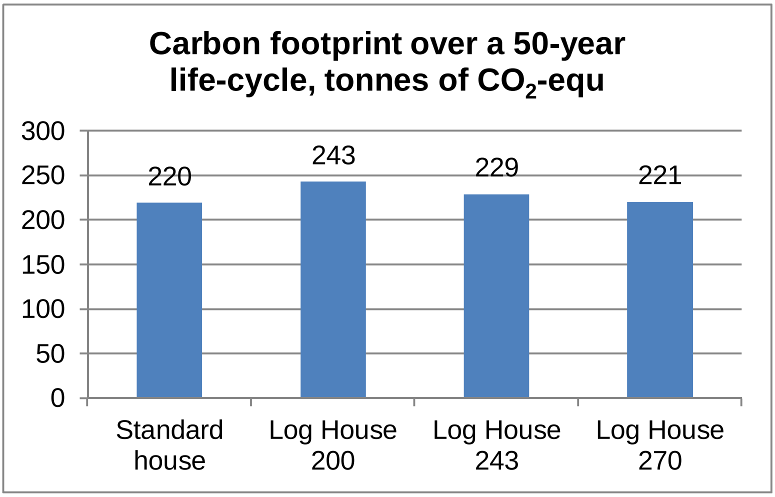

Figure 10. Comparison of carbon footprint between the cases, 50-year life-cycle, 50% of stored carbon credited in the calculations.

The Figure 10 shows that when 50% of the carbon storage is credited in the calculation of the carbon footprint, the differences between standard house and log houses diminish to a level of 0 to 10%. The carbon footprint of the log house 270 is practically the same as for the standard house, the difference being less than 0.5%

The scale of carbon storage can also be illustrated with a graph of Figure 11 including the carbon storage of all the cases, together with the annual emissions from the heating energy use of building. The following graph (Figure 11) shows the carbon content of a building, in relation to life-cycle emissions from heating energy use.

The horizontal axis shows the year since completion, the value zero of the horizontal axis showing the start of the use phase.

The vertical axis represents the cumulative CO_2-emissions of the cases over time. The values at the building completion express the difference between CO_2-emissions from the production and the carbon storage, which is called net carbon storage here. In other words, if the carbon storage exceeds the emissions from material production, the starting value is negative at time point zero. On the other hand, if the CO_2-emissions from material production exceed the amount of stored carbon, then the starting values are positive.

As time goes on, the cumulative emissions rise, due to annual heating energy consumption and the resulting emissions. The point where a graph line crosses the horizontal axis shows the point of time, when the emissions from space heating energy use exceed the amount of stored carbon in the structures.

As the emissions from material production exceed the amount of stored carbon in the structures, the standard house has no net carbon storage. However, for the log house cases, the structures of each of the cases act as carbon storage. For the case with 200 mm thick log walls, it takes a bit over 8 years of use, before the emissions from heating energy exceed the amount of stored carbon. The respective numbers for 243 mm and 270 mm cases are 9 and 11 years.

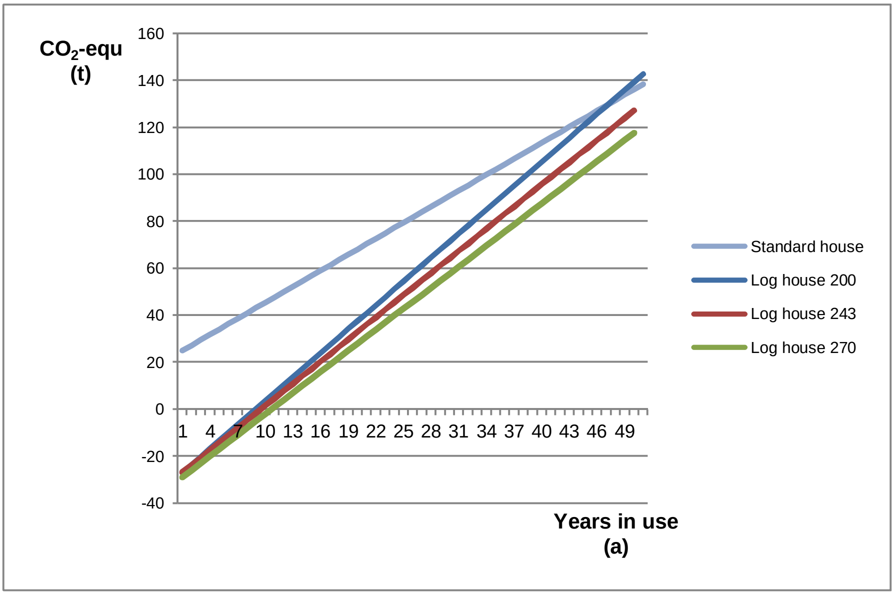

Figure 11. Carbon storage (net) versus emissions from heating energy use. The point where the graph lines cross the horizontal axel represents the point where the emissions from heating energy use are equal to the net carbon storage of the building.

Figure 11 also shows that when both the carbon storage and emissions from 50 years' heating energy consumption are considered, the total emissions from standard house is at the same level with the log houses' emissions. The log house 200 has 2% bigger emissions than the standard house. The log house 243 has 9% lower emissions, and the log house 270 16% lower emissions, than the standard house over the 50-year study period.

13.2 Bio-energy assessments of wood-based materials

This section presents results of theoretical assessments concerning the effects of bio-energy contained in the wood-based structures of a building.

13.3 Bio-energy in the wood-based structures of a building

This section estimates, how much near-zero-emission heating energy could be produced with the bio-energy contained in the structures of a building. The assessment is of a theoretical nature and it takes a look into how much heating energy could be produced by the energy contained in the building's structures.

The calculations are based on simple assumption, estimating that 90% of the energy contained in the structures of a building could be transformed to heating energy of the building. The energy gained from the structures is presented in Table 17. The energy could be produced, for example, by using the materials of the structures for district heat production at the end of a building's life-cycle.

Table 17. Number of years the buildings could be heated with the energy content of wood-based structures (a), including the mass of wood structures in the buildings (t), energy content (MWh) and theoretical amount of heating energy that could be used for space heating (MWh/a).

	Mass of wood-based structures in the building (t)	Total energy content of structures (MWh)	Energy conversion factor heating energy	Total heating energy from wood-based structures (MWh)	Heating energy need for space heating (MWh/a)	Number of years the building could be heated with the energy of wood-based structures (a)
Standard house	9	53	0,9	48	11	4
Log house 200	34	188	0,9	169	17	10
Log house 243	37	202	0,9	182	15	12
Log house 270	38	211	0,9	190	15	13

The result table shows that the energy of wood-based structures could provide enough heating energy for 4 years for the standard house and 10 years for the log house 200. The figures for log house 243 and 270 are 12 years and 13 years, respectively.

13.4 Bio-energy of the side-streams of wood-based structures production

The manufacturing of log creates side streams, which can be used as bio-energy in energy production. These side-streams are not completely emission-free, as a certain share of the emissions of log manufacturing is allocated to these streams. Allocation is typically done mass-based, so that the emissions caused by the log production are divided between the logs and the side products.

This section uses calculation values, where the side products are allocated a certain share of the log production. According to a research report by VTT[10], the energy content of the side products of log are at the level of 7,6 GJ per a tonne of log produced, which equals to 2,1 MWh per tonne of log with a density of 520 kg/m^3. In order to enable rough estimates, the same figures are used for all wood-based structures. In other words, for one tonne of wood, it is estimated that the energy content of side streams is 2,1 MWh.

Table 18. Number of years the buildings could be heated with the energy of the side streams (a), including the mass of wood structures in the buildings (t), energy content of the side streams (MWh) and theoretical amount of heating energy that could be used for space heating (MWh).

	Mass of wood-based structures in the building (t)	Heating energy content of the side streams (MWh/t)	Total heating energy from the side streams (MWh)	Heating energy need for space heating (MWh/a)	Number of years the building could be heated with the energy from the side streams (a)
Standard house	9	2,1	18,9	11,2	2
Log house 200	34	2,1	71,4	16,7	4
Log house 243	37	2,1	77,7	15,5	5
Log house 270	38	2,1	79,8	14,7	5

[10] Behm, Katri, Häkkinen, Tarja, ”Hirsitalotoimialan ekokilpailukyky tarkastelu – hirsitalomallin puumateriaalien elinkaariarviointi käsittäen hiilijalanjäljen, energiataseen ja päästöt”, 2010.

The result table shows that the energy from the side-streams of log production could provide enough heating energy for 2 years heating needs for the standard house and 4 years for log house 200. The figure for both log house 243 and 270 is 5 years.

13.5 Combined bio-energy of wood-based structures and side streams

This section looks into how the bio-energy of wood-based structures and side streams would impact the carbon footprint of buildings, if this bio-energy is considered emission-free energy.

The previous two sections showed the number of years the building could be heated with the bio-energy of the log structures and side streams. This section combines the results of these two sections to assess the total number of years the buildings could be heated with the energy of the structures and side streams.

Table 19. Number of years the buildings could be heated with the energy of the side streams (a) and the energy content of the wood-based structures (MWh), including energy content of side-streams and structures, and space heating energy need (MWh/a).

	Item	Total heating energy from bioenergy (MWh)	Heating energy need for space heating (MWh/a)	Number of years the building could be heated with the energy of logstructures (a)
Standard house	Wood structures	48	11,2	4
	Side streams	19	11,2	2
	Total	67	11,2	6
Log house 200	Wood structures	169	16,7	10
	Side streams	71	16,7	4
	Total	241	16,7	14
Log house 243	Wood structures	182	15,5	12
	Side streams	78	15,5	5
	Total	260	15,5	17
Log house 270	Wood structures	190	14,7	13
	Side streams	80	14,7	5
	Total	270	14,7	18

Table 19 shows that the bioenergy in wood structures of the building and the side streams of production would cover 6 years need of space heating energy for standard house and 14 years for log house 200. The figure for log house 243 is 17 years, and for log house 270, 18 years.

13.6 Impacts of bio-energy of structures and side streams on the carbon footprint of buildings

This section does theoretical assessments, where the theoretical space-heating energy from the bio-energy is subtracted from the life-cycle heating energy need of buildings. The bio-energy is assumed to be emission neutral with emission factor of zero. The remainder of space-heating energy is produced with the emission factor of typical district heating, as in earlier sections.

Table 20 shows the calculation results. The totals for energy consumption match the values of Table 12.

The results of Table 20 show that the carbon footprint for the standard house is 213 tonnes and for the log house 200, 221 tonnes (CO_2-equ). For log houses 243 and 270, the carbon footprints are 205 tonnes (CO_2-equ) and 196 tonnes (CO_2-equ), respectively. The results show that after reduction of bio-energy of wood-based structures from the heating energy needs, the log house 270 has the lowest carbon footprint.

Table 20. Carbon footprints after reduction of bio-energy of wood-based structures and side-streams (t CO_2-equ, 50a), table shows building-level life-cycle energy consumption (MWh, 50a), divided into separate items, emission factors for each of these items (kg CO_2-equ/MWh) and building level annual emissions (t CO_2-equ, a).

	Item	Building-level life-cycle energy consumption (MWh, 50a)	Emission factor for energy use (kg CO_2-equ/MWh)	Building-level annual emissions (tn CO_2-equ, a)	Carbon footprint (tn CO_2-equ, 50a)
Standard house	Building materials	-	-	-	39
	Space heating, total	558	-	-	-
	share of bio-energy	67	0	0,0	0
	share of district heat	491	203	2,0	100
	Hot water	213	203	0,9	43
	Electricity	335	92	0,6	31
	Total	1106	-	3,5	213
Log house 200	Building materials	-	-	-	26
	Space heating, total	835	-	-	-
	share of bio-energy	241	0	0	0
	share of district heat	594	203	2,4	121
	Hot water	213	203	0,9	43
	Electricity	335	92	0,6	31
	Total	1382	-	4	221
Log house 243	Building materials	-	-	-	26
	Space heating	773	-	-	-
	share of bio-energy	260	0	0	0
	share of district heat	513	203	2,1	104
	Hot water	213	203	0,9	43
	Electricity	335	92	0,6	31
	Total	1321	-	4	205
Log house 270	Building materials	-	-	-	27
	Space heating	735	-	-	-
	share of bio-energy	270	0	0	0
	share of district heat	465	203	1,9	95
	Hot water	213	203	0,9	43
	Electricity	335	92	0,6	31
	Total	1283	-	3	196

13.7 Combined impacts of bio-energy of wood-based structures and side streams, and carbon credits, on the carbon footprint of buildings

Section 13.6 assessed the impacts of bio-energy of wood-based structures and side streams on the carbon footprint of the building, and Section 13.1 discussed the impacts of crediting stored carbon. This section makes a combined assessment of these two. In other words, the impacts of bio-energy and carbon storage are assessed simultaneously.

The carbon footprints after reduction of bio-energy of log structures and side-streams, presented in Table 20, are presented in the following table together with a 50% credit of the carbon storage in the structures, presented in Table 16.

Table 21. Carbon footprints after reduction of bio-energy of log structures and side-streams (see Section 13.6 for details) and carbon credits (see Section 13.1 for details), table shows carbon footprint for bio-energy considerations, and for combined assessment of bio-energy and carbon credits.

	Carbon footprint with bio-energy consideration CO_2-equ (t)	Carbon credit, 50% of the carbon content, tonnes of CO_2-equ (t)	Carbon footprint with bio-energy consideration and 50% credit, tonnes of CO_2-equ (t)
Standard house	213	7	206
Log house 200	221	26	194
Log house 243	205	28	177
Log house 270	196	29	167

Table 21 shows that when both bioenergy and carbon credits are considered, the carbon footprint for standard house is 206 tonnes and for log house 200, 194 tonnes (CO_2-equ). For log houses 243 and 270, the figures are 177 tonnes (CO_2-equ), and 166 tonnes (CO_2-equ), respectively. The results show that when both bio-energy of side-streams and structures and carbon credits are taken into account, the carbon footprint of log houses are lower than that of the standard house. The carbon footprint of the log houses are 6 to 19% lower than that of the standard house with these calculation assumptions.

13.8 Result graphs

This section combines the results for carbon footprint from previous sections into a single graph. The graph shows the carbon footprint on the one hand with no credits for bioenergy of log structures, or for carbon storage. On the other hand, the results taking these both into consideration are also shown.

The results show that the carbon footprint over the 50-year life-cycle for the standard house is 227 tonnes. This is lower than for the log house cases, whose emissions vary from 250 to 270 tonnes.

When the carbon storage (marked CS in the graph) is credited for all the cases, the carbon footprint for the standard house is 220. This is slightly lower than for the log house cases, whose emissions vary from 221 to 243 tonnes.

However, when both bio-energy content of wood-based materials and side streams (BE in graph) and carbon storage are considered together, the carbon footprint of standard house is 206 tonnes. For log houses, the carbon footprint falls to the level of 167 to 194 tonnes of CO_2-equ greenhouse gas emissions.

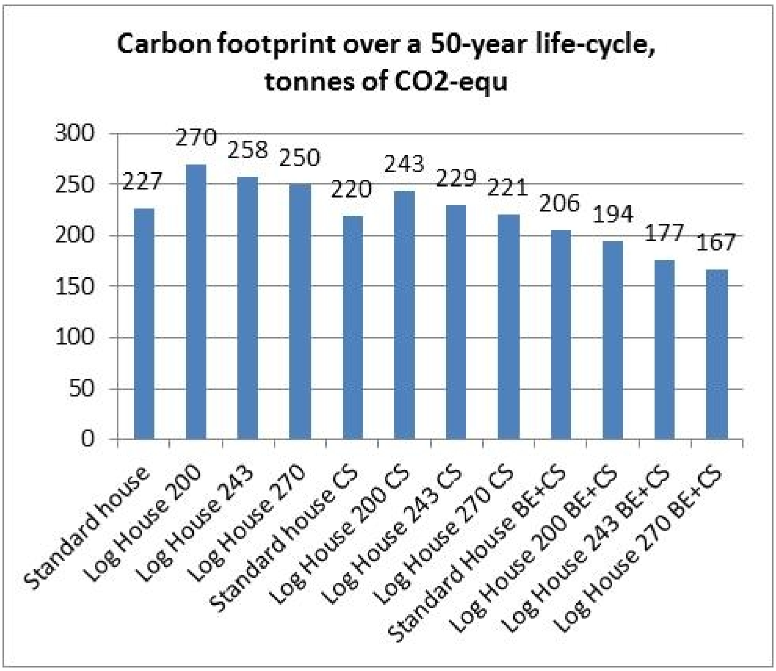

Figure 12. Carbon footprint of calculation cases, tonnes of CO_2-equ greenhouse gas emissions over a 50-year life-cycle, BE = bio-energy of log structures and side-streams is credited, CS = carbon storage is credited.

13.9 Total energy assessments

The Finnish building regulations[11] state that all the buildings need a total energy assessment, which is expressed in terms of an E-figure. The E-figure is calculated with standard usage of a building and with energy-specific weight factors. It expresses the annual purchased energy with the standard use of building. E-figure is calculated by multiplying each energy type by their specific weight factors and summing up the results.

The following table presents the total energy calculations for each of the cases.

Table 22. E-figures for the cases (kWh/m^2, a) with no bio-energy considerations. Divided between energy consumption items space heating, hot water and electricity. The table shows energy consumption per unit floor area (kWh/m^2, a), energy type and energy specific factors.

	Energy consumption item	Energy consumption per unit floor are (kWh/m^2)	Type of energy	Energy type-specific factor	Total energy consumption (kWh/m^2, a)
Standard house	Space heating	83	District heat	0,7	58
	Hot water	32	District heat	0,7	22
	Electricity	50	Electricity	1,7	85
	E-figure				166
Log house 200	Space heating	125	District heat	0,7	87
	Hot water	32	District heat	0,7	22
	Electricity	50	Electricity	1,7	85
	E-figure				194
Log house 243	Space heating	115	District heat	0,7	81
	Hot water	32	District heat	0,7	22
	Electricity	50	Electricity	1,7	85
	E-figure				188
Log house 270	Space heating	110	District heat	0,7	77
	Hot water	32	District heat	0,7	22
	Electricity	50	Electricity	1,7	85
	E-figure				184

[11] Suomen rakentamismääräyskokoelma, D3, ”Rakennusten energiatehokkuus – määräykset ja ohjeet” (2012).

The results of Table 22 show that the E-figure of the standard house is 166 kWh/m^2, and for the log houses 184 to 194 kWh/m^2.

13.10 Theoretical total energy assessment, considering combined impacts of bio-energy of wood-based structures and side streams

The previous section presented the total energy calculations for each of the cases. This section analyses the impact of bio-energy of wood-based structures and side streams by deducting the amount of bio-energy in them from the space heating needs.

Two alternative calculations are made. Firstly, the bio-energy is taken into account according to the Finnish building regulations, by using energy type specific factor of 0,5 for bio-energy used inside the building.

Secondly, bio-energy is taken into account with a theoretical approach, where the bioenergy is assumed to be emission free, thus using the value zero for its energy type specific factor.

The results of Table 23 show that the E-figure for the standard house is 164 kWh/m^2. For log houses, the E-figure varies from 176 to 187 kWh/m^2 with bio-energy considerations.

Table 23. E-figures for the cases (kWh/m^2, a), with bio-energy factor of 0.5. Divided between energy consumption items space heating, hot water and electricity. The table shows energy consumption per unit floor area (kWh/m^2, a), energy type and energy specific factors.

	Energy consumption item	Energy consumption per unit floor are (kWh/m^2)	Type of energy	Energy type-specific factor	Total energy consumption (kWh/m^2)
Standard house	Space heating	73	District heat	0,7	51
	Space heating	10	bio-energy	0,5	5
	Hot water	32	District heat	0,7	22
	Electricity	50	Electricity	1,7	85
	E-figure				164
Log house 200	Space heating	89	District heat	0,7	62
	Space heating	36	bio-energy	0,5	18
	Hot water	32	District heat	0,7	22
	Electricity	50	Electricity	1,7	85
	E-figure				187
Log house 243	Space heating	77	District heat	0,7	54
	Space heating	39	bio-energy	0,5	19
	Hot water	32	District heat	0,7	22
	Electricity	50	Electricity	1,7	85
	E-figure				180
Log house 270	Space heating	69	District heat	0,7	49
	Space heating	40	bio-energy	0,5	20
	Hot water	32	District heat	0,7	22
	Electricity	50	Electricity	1,7	85
	E-figure				176

Table 24. E-figures for the cases (kWh/m^2, a), with bio-energy factor of zero. Divided between energy consumption items space heating, hot water and electricity. The table shows energy consumption per unit floor area (kWh/m^2, a), energy type and energy specific factors.

	Energy consumption item	Energy consumption per unit floor are (kWh/m^2)	Type of energy	Energy type-specific factor	Total energy consumption (kWh/m^2)
Standard house	Space heating	73	District heat	0,7	51
	Space heating	10	bio-energy	0	0
	Hot water	32	District heat	0,7	22
	Electricity	50	Electricity	1,7	85
	E-figure				159
Log house 200	Space heating	89	District heat	0,7	62
	Space heating	36	bio-energy	0	0
	Hot water	32	District heat	0,7	22
	Electricity	50	Electricity	1,7	85
	E-figure				169
Log house 243	Space heating	77	District heat	0,7	54
	Space heating	39	bio-energy	0	0
	Hot water	32	District heat	0,7	22
	Electricity	50	Electricity	1,7	85
	E-figure				161
Log house 270	Space heating	69	District heat	0,7	49
	Space heating	40	bio-energy	0	0
	Hot water	32	District heat	0,7	22
	Electricity	50	Electricity	1,7	85
	E-figure				156

The results of Table 24 show that the E-figure for the standard house is 159 kWh/m^2. For log houses, the E-figure varies from 156 to 169 kWh/m^2 with bio-energy considerations. The results show that when the bio-energy is given a factor of zero, the E-figure for log house 270 is the lowest. The figures for standard house and log house 243 are at the same level, while the figure for log house 200 is the highest.

14. Conclusions

This publication shows that the increased wood use leads to decreased greenhouse gas emissions from material production. The greenhouse gas emissions of log houses are 40% lower than those of the standard house. The structures of log house cases store 3.8 to 4.2 times the carbon of the standard house in their structures. According to the results, the energy content of the structures of log house cases is 2.6 to 2.9 that of the standard house. The mass of standard house is 88 tonnes, while the total mass of log house cases vary from 70 to 74 tonnes.

When the total lifetime emissions from material-related sources are considered, the results show that the greenhouse gas emissions of log houses are some 33% lower than those of the standard house. The total material need over the 50-year lifetime of standard house is 106 tonnes, while the material need of log house cases vary from 81 to 85 tonnes.

The use of uninsulated log wall structures may lead to lower life-cycle greenhouse gas emissions, when compared to standard house, however, the results or not, the carbon storage and / or bio-energy of structures and side streams is considered, the log house cases may perform better or worse, compared to the standard house.

The theoretical calculation results presented in this publication show that when no bio-energy or carbon storage is credited, the the carbon footprint over the 50-year life-cycle of the standard house is 227 tonnes. This is lower than for the log house cases, whose emissions vary from 250 to 270 tonnes.

When the carbon storage (marked CS in the graph) is credited for all the cases, the carbon footprint for the standard house is 220 tonnes of CO_2-equ. This is slightly lower than for the log house cases, whose emissions vary from 221 to 243 tonnes.

Finally, when both bio-energy content of wood-based materials and side streams (BE in graph) and carbon storage are considered together, the carbon footprint of standard house is 206 tonnes. For log houses, the carbon footprint falls to the level of 167 to 194 tonnes of CO_2-equ greenhouse gas emissions.

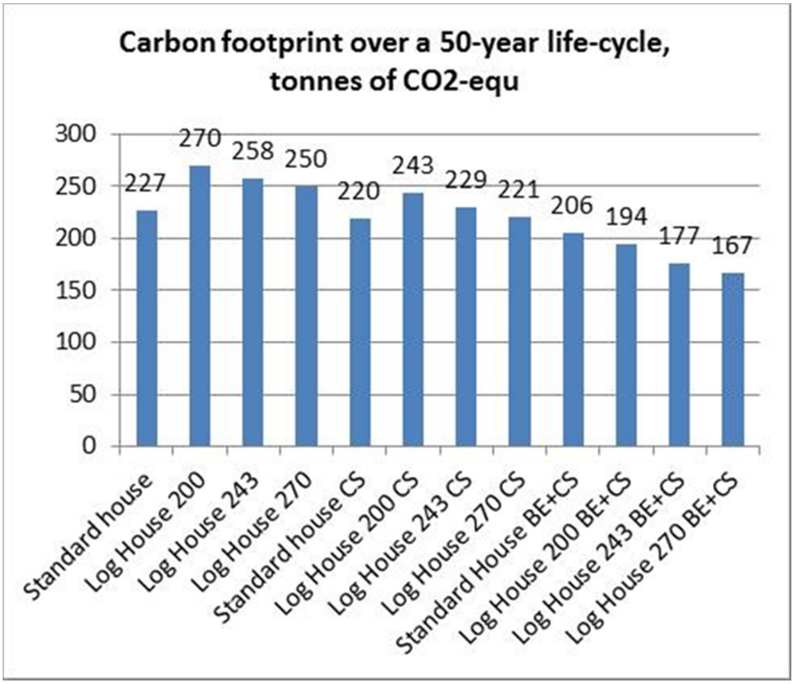

Figure 13. Carbon footprint of calculation cases, tonnes of CO_2-equ greenhouse gas emissions over a 50-year life-cycle, BE=bio-energy of log structures and side-streams is credited, CS=carbon storage is credited.

Acknowledgements

This publication is prepared for the Finnish Log Industry.

Appendix A: Environmental profiles for materials

Material	Energy content MJ/kg	Carbon content, CO_2-equ, kg/kg	GHG-emis. CO_2-equ, kg/kg
Mineral Wool	0,00	0	1,24
Glass Wool	0,00	0	0,92
Cellulose insulation	0,00	1,4	0,27
XPS-insulation	47,80	0	2,76
PUR-insulation	34,31	0	4,32
Moisture barrier (LD-PE)	51,54	0	2,10
Roofing sheet (PP)	52,72	0	2,70
Wind shield gypsum board	0,00	0	0,44
Gypsum board	0,00	0	0,44
Wood fibre board (LD)	19,48	1,5	0,49
Wood fibre board (HD)	22,35	1,5	0,28
Expanded concrete brick wall	0,00	0	0,31
Light weight gravel	0,00	0	0,42
Wood	16,40	1,4	0,07
Wood panel	16,40	1,5	0,07
Laminated wood	18,70	1,4	0,21
Plywood (deciduous)	19,21	1,3	1,05
Plywood (coniferous)	19,04	1,3	0,77
Stainless steel	0,00	0	1,73
Felt Roofing	33,50	0	2,25
Concrete, K30	0,00	0	0,09
Parquett	38,74	1,4	0,88
EPS-insulation	40,00	0	2,74
Ceramic tile	0,00	0	0,68
Log	20,60	1,4	0,12

Series title and number
VTT Technology 148

Title	**Life-cycle environmental impacts of a standard house and three log house cases** **A comparison of a typical Finnish house and three ecological log house designs with alternative external wall thicknesses**
Author(s)	Antti Ruuska
Abstract	This publication presents the calculation results for the life-cycle environmental impacts of a typical Finnish wood framed house, called 'standard house'. The calculation results are also presented for three alternative log house, with extensive use of wood and log products in structures. The log house cases vary only in their external wall log thickness. The results take into account the emissions from material acquisition, production and transportations, as well the emissions from construction phase. The lifetime emissions are considered in terms of materials for repairs and renovations, and emissions from operational energy use over a life-cycle of 50 years. Also, the energy use for demolition and removal of demolition waste from site is included in the assessment. The results for the material production show that the greenhouse gas emissions of log houses are 40% lower than those of the standard house. Total GHG emissions for standard house are 25 tonnes (in terms of CO_2-equ), whereas the emissions for log house scenarios are 15 tonnes. The structures of log house cases store 3.8 to 4.2 times the carbon of the standard house in their structures. The standard house stores some 14 tonnes of carbon dioxide, whereas the figures for log houses are 53 to 58 tonnes. According to the results, the energy content of the structures of log house cases is 2.6 to 2.9 that of the standard house. Energy content of standard house is 270 GJ, and the values for log houses vary from 720 GJ to 800 GJ. The mass of standard house is 88 tonnes, while the total mass of log house cases varies from 70 to 74 tonnes. When the total lifetime emissions from material-related sources are considered, the results show that the greenhouse gas emissions of log houses are some 33% lower than those of the standard house. Total emissions for standard house are 39 tonnes (in terms of CO_2-equ emissions), whereas the emissions for log house scenarios are some 26 tonnes. The total material need over the 50-year lifetime of standard house is 106 tonnes, while the material need of log house cases vary from 81 to 85 tonnes. The operational energy use of the log house cases of this publication is higher than that of the standard house, due to differences in space-heating energy needs. This is caused by differences in U-values of external walls. This results in a 10 to 19% higher carbon footprint of log houses, when no crediting for stored carbon or bio-energy are made. If the carbon storage is credited in the calculation of the carbon footprint, the differences between standard house and log houses diminish to a level of 0 to 10%.When both bioenergy and stored carbon are considered, the carbon footprint for standard house is 167 tonnes and for log house 200, 168 tonnes (CO_2-equ). For log houses 243 and 270, the figures are 150 tonnes (CO_2-equ), and 139 tonnes (CO_2-equ), respectively. The results show that when both bio-energy of side-streams and structures and carbon credits are taken into account, the carbon footprint of log house 200 is at the same level as the standard house. The carbon footprint of the log houses 243 and 270 are 10 and 16% lower than that of the standard house. This publication also studies the so called total energy consumption figures, as defined in Finnish building regulations. The figure for standard house is 166 kWh/m^2, and for the log houses 184 to 194 kWh/m^2, when calculation is done as stated in regulations. Two alternative calculations of theoretical nature are also made. Firstly, the bio-energy related to wood-based structures and their side-streams is taken into account by assuming this bio energy could be used to replace heating energy use in the building. This is done by assigning the energy in wood-based structures an energy-type factor of 0.5, as in the Finnish building regulations. The results show that with these assumptions, the total energy figure for standard house is 164 kWh/m^2. For log houses, the figures vary from 176 to 187 kWh/m^2. Secondly, bio-energy is taken into account by assuming it to be completely emission free bio-energy, thus using a value of zero for its energy type specific factor. The results show that the total energy figure for the standard house is 159 kWh/m^2. For log houses, the figures vary from 156 to 169 kWh/m^2.
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Julkaisun sarja ja numero

VTT Technology 148

Nimeke	**Elinkaarenaikaiset ympäristövaikutukset normitalolle ja kolmelle hirsitalolle** **Perustasoisen suomalaisen normitalon ja kolmen ekologisen hirsitalo-ratkaisun vertailu hirsitalojen erilaisilla ulkoseinäpaksuuksilla**
Tekijä(t)	Antti Ruuska

Tiivistelmä

Tämä raportti esittelee elinkaaren aikaisten ympäristövaikutusten laskentatulokset suomalaiselle perustasoiselle ‘normitalolle’. Tulokset esitetään lisäksi myös kolmelle hirsitaloratkaisulle, joissa puutuotteiden ja hirren käyttö on maksimoitu. Hirsitaloratkaisut poikkeavat toisistaan ulkoseinäpaksuuden osalta.

Tulokset huomioivat rakennusmateriaalien raaka-ainehankinnan, tuotannon ja kuljetuksen päästöt, sekä rakentamisesta aiheutuvat päästöt. Elinkaarenaikaiset päästöt huomioivat korjausten ja uusimisten, sekä käytönaikaisesta energiankulutuksesta aiheutuvat päästöt 50 vuoden elinkaaren aikana. Myös elinkaaren lopussa tapahtuvasta purkutyöstä aiheutuvat päästöt, sekä purkujätteen kuljetuksen päästöt on huomioitu laskennassa.

Materiaalituotannosta aiheutuvat päästöt ovat hirsitaloilla noin 40% matalammat kuin normitalolla. Tuotannon aiheuttamat kasvihuonekaasupäästöt normitalolla ovat 25 tonnia (CO_2-ekvivalenttitonnia), kun ne ovat kaikilla hirsitaloskenaarioilla 15 tonnia. Hirsitalojen rakenteet sitovat itseensä 3.8–4.2-kertaisen määrän hiiltä normitaloon verrattuna. Normitalon rakenteisiin sitoutuu noin hiiltä 14 tonnia, kun hirsitalon rakenteisiin sitoutuneen hiilen määrä on 53–58 tonnia (CO_2-ekvivalenttitonnia). Laskennan hirsitalojen rakenteiden energiasisältö on 2.6–2.9-kertainen normitaloon verrattuna. Normitalon energiasisältö on 270 GJ, kun se on hirsitaloilla välillä 720–800 GJ. Normitalon rakenteiden massa on 88 tonnia. Hirsitalojen rakenteiden massa vaihtelee välillä 70–74 tonnia.

Koko 50 vuoden elinkaaren aikaisten materiaalipäästöjen tarkastelu osoittaa että hirsitalojen kasvihuonekaasupäästöt ovat noin 33% matalammat kuin normitalolla. Normitalon elinkaarenaikaiset kokonaispäästöt ovat 39 tonnia (CO_2-ekvivalenttitonnia), kun taas hirsitalojen vastaavat päästöt ovat noin 26 tonnia. Rakennusmateriaalien kokonaistarve 50 vuoden elinkaaren aikana on normitalolla 106 tonnia, hirsitalojen materiaalitarpeen vaihdellessa välillä 81–85 tonnia.

Tässä raportissa käytetyt käytönaikaisen energiankulutuksen arvot ovat hirsitaloilla korkeammat kuin normitalolla, johtuen erosta tilojen lämmitystarpeessa. Lämmitystarpeen ero syntyy erosta ulkoseinien U-arvoissa. Jos hirsitalojen sitoutunutta hiiltä, tai bioenergiaa ei hyvitetä laskennassa, hirsitalojen hiilijalanjälki on 10–19% suurempi kuin standarditalolla.

Jos hiilivarasto huomioidaan laskennassa, on hirsitalojen hiilijalanjälki minimitapauksessa samaa tasoa (270 mm paksu ulkoseinä) kuin normitalolla. Maksimitapauksessa hirsitalon hiilijalanjälki on 10% suurempi (200 mm ulkoseinäpaksuus) kuin normitalolla, kun hiilivarasto on huomioitu.

Jos sekä hiilivarasto, että bioenergiatarkastelut huomioidaan laskennassa, on normitalon hiilijalanjälki ja hirsirakenteiden hiilijalanjälki samaa tasoa ohuimmalla ulkoseinäpaksuudella (200 mm hirsiseinä). Käytettäessä 243 mm tai 270 mm paksuutta, hirsitalojen hiilijalanjälki on 10–16% pienempi kuin normitalolla.

Tässä raportissa tarkastellaan myös kokonaisenergialukuja Suomen rakentamismääräyskokoelman mukaisilla laskenta-arvoilla. Normitalolle laskettu kokonaisenergialuku on 166 kWh/m^2 ja hirsitaloille 184–194 kWh/m^2.

Raportissa tehdään myös kaksi teoreettista tarkastelua. Ensiksi, rakenteiden bioenergian merkitystä tarkastellaan teoreettisella tasolla, olettamalla että rakenteiden bioenergiaa voitaisiin käyttää korvaamaan tilojen lämmityksen energiatarvetta. Tämä käsitellään laskennassa käyttämälle tilojen lämmitysenergiaa korvaavalle bioenergialle rakentamismääräysten mukaista bioenergian kerrointa 0.5. Näillä laskentaoletuksilla normitalolle laskettu kokonaisenergialuku on 164 kWh/m^2 ja hirsitaloille 176–187 kWh/m^2.

Toiseksi, rakenteiden bioenergia käsitellään muuten samoin kuin edellä, mutta bioenergialle käytetään määräyksistä poikkeavaa kerrointa ja sen energiamuodon kerroin oletetaan nollaksi. Näillä laskentaoletuksilla normitalon kokonaisenergialuku on 159 kWh/m^2, ja hirsitaloille 156–169 kWh/m^2.

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