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Heating and Ventilation of Highly Energy Efficient Residential Buildings: Environmental Assessment of Technology Alternatives

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MASTER THESIS

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Heating and ventilation of a highly energy efficient residential buildings: Environmental assessment of technology alternatives

Miljøvurdering av ulike løsninger for oppvarming og ventilasjon av en energieffektiv enebolig

Background and objective.

Significant reductions in operational energy use of residential buildings for heating, hot water provision and air conditioning is possible with new technologies, including well-insulated and air-tight building shells. Such buildings no longer provide for natural ventilation, and to remove humidity and provide for adequate air quality, an active ventilation system is required. Heat exchangers ensure that 80-90% of the heat in the outgoing air is recovered. The passive house standard calls for an environmentally friendly heating system, utilizing ambient energy with a heat pump or a renewable fuel like wood logs or pellets. As a result, passive houses in a cold climate require substantially more and more sophisticated ventilation equipment installed than conventional buildings. In addition, building specifications may lead to a need for cooling in the summer.

To understand the environmental costs and benefits of different systems for heating, ventilation and hot water meeting low-energy and passive house requirements, life-cycle assessment taking into account the production of the equipment, its installation, use, and disposal is required. Environmental cost and benefits of different energy solutions for a low-energy or passive building natural depend on climate, building characteristics, and the energy system. This thesis focuses on heating, ventilation and hot water provision for a single-family residence in Stord as designed by Nordbohus, a building company based in Trondheim. The objective is to compare the environmental performance of different heating, hot water and ventilation solutions for the same house designed to the standard TEK07 and to passive house standard.

The following questions should be considered in the project work:

1. What are feasible combinations of heating, ventilation and hot water equipment meeting the specifications of the standards?
2. What LCI data exists for the various components of the systems in question? Where are new assessments or improvements of assessments needed?
3. What is the LCI for these components, based on information provided by suppliers and in technical specifications?

4. What is the environmental benefit of heat-recovery through the heat exchanger?
5. What are the life-cycle impacts of the specified alternative hot water and heating/cooling systems in the buildings build to TEK07 and passive house standards?
6. From an environmental perspective, are the strict passive house standards reasonable?

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Department of Energy and Process Engineering, 17. January 2011

Olav Bolland
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Academic Supervisor

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Preface

This study is done as a master thesis connected to the Department of Energy and Process Engineering at the Norwegian University of Science and Technology in Trondheim, Norway.

The aim of this study was to assess the environmental impacts and the use of primary energy related to the heating and ventilation system of a wooden based residential houses. This was then compared to heating systems used in a passive house version of the same building. The project is part of a larger study where the overall life cycle assessments of the two houses are to be compared; the aim of which is to determine which alternative is preferable from an environmental impact standpoint. We are two students connected to this project and have separated the system into different parts and studied them separately. The results of both will be gathered and presented in a final report. This is done as a part of a larger project called KlimaTre, organized by SINTEF Building and Infrastructure, which aim is to promote use of Norwegian wood.

In the process of working with this study, several actors have been of great help. Special thanks go to:

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Trondheim, June 2011

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Abstract

The aim of this study was to determine the level of environmental impact and primary energy resulting from demands placed on residential ventilation and heating systems; a conventional residential house built to the 2007 Norwegian building code with a standard heating system was compared against three technology scenarios used in a passive house of the equivalent size. Both houses have wooden framework and cladding and are projected by the Norwegian building company Norbohus. An economical evaluation of the heating systems was also done.

The alternative heating option for the conventional house, Stord TEK 07, was based on current Norwegian energy consumption patterns; a combination of electricity and firewood is used to meet heating demand. This heating mix was also modeled as an option for the heating requirements of the passive house, named Stord Passive S1. Additionally, a solar collector system (Stord Passive S2) and an air-to-water heat pump (Stord Passive S3) were modeled for the passive house. Finally, a balanced mechanical ventilation system was evaluated for both buildings. The life-cycle assessment method used was the ReCiPe method and the electricity used in the operation phase was based on the Nordic electricity mix.

The results of this study indicate that Stord TEK 07 has the largest emission output in relation to output of CO_2-eq, presented in the impact category “Climate change”. From a life-cycle perspective, the heating system requirements of a Stord TEK 07 house are 47.5 and 45 percent higher than the renewable energy solutions of passive house scenarios S2 and S3, respectively. Total life-cycle primary energy requirements in the Stord TEK 07 house were almost twice that of the renewable solutions in the passive house. Using the Norwegian standard heating system of Stord TEK 07 in a passive house as was done in Stord Passive S1, also results in a large improvement; output of CO_2-eq and use of primary energy was reduced by 34-35 percent.

Stord TEK 07 has also the highest emission output in most of the other impact categories and the largest present value costs, when building constructing costs are excluded. The heat pump solution, Stord Passive S3, has the lowest impact in most categories; however, the solar collector system Stord Passive S2, had lower output of CO_2-eq. Stord Passive S2 has also lower present value costs then the air-water heat pump Stord Passive S3.

A balanced ventilation system with 80 percent heat recovery was studied for both the houses. The benefit of heat recovery is recognizable in all the impact categories considered. The energy consumption and potential harmful emissions resulting from the electrical energy used by fans during the life cycle far exceed the environmental impacts that result from manufacture and transportation of the ventilation unit. The study revealed that the heat-recovery system must have efficiency greater than 15 percent to achieve reduction concerning output of CO_2-eq and use of primary energy for Stord TEK 07; this requirement increases to 42 percent in houses built to the passive house standard house, Stord Passive.

Sammendrag

Målet med denne studien var å projisere miljøvirkninger og primær energi knyttet til i et varme- og klimasystem i en bolig konstruert basert på kravene i de norske byggeforskriftene fra 2007, og sammenligne dette til ulike varmeløsninger for en passivhusversjon av den samme bygningen. Begge husene er trebaserte konstruksjoner og er prosjektert av byggfirmaet Norbohus. En økonomisk evaluering av varmesystemene er også gjort.

Varmesystemet som ble vurdert for det konvensjonelle huset, kalt Stord TEK 07, er den tradisjonelle norske kombinasjonen av elektrisitet og ved. Dette er også en av de tre løsningene som er valgt for passivhuset (Stord Passive S1), men også et solfangersystem (Stord Passive S2) og bruk av en luft-til-vann varmepumpe (Stord Passive S3) er studert. Bruk av et balansert mekanisk ventilasjonsanlegg er vurdert for begge bygningene.

Når det gjelder potensialet for "Climate Change" eller klimaforandring som det heter på norsk, er Stord TEK 07 det alternativet med størst utslipp. Dette alternativet har 47.5 og 45 prosent høyere utslipp av CO_2-ekvivalenter enn de fornybare energiløsningene, henholdsvis Stord Passive S2 og S3. Akkumulert energi i systemet er også nesten dobbelt så stor som i de fornybare løsningene.

Et annet tydelig resultat er at ved å installere et tradisjonelt varmesystem i et passivhus, som gjort i Stord S1 Passive, vil en oppnå vesentlige forbedringer enn ved å installere samme system i et konvensjonelt hus. Nedgangen er 34-35 prosent CO_2 utslipp og akkumulert energi. Stord TEK 07 har høyest utslipp i de fleste av miljøpåvirkningskategoriene, og er også det dyreste alternativet om kostnaden med å bygge husene er ekskludert. Varmepumpeløsningen, Stord Passiv S3, har lavest miljøpåvirkning i de fleste kategorier, men er slått av solfanger alternativet, Stord Passiv S2, når det gjelder utslipp av CO_2-ekvivalenter. Dette alternativet har også mye lavere nåverdikostnader enn løsningen med en luft-vann varmepumpe.

Et balansert ventilasjonssystem med 80 prosent varmegjenvinning var analysert for begge bygningene. Det er tydelig at energiforbruket og potensielle skadelige utslipp som følge av den elektriske energien som brukes av vifter i løpet av livssyklusen overstiger de miljømessige konsekvenser som følge av produksjon og transport av aggregatet. Med fokus på produksjon av CO_2 ekv og akkumulert primær energi, vil varmegjenvinning lønne seg ved en effektivitet på varmeveksleren på ca 15 prosent når det gjelder Stord TEK 07, og ved en effektivitet på ca 42 prosent når det gjelder Stord Passive.

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Nomenclature

Calculation of delivered energy

$E_{delivered}$	Energy supplied over the building system boundaries (kWh)
E_{net}	Net energy delivered to the building (kWh)
η_{prod}	Efficiency of the energy production system
η_{dist}	Efficiency of the energy distribution system
η_{reg}	Efficiency of the energy regulation system
η_{sys}	Efficiency of the total heating system
E_{el}	Delivered electricity to the heating system (kWh)

Electricity in the heating system

$\mathrm{E}_{\mathrm{part,\ el}}$	Energy from annual delivered electricity (kWh/yr)
$\mathrm{E}_{\mathrm{part,\ oil}}$	Energy from annual delivered fossil oil (kWh/yr)
$\mathrm{E}_{\mathrm{part,\ gas}}$	Energy from annual delivered fossil gas (kWh/yr)
E_{t}	The total annual energy needs (kWh/yr)
$\mathrm{Q}_{\mathrm{w,nd}}$	Annual net energy need for heating of tap water (kWh/yr)

LCA method

pro	Process
str	Stressor
imp	Impact potential
A	Requirement matrix (pro x pro)
A_{ff}	Requirement matrix of the foreground from the foreground (pro x pro)
A_{fb}	Requirement matrix of the background from the foreground (pro x pro)
A_{bf}	Requirement matrix of the foreground from the background (pro x pro)

A_{bb}	Requirement matrix of the background from the background (pro x pro)
x	The matrix of total output (pro x 1)
y	The matrix of final demand (pro x 1)
I	The unit matrix
L	The Leontief Inverse matrix (pro x pro)
e	The total emissions matrix (str x 1)
S	The stressor matrix (str x pro)
E	The matrix showing the total emissions related to each process (str x pro)
d	The total impact matrix (imp x 1)
C	The characterization matrix (imp x str)
D	The matrix showing the total impacts related to each process (imp x pro)

Cost calculations

n	Year
E_n	Costs related to total energy consumption in year n (kr)
C_{energy}	Costs per energy unit (kr/kWh)
d_n	Discount factor
r	Discount rate
$E_{n,PV}$	Present value of energy costs in year n (kr)
$M_{n,PV}$	Present value of maintenance costs in year n (kr)
M_n	Maintenance costs in year n (kr)
C_{PV}	Present value of total costs through the entire life cycle (kr)
I_0	Investment costs (kr)

Solar collector theory

Q_{usable}	Usable delivered energy from the solar collector (kWh)

A_s	Solar collector area (m^2)
q_{in}	The total solar radiation absorbed in the collector (kWh/m^2)
q_{out}	The energy loss from the collector (kWh/m^2)
I_T	The solar radiation against the solar collector (kWh/m^2)
$(\tau\alpha)$	The product of the transmittance of the outer layer and the absorber factor
U_L	The coefficient of heat loss for given solar collector
t_{pm}	The mean temperature of the absorber in a solar collector (K)
t_{out}	The mean output temperature (K)
F_R	Regulating factor which so that one can express energy yield as a function of input temperature
t_i	Input temperature to the absorber (K)
η_s	The efficiency of the solar collector

Heat pump theory

SPF	Seasonal Performance Factor
Q_{yr}	Annual delivered energy from the heat pump (kWh/yr)
W_{yr}	Annual electrical power needed to supply the heat (kWh/yr)
COP	Coefficient of Performance
W	Electrical power (kWh)
Q	Delivered heat (kWh)
$COP_{heating}$	Coefficient of Performance, heating
$COP_{\max,id}$	Coefficient of Performance, maximum
T_N	The temperature generated by heat in the heat pump (K)
T_U	The temperature of the heat source (K)

η_{hp}	The efficiency of the heat pump

1 Introduction

The energy demand in the building stock in Norway represents about 40 percent of the final energy consumption. Of this is 22 percent ascribed to the residential sector and 18 percent to the non-residential sector [1]. The phases of extraction, processing, manufacturing, transportation and use of materials and technology consume energy and cause environmental impacts throughout the entire life cycle of a construction. Energy use and impacts regarded to extraction, processing and transportation of materials and components are seen as hidden or embodied burdens, as opposed to the more evident impacts related to operational energy consumption in the use phase of a building.

Embodied carbon and energy is of particular importance for efficient low energy buildings because although less energy is used during occupation, additional energy is often required for the manufacture of the increased levels of insulation, the heavier mass materials used and the additional technologies often deployed [2].

To meet the goal of sustainable development, it is important that houses are build by the claim of limited natural resource use and low environmental impact. Life Cycle Assessment or LCA is a technique to assess the environmental aspects and potential impacts associated with a product, through the entire life cycle. By compiling an inventory of relevant energy and material inputs, and evaluating the potential environmental impacts associated with the identified inputs, the results can be interpreted to see where in the life cycle the main environmental impacts can be assigned. This is an acknowledged method based on the international standard ISO14040.

This report presents results from life cycle assessments and private economical analysis of heating and ventilation systems used in two wooden based residential buildings, delivered by the building company Nordbohus AS. The first house, Stord TEK 07, meets the requirements given by the Norwegian Technical Building Code revised in 2007 which also has given the main premises for how the house is projected. The heating system chosen for this house is a standard Norwegian heating system, based on electricity and fire wood.

The second house, Stord Passive, is a passive house version of the same house as the first one, meeting the Norwegian passive house requirements given by Standard Norway in NS 3700. Three different system solutions are compared for this house; an air to water heat-pump system, a solar collector system and a standard electrical system including a wood stove.

For both houses is a balanced ventilation system with 80 percent heat recovery considered.

The study has a cradle- to-grave perspective where the embodied carbon and energy of the whole life cycle of 50 years is taken into account. This includes the production of materials, the operation phase, disassembly and waste management of the heating systems**.** It must be noticed that the construction of the buildings is not taken into account in this study. The aim of this research is to compare the environmental impact of the defined heating and ventilation system concepts and related maintenance scenario for the different buildings. A private economical evaluation of the heating systems based on present value is also performed and presented.

1.1 Objective of this study

In Norway it is at present stage an ongoing discussion around the passive house technology and it is under consideration whether to introduce a passive house standard for all new buildings by 2020. The passive house technology is supposed to be energy efficient, but it is important that the extra use of energy in the production phase not exceeds the environmental benefit of the energy savings during the use phase of the building. The aim of this study was to assess the environmental impacts and the use of primary energy related to the heating and ventilation system of newly built residential houses. This was then compared to heating systems used in a passive house version of the same building.

The overall goal of this study is to evaluate the possible benefit of passive house technology and to consider the impacts due to implementation of renewable heating systems compared to a standard system based on electricity and fire wood.

This study is a part of a larger project where the overall life cycle assessments of the two houses, construction included, are to be compared to each other to see what alternative that might be preferable regarding the total environmental impacts.

1.2 The Norwegian Building code and Standard Norway

In Norway there are two regulating building instructions to follow; The Norwegian building code and the building standards.

The Norwegian building code is called the Planning and Building Act (TEK) and this set parameters for how Norwegian buildings of today should be built.

In the last years have two new revisions been made;

1) At 01.02.2007, new energy requirements were introduced. The code is often referred to as TEK 07. It was a 2.5-year transition period. The new requirements became mandatory from 08.01.2009.
2) At 07.01.2010 the revised regulations were changed. New technical building regulations entered in force, often referred to as TEK 10. TEK 10 resulted in some changes in demand for energy efficiency and energy supply.

It is a one year transition period, until 01.07.2011, where the developer can choose whether the project should follow TEK 10 or TEK 07. In this study TEK 07 will be used as a basic.

When it comes to Standards Norway (SN), this is a private and independent member organization, and is one out of three standardization bodies in Norway [3]. Standards Norway is responsible for standardization activities in all areas except the electro technical field and the telecommunications field.

Standards Norway is the national member of the International Organization for Standardization (ISO) and the European Committee for Standardization (CEN) [3].

In connection with energy requirements in technical regulations in the Planning and Building Act and the energy labeling of buildings, NS 3031 is used as the reference standard. NS 3031 is the standard that gives the methods and data for calculation of energy performance of buildings based on this act.

1.2.1 The Norwegian passive house standard NS 3700

In the spring of 2010, a new Norwegian standard for low-energy and passive houses was founded under the name NS 3700. The standard provides guidance for planning, construction and evaluation of residential buildings with a low energy need and implementation of renewable energy (Standard NS 3700).

Germany has been the leading country when it comes to passive house technology and the passive house standard is based on the German standard made by Passivhaus Institutt. The reason to say that the house is passive, is that it uses the energy that whatever is present in the building. This energy includes the heat from computers and other electrical appliances, as well as the heat emitted by the users of the building. Energy consumption is reduced by passive measures where important items are extra insulation, tight construction and compact body, high-insulating windows and normally a good ventilation system with heat recovery. Secondary attempts are to exploit passive solar heating in an efficient manner (most windows facing the sunny orientation). Finally, an energy source and heating solution that is adapted to the low demand for heating is chosen.

It is emphasized that the Norwegian standard for passive houses does not have to deviate too much from the criteria used in Sweden and Europe. Nevertheless, it is taking into account special Norwegian conditions such that a large proportion of residential buildings consist of smaller homes and that a significant portion of the housing stock is built in especially cold climates [4]. For example, when considering energy needs for a building, the standard requires energy calculation based on local climate where the house is to be constructed.

Included in the passive house standard is the requirement that the building also must satisfy the technical building code.

1.2.2 Building technical requirements

There are great differences regarding the building technical requirements in a conventional TEK house and a passive house. Some of the main premises for the two standards will be presented in this chapter.

Table 1.1 shows a comparison of the lower requirement of current regulation and the passive standard of total energy needs, also called the energy framework, for residential buildings. The unit in the table is kWh /m^2 heated usable floor area per year.

Table 1.1: A comparison of the energy frame from TEK 07 and the passive house standard [4-7]

	TEK 07	*Passivhouse standard*
Residential house	125 + 1600/ m2 heated UFA*	80

* The energy frame is dependent on the heated Usable Floor Area (UFA)

Table 1.2 shows the proposed insulation requirements, while Table 1.3 and Table 1.4 show specific U-value requirements concerning the construction and windows. The thermal transmittance, or U-value for a component, is a measure of how good the heat insulation is. The U-value is measured in W/m^2 K, and indicates the amount of heat per unit time passing a square meter of construction at a temperature difference of one degree Kelvin between the two sides of the structure. In short, a low U-value provides good heat insulation.

Table 1.2: Insulation requirements from TEK 07 and the passive house standard [4, 5]

Construction	*TEK 07*	*Passivhouse standard*
Outer walls	250mm mineral wool	300 - 450mm mineral wool
Roof	350mm mineral wool	450 - 550mm mineral wool
Ground floor	200mm exp. polystyrene	300 - 350mm exp. polystyrene

Table 1.3: U-value requirements of TEK 07 and the passive house standard [4, 5]

Construction	*TEK 07 (W/m² K)*	*Passivhouse standard (W/m² K)*
Outer walls	0,18	0,12
Roof	0,13	0,07-0,10
Ground floor	0,15	0,07-0,10
Normalized cold bridge	0,05	0,03

Table 1.4: Window requirements from TEK 07 and the passive house standard [4, 5].

	TEK 07	*Passivhouse standard*
Type	Insulated frame and two-layer energy glas with argon in the cavity, or common frame with triple energy glas and argon in the cavity	Insulated frame and triple energy glas with argon in the cavity
U-value	1,2 W/m2K	0,8 W/m2K

The density or tightness of the building envelope can be described by a “leakage number”, which is the air change rate measured at a pressure of 50 Pa. This parameter is called N50 and is presented in Table 1.5.

Table 1.5: Window requirements from TEK 07 and the passive house standard [4, 5].

	TEK 07 (air change/h)	*Passivhouse standard (air change/h)*
Density,building body (N50)	2,5	0,6

According to the passive house standard, technical equipment and lighting are strongly proposed to be energy efficient and be marked as a product using low amounts of energy. Table 1.6 shows the instructive energy needs regarding lighting, technical equipment and hot water in a dwelling based on the requirements from TEK 07.

Table 1.6: Standardized energy requirements regarding lighting, technical equipment and hot water in a dwelling [4, 5].

Energy post	*TEK 07 (kWh/m2 år)*
Lighting	17
Technical equipment	23
Hot water	30

Main requirements regarding the ventilation system is presented in Table 1.7. An important feature of the ventilation systems is the specific fan power, also called SFP factor. This factor is measured with the unit kW/ (m^3/s) and provides a measure of the ventilation fans' efficiency. For conventional homes, is the SFP factor according to the regulations set to be 2.5 kW/(m^3/s) [5]. According to the passive house standard 1.5 kW/ (m^3/s) or less is preferred.

Heat recovery is the amount of energy that is recovered after it is taken out from the hot reservoir. The air change rate needed is 1.2 m3/ (h m^2) and is the same for the two standards.

Table 1.7: Requirements regarding ventilation [4, 5].

Spesification, ventilation	*TEK 07*	*Passivhouse standard*
SFP factor	2,5 kW/(m3/s)	1,5 kW/(m3/s)
Heat recovery	70 %	80%, balanced
Air change rate	1,2 m3/(h m2)	1,2 m3/(h m2)
Energy use	-	4 kWh/m2 yr

1.2.3 Heating system requirements

TEK 07 says that a minimum of 40 percent of estimated net energy for space heating (including heating ventilation air) and hot water in new residential buildings and the refurbishment should be met by other energy than electricity or fossil fuels.

The obligation ceases if one of the following criteria are met [8]:

a) if the net heating of the building is less than 17 000 kWh / year.
b) if the developer can show that heat the solutions involves extra costs over the building life cycle, compared with the use of electricity or fossil fuels.

In such cases, the homes of over 50 m^2 UFA still needs to have a closed chimney and fireplace for use of biofuels such as wood stove or pellets.

Further, valid for the passive house, formula 1.1 shows the main principle when it comes to energy supply according to the passive house standard NS 3700.

1.1 $$E_{part,\,el} + E_{part,\,oil} + E_{part,\,gas} < E_t - 0.5 * Q_{w,nd}$$

where

$E_{part,\,el}$ is energy from annual delivered electricity (kWh/yr);

$E_{part,\,oil}$ is energy from annual delivered fossil oil (kWh/yr);

$E_{part,\,gas}$ is energy from annual delivered fossil gas (kWh/yr);

E_t is the total annual net energy need (kWh/yr);

$Q_{w,nd}$ is the annual net energy need for heating of tap water (kWh/yr).

The upper amount of acceptable energy need for space heating in a passive house with less than 250 m^2 heated floor area, heat from the ventilation system included, is described by formula 1.2 and 1.3. A_{fl} is the heated part of usable floor area and θ_{ym} is the outside mean temperature. Formula 1.2 is going to be used when the mean outside temperature is or is higher than 6.3 °C, and formula 1.3 shall be used otherwise.

1.2
$$15+5,4\times\frac{\left(250-A_{fl}\right)}{100}$$

1.3
$$15+5,4\times\frac{\left(250-A_{fl}\right)}{100}+\left(2,1+0,59\times\frac{\left(250-A_{fl}\right)}{100}\right)\times\left(6,3-\theta_{ym}\right)$$

1.2.3.1 Calculation of delivered energy

Delivered energy is the energy you need to buy to cover the building's net energy demand and is defined as the sum of all energy supplied over the building system boundaries. This energy includes both net energy and system losses that are not recovered. The system efficiency is a product of the production efficiency, distribution efficiency and regulatory efficiency. Distribution efficiency includes losses in the distribution system as well as in the storage device, the accumulator. The relationship between delivered energy and net energy is described by equation 1.4, taken from NS 3031 [5].

1.4
$$E_{delivered}=\frac{E_{net}}{\eta_{prod}*\eta_{dist}*\eta_{reg}}=\frac{E_{net}}{\eta_{sys}}$$

where

η_{prod} is the efficiency of the energy production system

η_{dist} is the efficiency of the energy distribution system

η_{reg} is the efficiency of the energy regulation system

η_{sys} is the efficiency of the total heating system

In contrast to the net energy, the need for energy delivered is a measurable size. The amount of delivered energy may therefore be based on measurements, or on estimates of net energy and a given system efficiency.

NS 3031 provides a list of standard values for efficiencies for different heating systems. Table 1.8 shows efficiencies for selected heating systems.

Table 1.8: Guided system efficiencies for the chosen heating systems [5].

Heating system	*Production efficiency,* ηprod	*Distribution efficiency,* ηdist	*Regulation efficiency,* ηreg	***System efficiency,* ηsys**
Sun collector, radiators	9,00	0,95	0,95	8,12
Air-water heat pump, radiators	2,30	0,95	0,95	2,08
Wood stove	0,80	1,00	0,80	0,64
Direct electrical heating, panel heaters	1,00	0,98	1,00	0,98
Electrical hot water heater	0,98	1,00	1,00	0,98

The need for delivered electricity to a heat system, E_{el}, can be calculated by formula 1.5 [5].

1.5

$$E_{el} = \frac{E_{delivered}}{\eta_{sys}}$$

1.3 Earlier LCA studies on energy and climate systems

The life cycle impacts have a growing interest in the research field of buildings and infrastructure. As a result of this, the body of published literature in this field is increasing. The effect due to the phase of production compared to the phase of operation is a common angle of study, but there are big differences regarding objective and scope of the reviewed studies. Most comparative studies include both the construction of the building and the heating system over the entire life cycle. Not many studies focus only on heating and ventilation, and exclude the rest of the energy system and construction, which is the case in this study.

Nevertheless, the reviewed studies can give knowledge about trends that may be comparable with the results of this study.

As an example, Sartori and Hestnes do see a large effect of the operation phase, performing a literature survey on buildings' life cycle energy use of 60 cases from nine countries studied in 2006 [9]. Despite climate and other background differences, the study revealed a linear relation between operating and total energy valid through all the cases. Case studies on houses built according to different design criteria and other conditions showed that design of low-energy buildings induces both a net benefit in total life cycle energy demand and an increase in the embodied energy [9].

The large energy use and corresponding environmental impact of the operation phase is evident in most studies reviewed, but the improvements due to a conversion into passive house technology are discussed. The report "*Illustrating limitations of energy studies of buildings with LCA and actor analysis*" [10] by Brunklaus in 2010, focuses on the role of the chain of actors influencing the choices done in different stages in a life cycle. A special emphasis is placed on actors in the interpretation phase and LCA results are analyzed with help of actor analysis to trace environmental impacts to each respective actor. The comparison confirms that passive houses have lower energy use than conventional houses, but when the environmental impact of energy production is taken into consideration, the outcome is less clear. The study reveals that conventional houses are shown to be equally good environmentally in terms of global warming, acidification, or radioactive waste as typical passive houses with electrical heating depending on the actors' choices. Actor analysis shows that inhabitants' and material producers' electricity choice are very important, while other choices (f. ex. green transport) are less important [10].

Not many LCA-studies exist on ventilation units, but Mikko Nyman and Carey J. Simonson studied two types of ventilation systems including heat exchangers in 2004. It concludes that the systems installed in conventional houses have a positive impact on the environment with a heat exchanger having a greater effectiveness than 15 percent.

Most of the studies done in the field of building technology are primarily concerned with the embodied energy and carbons. The biggest concern is connected to climate change, while there is a lack of focus on other impact categories.

1.4 Structure of the report

Chapter 1 makes an introduction to the study, describing the premises for the study based on Norwegian building code and standards. Previous studies on this topic are also presented. Chapter 2, named Materials and methods, introduce the case studies, methods used and a description of the systems analyzed. Chapter 3 presents the results based on the calculations, while chapter 4 evaluate and discuss the results. Finally a conclusion is drawn in chapter 5, followed by two chapters presenting bibliography and appendixes.

2 Materials and methods

2.1 The case studies

The case studies, Stord TEK 07 and Stord Passive, are assumed to be placed in the municipality Stord, a small city on the southwestern side of Norway.

The buildings have the same type of architectural design, but while Stord TEK 07 is based on the Norwegian building code revived in 2007, is Stord Passive built after the passive house standard NS 3700. They are typical single-family dwellings, delivered by the Norwegian building company Nordbohus AS. Both of them got two floors, and have a total usable area of 187 m^2.

2.1.1 Stord TEK 07

Figure 2.1 and Figure 2.2 present the construction and exterior of the dwelling Stord TEK 07. Appendix 7.6 shows a larger version of the illustrations. Both the cladding and the framework of the house are made of timber. The insulating material in the walls and roof is rock wool and meets the minimum building regulation thickness standards of respectively 200mm and 350mm.

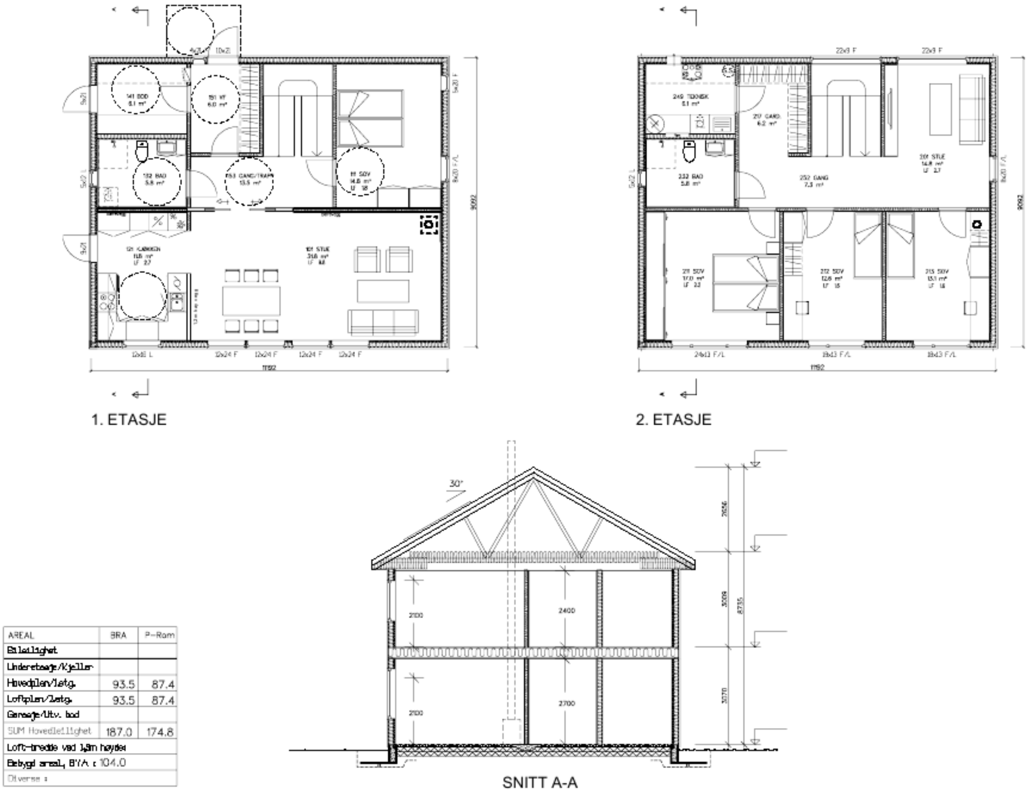


Figure 2.1: The construction of Stord TEK 07

Figure 2.2: The facade of Stord TEK 07

2.1.1.1 Building characteristics of Stord TEK 07

Table 2.1 presents some of the dwellings` characteristics and the heat loss framework of the building code of 2007. The energy framework recommends a U- value of 0.18 W/m^{2}K in the outer walls. This is lower than the case study value of 0.22 W/m^{2}K, but the energy amount lost is recovered because of the low U-value of the ground floor of 0.13 W/m^{2}K compared to the recommendation of 0.15 W/m^{2}K. Another section where the building is “earning” energy loss is by the choice of ventilation system where the heating recovery efficiency is 80 percent instead of the required 70 percent. If all the heat loss is counted for will the heat loss factor, H”, exceed 0.86 W/m^{2}K which satisfies the building code.

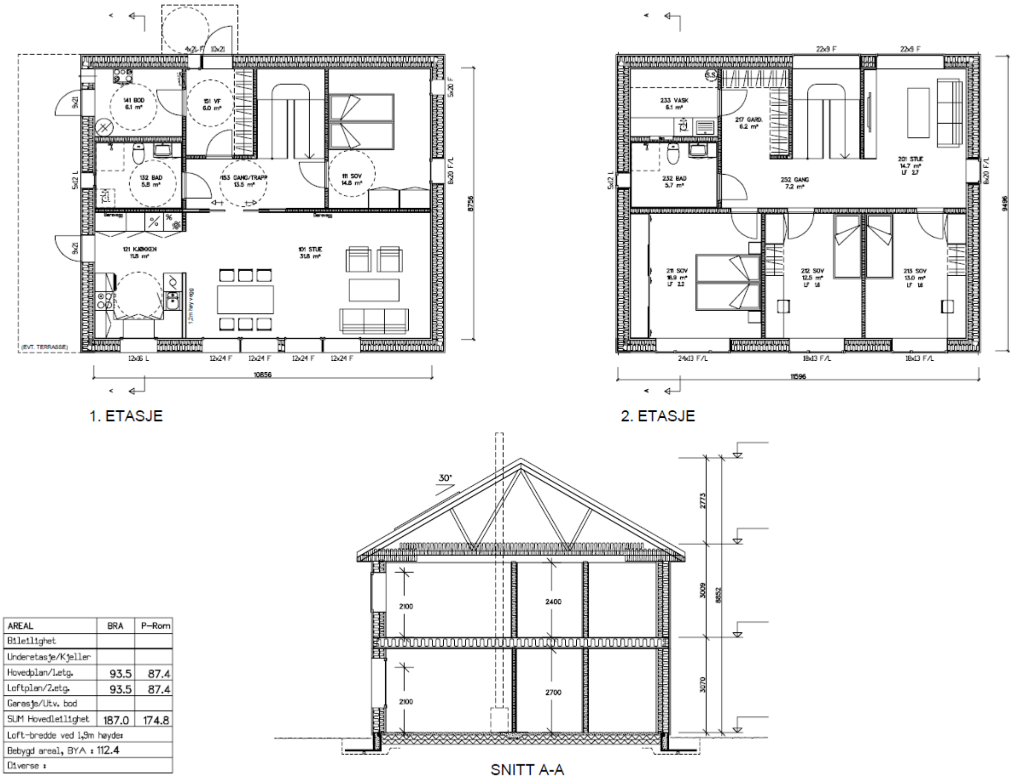
Table 2.1: The characteristics of Stord TEK 07 and the framework of the building code.

Stord TEK 07				**TEK 07 framework**
	Area m2	*U - value W/(m2K)*	*Heat loss W/(m2K)*	*Heat loss W/(m2K)*
Outer walls, net area	198,9	0,22	43,8	35,9
Windows and doors	37,7	1,17	44	44,9
Roof	93,5	0,12	11,2	12,2
Ground floor	93,5	0,13	12	14
Normalized cold bridge	187	0,05	9,4	5,6
	Air load m3/h	*Efficiency %*		
Infiltration	78	-	25,6	25,6
Ventilation	224	80	14,8	22,2
Heat transport coeffecient H (W/K)			160,7	160,3
Heat loss factor, H" (W/(m2K))	**-**	**-**	**0,86**	**0,86**

Specific fan capacity, SFP	1,5	kW/(m3/s)

2.1.2 Stord Passive

Figure 2.3 and Figure 2.4 present the construction and facade of the dwelling Stord Passive. Appendix 7.7 shows a larger version of the illustrations. The building is similar constructed as the TEK 07 house; the cladding and framework are also made of timber and the insulating material in the walls and roof is rock wool and meets the minimum building regulation thickness standards.



AREAL	BRA	P-Rom
Bileilighet		
Underetasje/Kjeller		
Hovedplan/1.etg.	93.5	87.4
Loftplan/2.etg.	93.5	87.4
Garasje/Utv. bod		
SUM Hovedleilighet	187.0	174.8
Loft-bredde ved 1,9m høyde:		
Bebygd areal, BYA : 112.4		
Diverse :		

Figure 2.3: The construction of Stord Passive

Figure 2.4: The facade of Stord Passive

2.1.2.1 Building characteristics of Stord Passive

Table 2.2 shows the building characteristics and the heat losses of Stord Passive. The U-value of outer walls, windows and roof are similar to the passive house standard recommendation values. The U-value of the ground floor turn off from the advice, but the extra heat loss here is gained by the overall low infiltration loss. The heat loss factor is 0.51 W/m^{2}K compared to the requirement from NS 3700 of 0.55 W/m^{2}K [4].

Table 2.2: The characteristics of Stord Passive and the framework of the building code.

Stord Passive				**TEK 07 framework**
	Area m2	*U - value W/(m2K)*	*Heat loss W/(m2K)*	*Heat loss W/(m2K)*
Outer walls, net area	198,9	0,12	23,9	35,9
Windows and doors	37,7	0,72	27	44,9
Roof	93,5	0,09	8,2	12,2
Ground floor	93,5	0,11	10,6	14
Normalized cold bridge	187	0,03	5,6	5,6
	Air load m3/h	*Efficiency %*		
Infiltration	19	-	6,1	25,6
Ventilation	224	80	14,8	22,2
Heat transport coeffecient H (W/K)			96,3	160,3
Heat loss factor, H" (W/(m2K))	-	-	**0,51**	**0,86**

Specific fan capacity, SFP	1,5	kW/(m3/s)

2.1.3 The municipality Stord

The case studies are assumed to be located in the municipality Stord, which is a small city on the southwestern side of Norway. The city has a typical coastal climate with higher mean temperature and less “degree days” then the national average. Figure 2.5 shows where the city is located on the map. Typical climate data for the municipality is given in Table 2.3 and Figure 2.6 show mean temperatures over the year. The yearly mean temperature is 7.4 ^{0}C.

Table 2.3: Climate data for Stord, Norway [11].

Climate data		
Place	Stord	-
Latitude	59,8	^{o}
Longitude	5,5	^{o}
Mean annual temperature	7,4	^{o}C
Mean solar radiation, horizontal plate	2,27	kWh/m2/d

Figure 2.5: Map showing location of Stord on the western side of Norway [11]

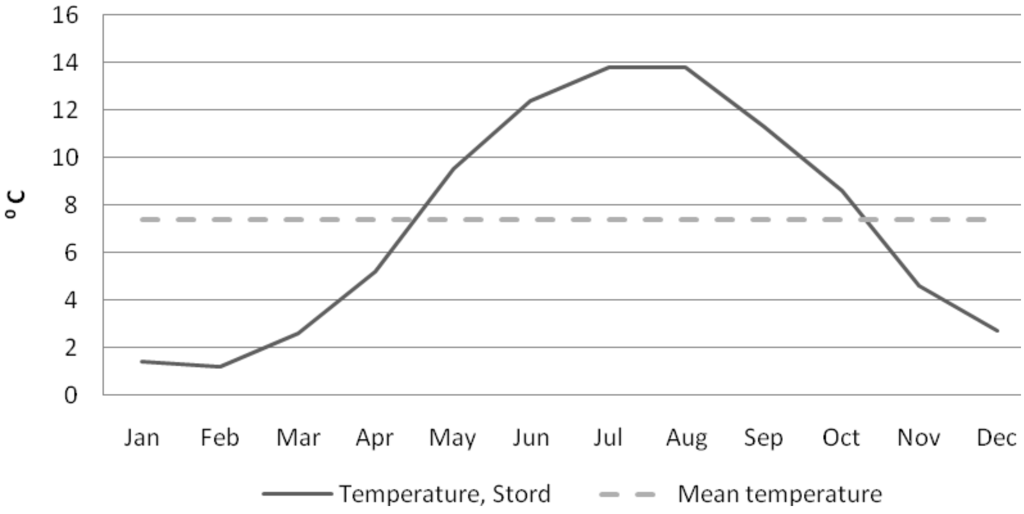


Figure 2.6: Mean temperatures at Stord [12].

2.1.4 Calculated energy need for the case studies

There are different simulation tools that can be used to find the energy need of the two houses. In this study the software SIMIEN is used, made by Programbyggerne AS. The software does not have climate data based on Stord, but uses data based on the nearby city Bergen instead. This city has mean temperature of 7.5 ^{0}C. It is assumed that mean inside temperature is 20 ^{0}C.

The results are presented in Table 2.4 and Table 2.5. Figure 2.7 shows an illustration of the difference of the two building versions.

In both houses is a high degree of sun screening on the southern side taken into account. The energy used by “Fans” is the energy needed for the fans of the balanced ventilation system. For the passive house is also delivered energy needed to run pumps connected to a hydronic heating system included in this table.

Figure 2.7 shows that energy for space heating is the energy post which distinguishes the most from each other. Stord Passive has a third of the energy need for space heating than the conventional house Stord TEK 07.

The space heating amount needed for the passive house of 18.4 kWh/m^2 yr does satisfy the passive house standard requirement of upper amount of heating need calculated by formula 1.2, presented in chapter 1.2.3.

Table 2.4: Energy need in the two case studies, Stord TEK 07 and Stord Passive (kWh/yr).

	Stord TEK 07 (kWh/yr)	*Stord Passive (kWh/yr)*
Space heating	9306	2997
Heat from ventilation, heat battery	623	454
Hot tap water	5573	5572
Pumps	-	113
Fans	819	819
Lighting	3167	2131
Technical equipment	4368	3278
Total	23856	15364

Table 2.5: Energy need in the two case studies, Stord TEK 07 and Stord Passive (kWh/m^2 yr).

	Stord TEK 07 (kWh/m2 yr)	*Stord Passive (kWh/m2 yr)*
Space heating (incl.vent)	53,1	18,4
Hot water	29,8	29,8
Electricity spesific	44,7	33,9
Total	127,6	82,1

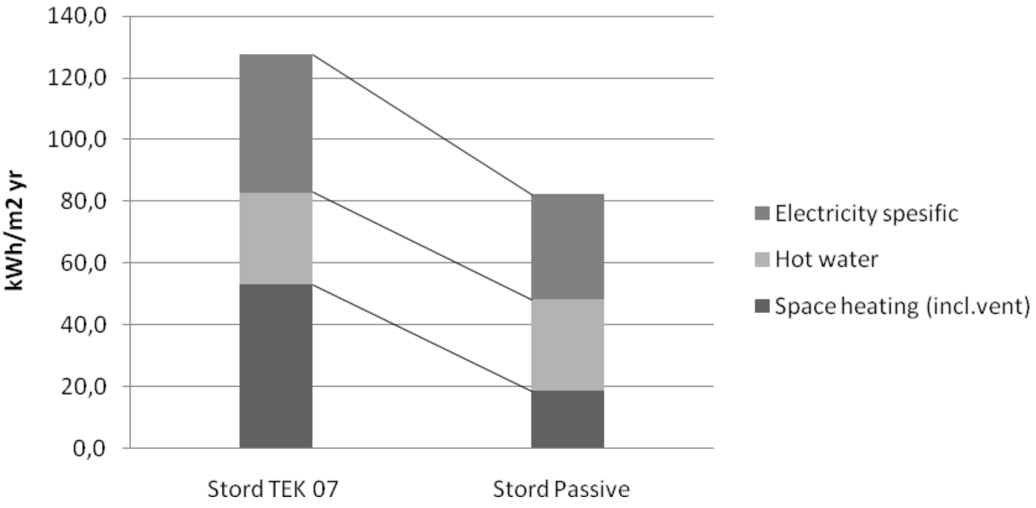


Figure 2.7: Comparison of the division of energy need between the two case studies (kWh/m^2/yr).

2.2 Life cycle assessment methodology

Life-Cycle Assessment or LCA is a standardized technique to assess and report environmental impacts of a products' life cycle through the raw material production, manufacture, distribution, use and disposal, including all intervening transportation steps necessary or caused by the product's existence. As LCA is process based, this method has a bottom- up perspective.

According to the ISO 14040 standard [13], a Life Cycle Assessment is carried out in four distinct phases. The four phases are:

- **Goal and scope**
  The LCA- practitioner formulates the goal and scope of study in relation to the intended application. The object of study is described in terms of a functional unit and the system boundaries are established.
- **Life cycle inventory**
  The inventory phase is when the data are collected and the product system is modeled.
- **Life cycle impact assessment**
  The LCA-practitioner evaluates the contribution to impact categories such as global warming, acidification, etc.
- **Interpretation**
  The Interpretation phase stage is an analysis of the major contributors. This stage leads to the conclusion whether the ambitions from the goal and scope can be met.

2.2.1 Theoretical framework

The theoretical framework is based on lecture notes and readings from course TEP 4223 in 2009 [14].

The foundation of an LCA analysis is the requirements matrix, A. In this matrix, all the information of the inputs and outputs from the different processes in the system are gathered. Each term, a_{ij} gives the output in process i per unit output in process j. The A matrix is divided in different sections. Formula 2.1 shows an illustration. The foreground system, A_{ff}, is where the main system components are gathered and where all other inputs from the background are connected. A_{bb} is the background system and A_{bf} is the amounts going from the background to the foreground. A_{fb} gathers the requirements from the foreground to the background.

2.1
$$A = \begin{bmatrix} A_{ff} & A_{fb} \\ A_{bf} & A_{bb} \end{bmatrix}$$

For a functional unit y, or the final demand, the total outputs from the different processes in the system can be calculated. This matrix is called the x-matrix and the equation is expressed in formula 2.2 and 2.3. The total production equals the internal production plus the final demand.

2.2
$$x = Ax + y$$

2.3
$$x = (I - A)^{-1} y = Ly$$

The term $(I\text{-}A)^{-1}$ is called the Leontief Inverse matrix, or the L-matrix, and gathers the output from process i per unit external demand of product j. To find the total emissions from the processes in the system, the total output must be multiplied with a stressor matrix called S. $S_{str,pro}$ is the emissions of stressor str per unit output of process pro. Formula 2.4 shows the resulting emission matrix e.

2.4
$$e = Sx$$

e_{str} gives the total emissions of stressor str for the given external demand y. To find the stressor amount of each process, the x matrix must be diagonalized, giving the resulting E-matrix as shown by formula 2.5.

2.5
$$E = S\hat{x}$$

The characterization matrix, C, distributes the stressors to the different impact categories. Examples of impact categories are Climate Change or Acidification potential. To find the total impact potential, the C-matrix must be multiplied with the emission matrix, e. The result is formula 2.6 which shows the total impact potential of the system as a whole.

2.6 $$d = Ce$$

To see what impacts can be attributed to the different processes in the system, must the C-matrix be multiplied with the E-matrix (formula 2.5) to make formula 2.7.

2.7 $$D = CE$$

2.2.2 Characterization and Normalization factors

How the characterization matrix distributes the stressors to the impact categories is in this study decided by the ReCiPe method. The primary objective of the ReCiPe method is to transform the long list of inventory results, into a limited number of indicator scores [15]. These indicator scores express the relative severity on an environmental impact category. Table 2.6 shows the different impact categories and corresponding units used in the analysis.

Table 2.6: Impact categories and corresponding units and description.

	Impact category	*Unit*	*Description*
CC	Climate change	kg CO2 eq	Emissions contributing to the greenhouse effect
HT	Human toxicity	kg 1,4-DB eq	Indication of risk to human health
POF	Photochemical oxidant formation	kg NMVOC	Photo smog: Produduction of ground-level ozone
PMF	Particulate matter formation	kg PM10 eq	Particles in the air generated by the use of fuels
IR	Ionising radiation	kg U235 eq	Emissions causing radioactivity
TA	Terrestrial acidification	kg SO2 eq	Acidifying gases that may dissolve in water.
FE	Freshwater eutrophication	kg P eq	Nutrient-rich ocmpounds released into water bodies
ME	Marine eutrophication	kg N eq	Eutrophication of sea water
TE	Terrestrial ecotoxicity	kg 1,4-DB eq	Risks of damage to ecosystems on land
FE	Freshwater ecotoxicity	kg 1,4-DB eq	Risks of damage to fresh water bodies
ME	Marine ecotoxicity	kg 1,4-DB eq	Adverse effect on the marine organisms and environment
WD	Water depletion	m3	Water resource extraction
MD	Metal depletion	kg Fe eq	Metal mineral resource extraction
CE	Cumulated energy	MJ eq	Accumulated primary energy

Some impact categories included in the ReCiPe method are taken away and not used in this study. The impact category called “Ozone depletion” is taken away because this category is not valid anymore because of the strict regulations regarding emissions that can cause depletion of the ozone layer. All three impact categories related to occupation and transformation of land area are not considered because of the large degree of uncertainty and lack of knowledge of the impacts on the Norwegian ecosystem, especially due to the use of wood. The category “Fossil depletion” is also rejected, mainly because “Cumulated energy” is included instead, considering the total use of primary energy including fossil fuels.

The last category, “Cumulated energy”, is actually not an impact category, but is a method of calculating the entire accumulated primary energy in the system. It was published by Ecoinvent version 2.0 and expanded by PRé Consultants.

When using the ReCiPe method it is possible to choose between midpoint and endpoint indicators [15]. Endpoint indicators are damage-oriented: they represent the ultimate consequences of negative environmental impact to humans and ecosystems. These indicators are the “endpoint” of a possible chain of causes and effects. A drawback of these indicators is higher level of uncertainty bacause it may be difficult to assess where the emissions are ending and what the resulting impacts will be. Midpoint indicators, in contrast, show direct impact on the environment, which are situated along the chain of causes and effects.

Each indicator set has also three different cultural perspectives. These perspectives represent a set of choices on issues like time perspective or expectations that proper management or future technology development can avoid future damages. The three perspectives are individualist, egalitarian and hierarchic;

- **Individualist:** Has a short term view with optimism that technology can avoid many problems in the future.
- **Hierarchic:** The consensus model. Often encountered in scientific models and often considered to be the default model.
- **Egalitarian:** Has a long term view based on precautionary principle thinking.

As a part of the ReCiPe method is also normalization factors included to be able to compare the relative importance of the emission output of each category [16].

More about the method can be read on ReCiPes’ webpage; www.lcia-ReCiPe.net [15]. The method is created by RIVM, CML, PRé Consultants, Radboud Universiteit Nijmegen and CE Delft.

2.3 Economical methodology

There are many ways to do an economical evaluation of different alternatives. In this study is a comparison based on present value done, considering the overall expenses due to investments and annual expenses of the different heating systems at present day.

The total cost consists of the following;

$$\textbf{Total Cost} = \textbf{Investment Cost} + \textbf{Energy Cost} + \textbf{Maintenance Cost} \tag{2.8}$$

The annual energy expenses, E_n, must be based on delivered energy calculated by the system efficiency to the current heating system as is shown in equation 2.9. E_{net} is the estimated annual net energy consumption in kWh per year, the η_{system} is the system efficiency for the heating system, and C_{energy} is the cost per kWh.

2.9
$$E_n = \frac{E_{net}}{\eta_{sys}} \cdot C_{energy}$$

The energy costs must be discounted to get the present value of the 50 years of annual expenses. Formula 2.10 show the discount factor, d_n, which is an equation decided by the discount rate r, and the year it is discounted from, n. In the calculations is the rate set at 4 percent as recommended in the building code [7]. The present value of the energy costs, $E_{n,PV}$, is then presented by formula 2.11.

2.10
$$d_n = \frac{1}{(1+r)^n}$$

2.11
$$E_{n,PV} = E_n \cdot d_n$$

The maintenance costs, M_n, must also be discounted and the present value of these costs are then $M_{n,PV}$, shown by equation 2.12.

2.12
$$M_{n,PV} = M_n \cdot d_n$$

Writing paragraph 2.8 with the presented variables gives the formula 2.13 which shows the total costs through the 50 year life cycle, C_{PV}. I_0 is the investment costs.

2.13
$$C_{PV} = I_0 + \sum_{n=0}^{50} E_{n,PV} + \sum_{n=0}^{50} M_{n,PV}$$

2.4 The analyzed heating systems and input data

In the process of choosing what heating systems to analyze for the two houses, the underlying criteria have been to find as realistic systems as possible.

Electricity has for a long time been the main source of heating in Norway. Historically speaking, Norway has had low electricity prices due to heavy water power and correspondingly little demand for other renewable energy sources. Therefore the demand of that 40 percent of the net heating need should be covered by renewable energy, as described in chapter 1.2.3, was stated in the building code of 2007.

As long as balanced ventilation with heat recovery is used, there will be a net energy need for heating of less than 17 000 kWh/yr in both of the studied cases. This means that the requirement of chapter 1.2.3 is not valid for this study.

According to the present Local Government Minister Liv Signe Navarsete it is a goal in Norway to increase the use of central heating based on renewable energy [17]. Central heating is a water based system where water is circulating in a building delivering energy which can heat tap water and deliver heat through pipes in the floor or radiators on the wall. District heating, geothermal heat, biomass, solar and heat pumps are examples which are used in collaboration with a hydronic heating system, which are based on energy sources that otherwise might not have been used. Hydronic heating is therefore considered in two of the system solutions for the passive house.

Under are the heating systems for space and tap water for the two houses listed. The percentage shares presented in the brackets are describing the share of total net heating demand (excluding heat from ventilation), covered by the associated energy source.

The chosen heating system for Stord TEK 07 is the standard Norwegian heating combination of;

- Electricity for warming water and used for heating through panel heaters (60%).
- Wood stove for heating purpose in the coldest months (40%).

This is also one of the three compared solutions to Stord Passive, but also the use of an air-to-water heat pump and a solar collector system are studied;

1. *Standard Norwegian electricity system – Stord Passive S1*
    - Electricity for warming water and used for heating through panel heaters (60%).
    - Wood stove for heating purpose in the coldest months (40%).
2. *Solar collector system – Stord Passive S2*
    - Vacuum solar collector used to warm water and heating through a hydronic heating system with two radiators, one in each floor. The two bathrooms have under floor heating (38%).
    - Electricity through a heating element to be used to cover the remaining energy need when the solar collector is not enough to heat the water (62%).
3. *Heat pump system – Stord Passive S3*
    - Air to water heat pump for warming water and heating the house through a hydronic heating system with two radiators, one in each floor. The two bathrooms have under floor heating (75%).
    - Electricity through a heating element to be used to cover the remaining energy need when the heat pump is not enough to heat the water (25%).

On the hottest summer days there may be a need for cooling in the passive house, especially in the rooms with windows facing south. In this study it is assumed that this can be done by passive measures such as sun shading, night cooling via open windows and increased ventilation and is therefore not taken into account in the analysis.

2.4.1 General data sources and inventory input for the heating systems

The main phases in a life cycle of a product or a system is production, use and demolition. Figure 2.8 illustrates the entire cradle-to-grave life cycle, which are included in the assessments of the heating and ventilation systems.

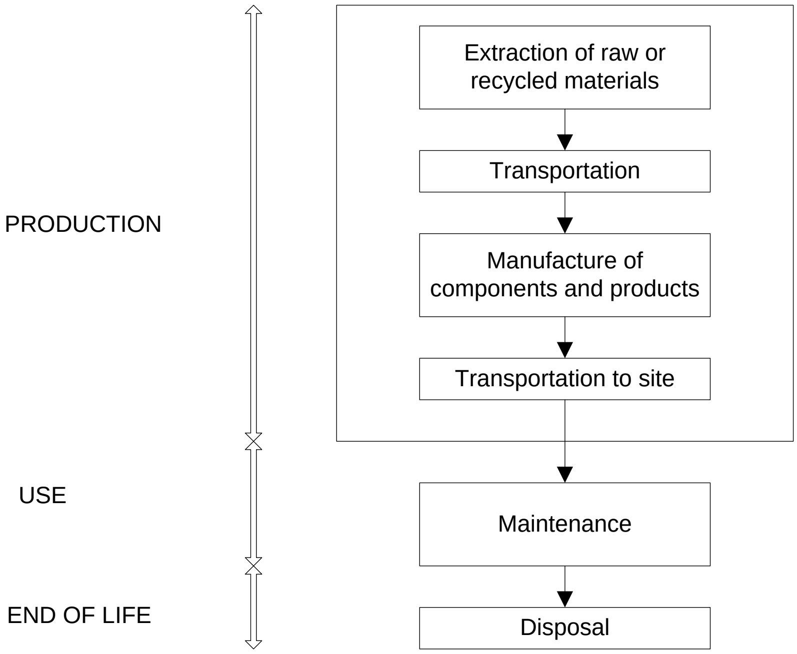


Figure 2.8: Flow chart of the life cycle of a heating system.

The life cycle length of the study is chosen to be 50 years. Input data to the different systems are based on literature, collected material from manufactures and technical specification sheets. Further information of the specific systems is presented in later chapters describing each heating system in detail.

There are some general principles that are followed regarding the inventory input. First of all it must be mentioned that the electricity chosen for the use phase of the buildings is the Nordic electricity mix, called NORDEL. Norway is a part of the Nordic electricity marked and this mix is considered the most accurate at present day. Further discussion on this choice can be read in chapter 4.2.1.

The Ecoinvent process called the NORDEL mix is based on a study done in 2007 [18]. The allocation of energy sources from this study can be viewed in Table 2.7. For products with manufacturing abroad is the European electricity mix chosen.

Table 2.7: Division between energy sources in the Nordic electricity mix, NORDEL [18].

	Nuclear power	*Water power*	*Pumped storage*	*Fossile - thermal*	*Wind power and biomass energy*	*Waste*	*Total production*	*Part of the NORDEL production*
	%	%	%	%	%	%	GWh	%
Sweden	50,5	40,1	0,1	3,4	5	0,9	148411	39,3
Norway	0	98,5	0,5	0,4	0,5	0,1	109376	29,0
Danmark	0	0,1	0	74,1	22,3	3,5	38366	10,2
Finland	26,7	17,9	0	42,8	12	0,6	81551	21,6
NORDEL	25,6	48,1	0,2	18,2	7	0,9	377703	

Another area with different ways of handling is how to treat the wasted material for each of the inputs. For the component processes which are based on collected data, are the waste scenarios in this study assumed on the basis of current statistical data gathered from Statistics Norway [19]. The latest year possible with full data on disposal is currently 2008. Figure 2.9 shows the total treated waste of different material categories and Figure 2.10 gives an illustration of the division of treatments.

The recycling amount is high when it comes to metal. 91 percent of the total of 1134 kg is recycled. Also the paper has a big fraction of recycling. Including the energy utilization is the total amount for a secondary use 72 percent. Plastics have a recycled amount of 14 percent together with an energy utilization of 29 percent.

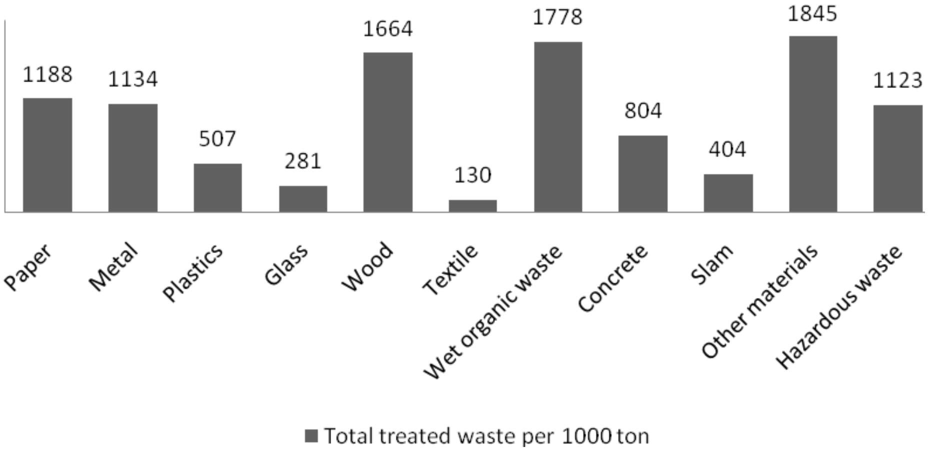


Figure 2.9: Statistical data on the amount of total treated waste in Norway in 2008 [19].

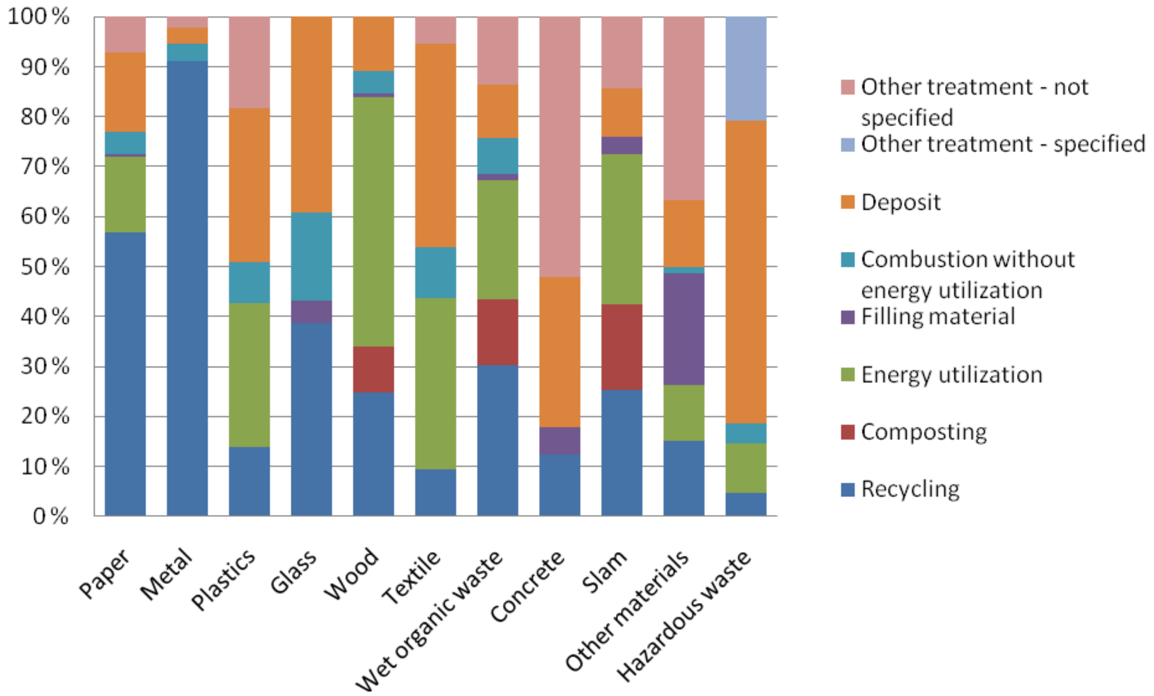


Figure 2.10: Statistical data on waste management in Norway in 2008 [19].

2.4.2 Heating system Stord TEK 07 and Stord Passive S1: Electrical panel heaters and a woodstove

The combination electricity and a wood stove has been the most used heating solution in Norwegian homes in the last decades. Electric space heating in low energy houses and passive houses is said to be acceptable if not more environmentally friendly energy supply is convenient and economical defensible [20]. Heating hot water, which is usually the largest energy post in passive and low energy housing, should be tried covered by other, more environmentally friendly energy sources than electricity. Nevertheless, a system based on electricity is studied to be able to compare the passive house to the conventional house.

Included in the system inventories are;

- **Electrical panel heaters**

- **Warm water tank**
  The tank is based on electrical heating.

- **Wood stove system**
  Wood stove, chimney pipes and fire wood through the entire life time is included.

- **Maintenance**
  Transportation of chimney sweeper ones a year is included.

- **Transport**
  Transportation of the system components and the maintenance personal during the lifetime is included.

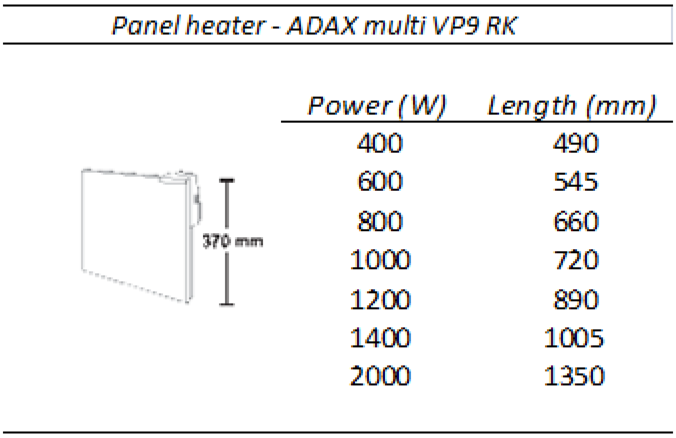
- **Demolition**

2.4.2.1 Data sources and inventory input

The system solutions with electrical panel heaters and a wood stove are mainly based on data collected from manufacturers and technical descriptions.

The heaters analyzed in this study are regular electrical heaters normally caught to the wall. Data are collected from the manufacturer Adax, a Norwegian company producing different types of electrical equipment. The manufacture of the electrical heaters is assumed located in Svelvik, Norway. The heater inputs contains of 80-90 percent steel, together with different kinds of plastics and electronics. Table 2.8 shows the dimensions of different models and Table 2.9 shows the chosen size of the heaters in each of the rooms. Total installed power by electrical heating is then about 28.9 W/m^2 for Stord TEK 07, while it is about 19.3 W/m^2 for Stord Passive S1.

Table 2.8: Dimensions of Adax multi electrical heaters [21].



Panel heater - ADAX multi VP9 RK

Power (W)	Length (mm)
400	490
600	545
800	660
1000	720
1200	890
1400	1005
2000	1350

Table 2.9: The chosen power size on the electric heater in each room in the two houses.

Innstalled power of electrical panel heaters			
First floor		***Stord TEK 07***	***Stord Passive S1***
	Area (m2)	*Power heater (W)*	*Power heater (W)*
Living room/kitchen	43,6	2 x 600	600
Bedroom	14,8	600	400
Bathroom	5,8	400	400
Hall/Stairs	13,5	-	-
VF	6	-	-
Bod	6,1	-	-
Second floor			
	Area (m2)	*Power heater (W)*	*Power heater (W)*
Living room	28,3/28,1*	1000	600
Bedroom 1	17/16,9*	600	400
Bedroom 2	12,6/12,5*	600	400
Bedroom 3	13,1/13*	600	400
Bathroom	5,8/5,7*	400	400
Washroom	6,1	-	-

*Stord TEK 07/Stord Passive S1

When it comes to the electrical water tank, the analysis is based on a 200l standard electrical tank which input data was given by the company OSO Hot water. The transport distance is calculated with the assumption that the water tank is produced in Hokksund, Norway, where a big factory of them is located.

The life time expectancy of the electrical heaters and the hot water tank is regarded as 25 years.

Data regarding the wood stove and chimney pipes are based on information found in technical descriptions provided by Nordpeis. Nordpeis is a Norwegian based company with a subsidiary company named Northstar which owns two factories in Poland. The transportation is therefore based on manufacturing here.

An illustration of the stove and the chimney is given in Figure 2.11. The stove is assumed to be the model Saturn which is made of 115 kg cast iron and have a capacity of 2-9 kW.

Figure 2.11: Left: Photo of the wood stove "Saturn". Right: Illustration of a Nordpeis stove and chimney installed in a two floor high residential building [22].

The data on wood used in the analysis is based on information got from SINTEF Building and Infrastructure who has made Environmental Product Declarations on different types of wood products used in the Norwegian building stock.

The emission output associated to climate change of burning the Norwegian timber is in this study 12.7 g CO_2 -eq/kWh. This number is based on the assumed direct emission output using the Ecoinvent process "Logs, softwood, burned in wood heater/CH". It is assumed a heating value of 15 MJ/kg fire wood [23] which for the Stord TEK 07 house gives an annual consumption of 1396 kg and for the passive house an amount of 450 kg.

The wood stove and chimney pipes are assumed to last for the whole life time of the house of 50 years.

The material inventories of the heaters and the total system for the 50 year period can be further studied in appendix 7.4.1.

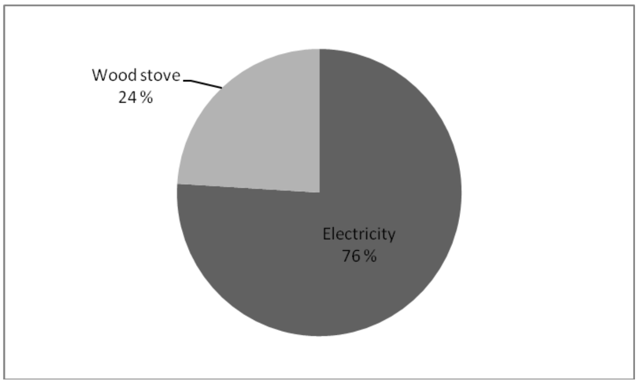
2.4.2.1 Differentiating between energy sources –Stord TEK 07 and Stord Passive S1

The differentiating between the energy sources can vary to a large extent depending on the residents, but in this study it is assumed that 40 percent of net energy need for space heating is covered by the renewable energy source wood, while the rest is covered by electricity. This division is used for both the case studies.

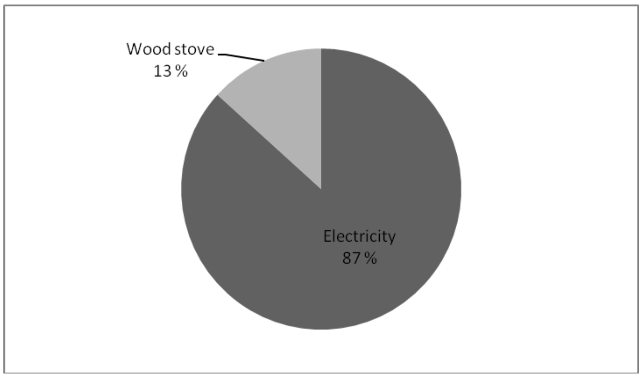
The energy requirement from NS 3700, formula 1.1, makes it difficult to choose a system not based on renewable energy for the passive house. Even though the requirement of formula 1.1 is not satisfied, a solution of 60 percent of net energy covered by electrical heating is nevertheless used as an alternative for this house. This is done to be able to compare this alternative with the same system in a conventional house. Appendix 7.3.1 shows the results of the calculation of the formula.

The total electrical net energy for heating, ventilation included, is 76 percent for Stord TEK 07 and 87 percent for Stord Passive. This is shown by Figure 2.12.

Net energy is the amount of energy needed when the losses in the system are not taken into account. Figure 2.13 show *delivered* energy which is calculated using the theory from chapter 1.2.3.1.



Stord TEK 07



Stord Passive S1

Figure 2.12: Illustrations of the division of net energy with ventilation included for Stord TEK 07 and Stord Passive S1.

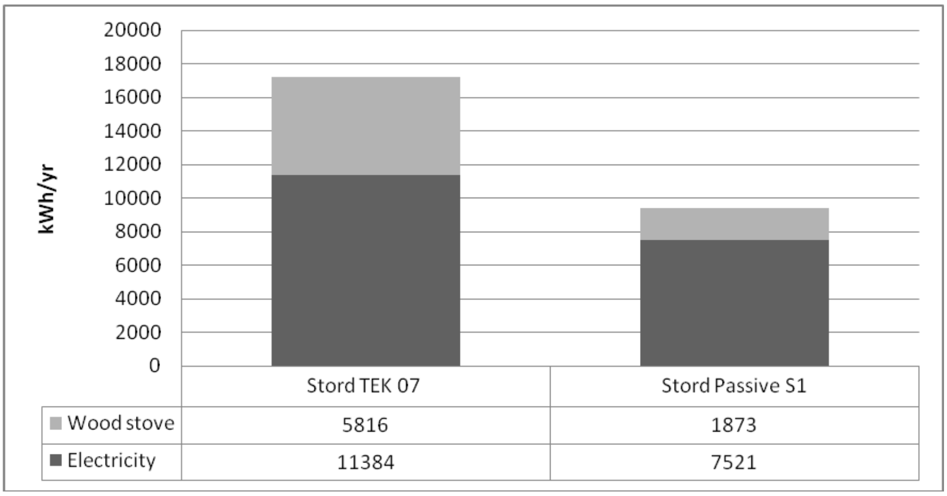


Figure 2.13: The delivered energy at Stord TEK 07 and Stord Passive S1.

2.4.3 Heating system Stord Passive S2: Solar collector system

Despite the popularity in other northern parts of Europe, solar collectors have traditionally not been utilized for heating purpose in Norway. The annual solar radiation in Norway varies from around 700 kWh / m^2 in the north to about 1100 kWh / m^2 in the south, which is equivalent to 30-50 percent of the radiation at the equator [24]. This amount can be exploited for heating purposes, especially for hot water heating where the needed amount of heat is pretty constant.

Included in the system inventory are;

- **The vacuumtube collectors**
  Three collectors mounted on the 30 degree sloped roof.

- **All extras to make the solar collector work**
  That is; copper pipes, pumps, vessel and similar to make the solar system function, including electricity for the electrical equipment.

- **Warm water tank**
  Based on hydronic heating

- **Hydronic pipe system**
  It is assumed an installation of two radiators in the building, one at each floor and hydronic floor heating in both the bathrooms.

- **Electricity**
  Electricity through a heating element will compensate the solar collector when the heat production is not sufficient.

- **Maintenance**
  Pumps and the antifreeze-inhibitor will be renewed every tenth year.

- **Transport**
  Transportation of the new system and the maintenance personal during the lifetime is included. It is assumed that control and maintenance personal is arriving every fifth year.

- **Demolition**

2.4.3.1 Data sources and inventory input

The system solution with solar thermal collectors is based on an analysis published in the Swiss Ecoinvent report No.6-XI, made by Niels Jungbluth in 2007 [25]. Jungbluth has done the analysis of the solar collector and basic components, but several points have been substituted to fit current project of the Stord Passive house. The simulation tool Polysun is used to find the most efficient size of the collector and the corresponding usable solar energy at the passive house located at Stord.

The vacuum tube model used in the analysis is Mazdon 30, supplied by the manufacturer Thermomax. The company is currently sold to over 40 countries with Western Europe and the United States as its main markets. It is based in two locations in the United Kingdom, and a unit in Italy. The production in this study is assumed located in Bangor, Northern Ireland.

The analysis is based on a 600 l hot water tank delivered by Jenni Energietechnik AG near Burgdorf in Switzerland, but the transport distance is calculated on the assumption that the water tank is produced in Hokksund, Norway. This is the place where the Norwegian manufacture of hot water tanks, OSO Hot Water, is located. Appendix 7.4.2.7 shows the material list of the water tank.

The main materials in a tube collector are chromium steel, copper, glass and rock wool as insulation. The material list can be studied in appendix 7.4.2.3.

The life time expectancy of a solar collector system is regarded as 15 – 30 years [25]. In this analysis is a life time expectancy of 25 years used. In the 50 years perspective is therefore two systems of a collector and a water tank included.

All the components included in the system as hot water tank, pumps, vessel and so on are to comprehensive to present in this chapter, but can be studied further in appendix 7.4.2, while the total system is presented.

The radiators used in the analysis are assumed delivered from one of the largest companies within radiators in Scandinavia, Purmo. The model C22 is used as reference of material input and the transport length is calculated on the assumption of the manufacturer located in Jakobstad, Finland. Specifications regarding the radiator can be studied in Table 2.10.

Table 2.10: Specifications regarding the radiator [26].

Radiator	
Manufacturer:	Purmo
Model:	C22
Dimensions	
Effect (55/45/20)	741 W
Material	Steel
Hight	400mm
Length	1200mm
Mass	26,4 kg
Volume	5,4 l

When it comes to the pipes, Table 2.11 shows the amount material per meter on the assumed pipe types used. The amounts of material depend on where the radiators are located in the room. It is assumed that 16 kg of steel and 16 kg of copper is used. This is the same assumption that Jungbluth did in his analysis of the solar collector system [25]. The radiant floor heating on the bathrooms is assumed to require 1.24 kg of elastomeric pipes.

Table 2.11: Material per meter regarding hydronic distribution pipes [25].

The hydronic distribution system

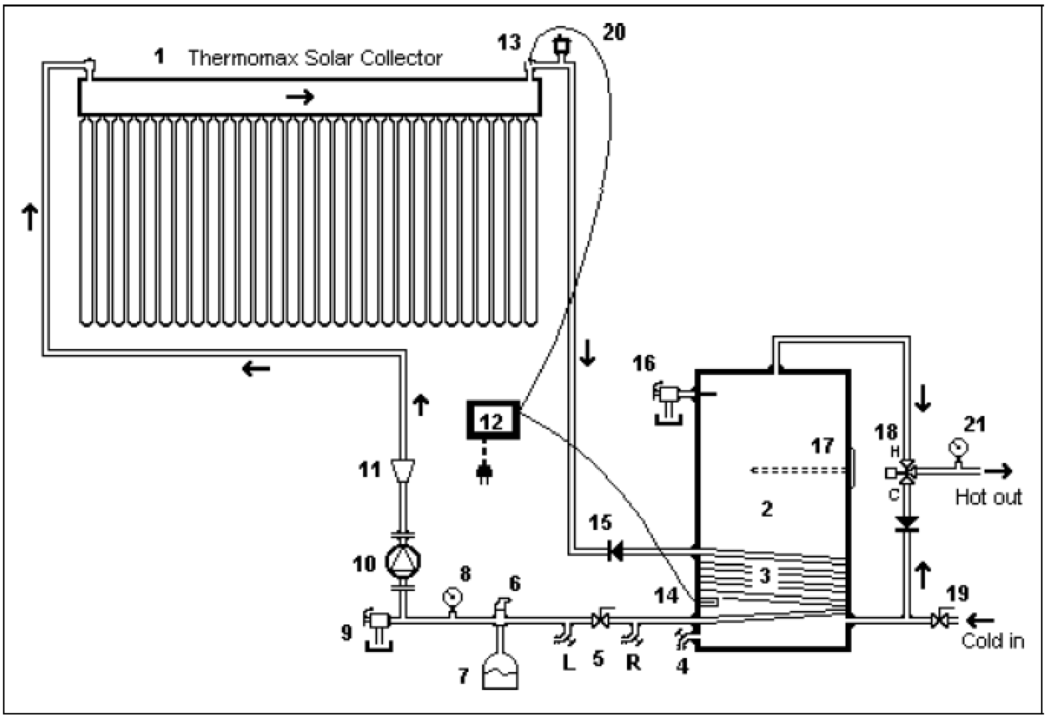
Material	***Type***	***kg/m***
Steel pipes	3/8"	0,68
	1 1/4 "	2,25
Copper	DN12	0,35
	DN32	1,41
Silicone	-	0,052
Mineral wool	Thickness: 20 mm	0,06

Appendix 7.4.2.6 shows the total inventory of the distribution system and appendix 7.1 illustrates a possible installation of where the pipes and radiators can be installed. The drawing shows the possible location of a heat pump which will be different than for a solar collector, but it is assumed that about the same amount of materials are used.

The distribution pipe system is assumed to last for the whole 50 year period.

2.4.3.2 The vacuumtube collector system

A solar collector uses solar energy to heat up water. Figure 2.14 shows the solar collector system, Mazdon 30.



1. Solar Collector	8. Pressure Gauge	15. Check Valve
2. Storage Tank	9. Pressure Relief Valve	16. T & P Valve
3. Solar Heat Exchanger	10. Circulating Pump	17. Backup Electric Element
4. Tank Drain	11. Flow Meter	18. Tempering Valve
5. Service Valves	12. Differential Solar Controller	19. Isolation valve
6. Air Purger	13. Collector Sensor	20. Automatic Air-Vent
7. Expansion Vessel	14. Tank Sensor	21. Temperature gauge

Figure 2.14: The studied vacuum collector system Mazdon 30 [27].

The heat transfer from the collector to the heat exchanger in the tank is done by a closed loop system. A small pump circulates a solution of propylene glycol, picking up heat from the collector and delivering it to the tank heat exchanger. The glycol is used to prevent the loop from freezing, and act as a corrosion inhibitor, protecting the components. Properly mixed and maintained, this glycol is said to protect the system down to minus 50°C [27].

A controller has sensors that monitor the temperature at the collector and the tank, switching on the pump when the collector temperature reaches a preset 12° above the storage tank temperature, and turning it off when this difference falls to 4° [27].

Collector output is directly related to the total radiation falling on it, and should be minimally affected by wind and cold. Many other factors can affect the system performance though. This includes tilt and orientation of the collector, maintenance, air temperatures and hot water load.

- **Collector Tilt**

Maximum performance is often said to be achieved by tilting the collector at an angle of tilt as the same as the geographical latitude of the building [28]. It should be some lower than this to be able to capture a greater quantity of diffuse radiation which a good part of the light propagated by the clouds. The collector should be at least at an angle of 30° from horizontal to maximize the heat transfer in the solar tube, and collect winter radiation when the sun is low [27]. Because of the angle of the tilted roof and the wish of the building company to mount it on the roof, it is assumed that the collector is mounted with a 30 degree slope, which is the angle of the roof. The energy output from a collector mounted by an optimal tilt and on the roof angle is not that large and will be discussed in chapter 4.2.2.

- **Orientation**

The collector should be sited facing as true South as possible. According to the user manual of Thermomax Mazdon 30, the performance will suffer very little if it is oriented up to 45° East or West of true South. In this case it is facing 11 degree against West.

- **Maintenance**

Propylene glycol can degrade over time and this is accelerated by heat or oxygen. Therefore it is important with a maintenance schedule to monitor the pH, which should be maintained between 8 and 10 to prevent oxidation and corrosion. Freeze tolerance limits are based upon an assumed set of environmental conditions. Extended periods of cold weather, including ambient air temperatures above the specified limit, may cause freezing in exposed parts of the system.

According to the user manual the system should be completely drained and flushed then re-filled with new antifreeze inhibitor every five or ten year [27]. In this study it is re-filled every tenth year.

2.4.3.3 Energy output and efficiency of the solar heating system

The main equation for calculating the usable energy output from the solar radiation is shown in formula 2.14 [29].

2.14
$$Q_{usable} = A_s(q_{in} - q_{out})$$

A_s is the solar collector area with unit m^2. The variable q_{in}, shown by equation 2.15, is the total solar radiation absorbed in the collector. Formula 2.16 shows the equation for the energy loss from the collector, q_{out}.

2.15
$$q_{in} = A_s I_T(\tau\alpha)$$

2.16 $$q_{out} = A_s U_L (t_{pm} - t_{out})$$

The parameter I_T is the solar radiation against the solar collector, given in kWh/m^2 and (τα) is the product of the transmittance of the outer layer and the absorber factor to the absorber. U_L is the coefficient of heat loss for the given solar collector and has the unit kWh/(m^{2}K). t_{pm} is the absorber mean temperature and t_{out} is the output temperature from the absorber, both given in Kelvin.

The problem with this equation is that the absorber mean temperature is difficult to calculate or measure. One has therefore introduced a factor F_R, which means that one can express
energy yield as a function of input temperature, t_i, to the absorber. See formula 2.17.

2.17 $$Q_{usable} = A_s F_R \left[I_T (\tau\alpha) - U_L (t_i - t_{out}) \right]$$

F_R is a complex function of many variables. The thermal conductivity of the absorber and the designing of the heat pipe are two important inputs in this matter. A further derivation of F_R is beyond the scope of this study and will not be explained into detail here.

The next step is to set up the equation that defines the collector efficiency, η_s. This says something about the relation between the amounts of energy the collector supplies as usable energy to the amount of energy that hits the collector. See equation 2.18.

2.18 $$\eta_s = \frac{Q_{usable}}{A_s I_T}$$

If we combine the two equations, we get an expression for efficiency as expressed by a straight line shown by formula 2.19.

2.19 $$\eta_s = F_R (\tau\alpha) - \frac{F_R U_L (t_i - t_{out})}{I_T}$$

$F_R U_L$ represents the slope of the line and F_R (τα) is the point where the line crosses the y-axis. These figures are important design parameters that describe the individual collector. The values are based on measurement data and provided by the collector manufacturer.

2.4.3.4 Characteristics of the solar collector system

Table 2.12 show dimensions and technical data describing the chosen solar collector.

Table 2.12: Facts about the solar collector model Thermomax Mazdon 30 [27]

The solar collector model - facts		
Type:	Evacuated	
Manufacturer:	Thermomax	
Model:	Mazdon 30 - TMA 600S	
Dimensions		
Total length	2,021	*m*
Total width	2,21	*m*
Gross area	4,466	*m2*
Aperture area	3,215	*m2*
Absorber area	3,04	*m2*
Weight empty	78	*kg*
Technical data		
Minimum flowrate	180	*l/h*
Nominal flowrate	240	*l/h*
Maximal flowrate	450	*l/h*
Fluid content	0,8	*l*
Maximum operating pressure	5	*bar*
Stagnation temperature	184	^{o}C
FR (τα) coefficient	0,54	-
FR UL coefficient	1,27	W/m2/^{o}C

2.4.3.5 Solar radiation and usable energy outcome

The solar radiation differs much depending on latitude and longitude of the location. See Figure 2.15 for an illustration of the solar radiation in Norway. Table 2.13 shows the solar radiation near Stord, measured in the close city Bergen. The difference between Stord and Bergen is assumed to be small.

The first column show the horizontal radiation, while the second column show the radiation mounted on a 30 degree sloped roof similar to the Stord Passive case in this study. Figure 2.16 shows an illustration. As stated before; the house is not facing exactly true South, but has an azimuth of about 11 degrees.

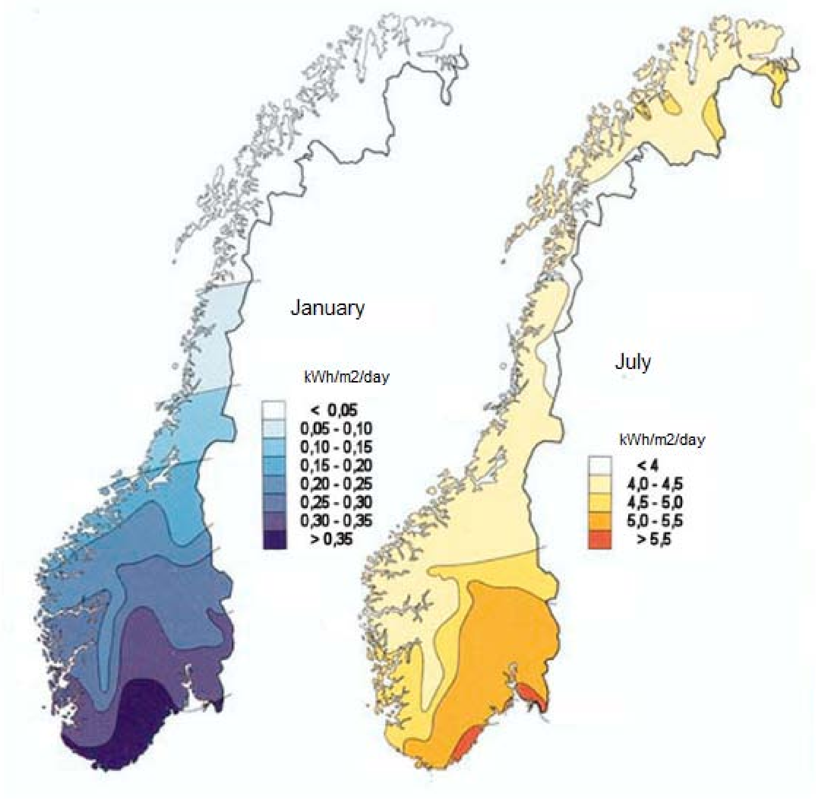


Figure 2.15: Illustration of solar radiation in Norway [30].

Table 2.13: The solar radiation in a city near Stord, Bergen [31].

	Solar radiation - horizontal (W/m2)	*Solar radiation - tilted (W/m2)*
Jan	14	39
Feb	33	55
Mar	81	113
Apr	122	140
May	206	219
Jun	194	195
Jul	180	183
Aug	144	159
Sep	83	102
Oct	47	77
Nov	18	44
Dec	8	24
Mean	94,1	112,4

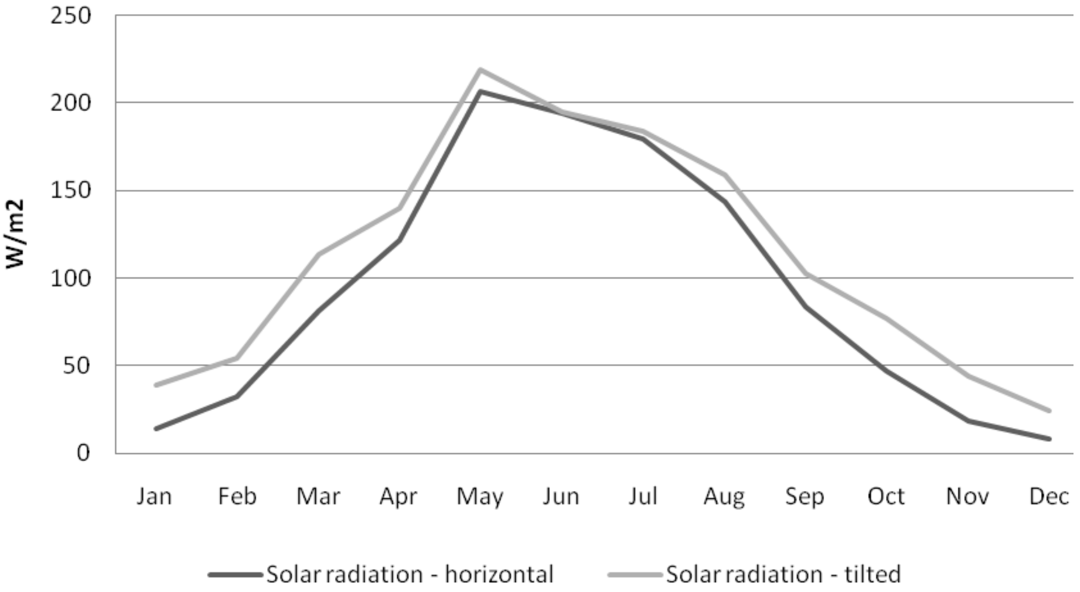


Figure 2.16: The solar radiation in a city near Stord, Bergen [31].

A calculation of the usable solar energy with three collectors of the Thermomax Mazdon type, mounted to the 30 degree sloped roof, gives the results showed in Table 2.14. The collectors covers an area of 13.4 m^2, expecting about 3511 kWh of usable energy to the system.

Table 2.14: The calculation results of mounting three collectors to the roof of Stord Passive.

The Stord Passive house - solar collector spesifications		
Roof slope	30	o
Azimuth angle	11	o
Number of collectors	3	*pcs*
Solar collector area	13,4	*m2*
Heating to the system	3,51	*MWh/yr*

As mentioned, the amount of heat delivered each day is highly dependent on what time of year it is. Figure 2.17 is showing the delivery of solar energy to the system during the year.

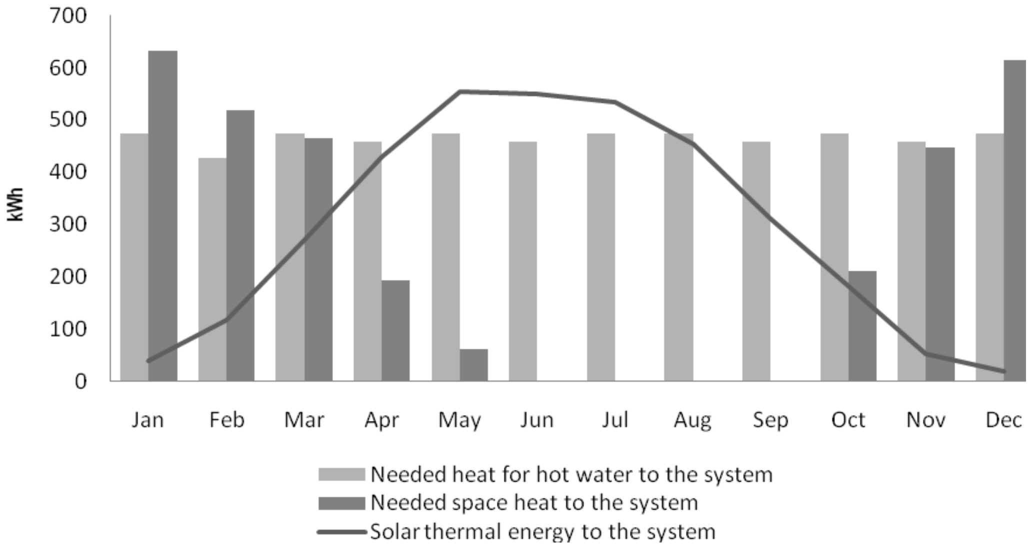


Figure 2.17: Delivered solar thermal energy to the system compared to the heat needed.

Some of the energy outcome from the solar collector is not useful because most of the energy is produced when the need is at its lowest. This especially concern the summer months and is regarded as lost energy. The total contribution of energy from the solar collector to the system is then about 3311 kWh, which covers 58 percent of the total heat need for hot tap water and 2 percent of the space heat demand. The latter share is due to the amount needed for space heating in May. In this month it is a surplus of solar energy after the tap water has been heated.

2.4.3.1 Differentiating between energy sources – Stord Passive S2

The remaining energy needed in Stord Passive S2 which is not covered by solar thermal energy is assumed to be covered by electricity. The total electrical net energy for heating, ventilation included, is then 69 percent. This is shown by Figure 2.18. This allocation will satisfy the passive house requirement of formula 1.1. Appendix 7.3.2 shows the results of the calculation of the formula.

Figure 2.19 shows the total electricity delivered to the system, compared to the amount of solar thermal energy.

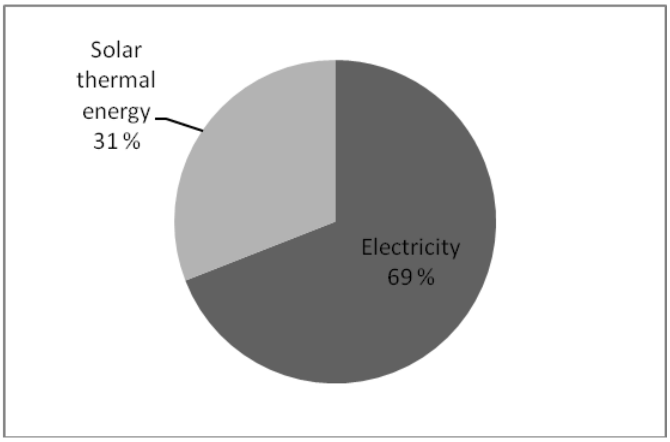
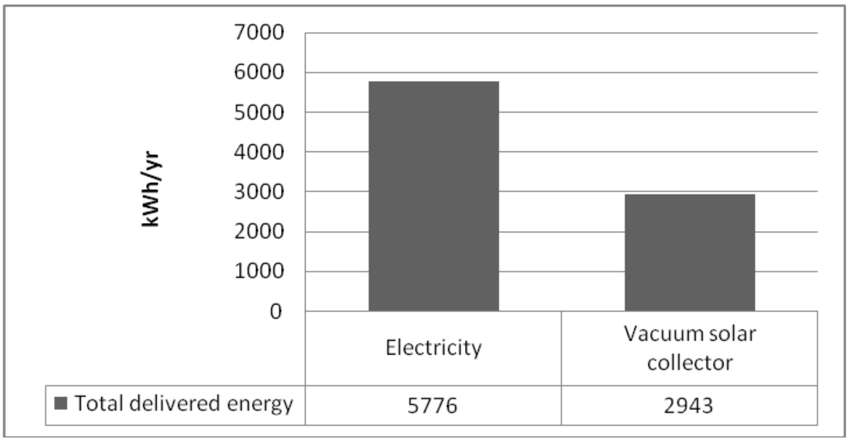


Figure 2.18: Illustration of the division of net energy with ventilation included for Stord Passive S2.



	Electricity	Vacuum solar collector
■ Total delivered energy	5776	2943

Figure 2.19: Energy delivered to the system, Stord Passive S2.

2.4.4 Heating system Stord Passive S3: Air -to- water heat pump system

Energy solutions in Norwegian homes have changed radically in recent years, and the sale of heat pumps has skyrocketed. Today, there are heat pumps in more than 500 000 homes in Norway, which means that every third household has one [32].

Included in the system inventory are;

- **The air-water heat pump**
- **All extras needed to make the heat pump system work**
  That is; the fan and needed electricity input, pipes and other components to make the system function.
- **Warm water tank**
  Based on a hydronic heating system

- **Hydronic pipe system**
  It is assumed an installation of two radiators in the building, one at each floor, and hydronic floor heating in both the bathrooms.

- **Electricity for the peak load**
  Electricity through a heating element will compensate the heat pump when the climate is at it coldest.

- **Maintenance**
  Lost refrigeration liquid will be renewed

- **Transport**
  Transportation of the new system and the maintenance personal during the lifetime is included. It is assumed that control and maintenance personal is arriving every seventh year to check out the pump.

- **Demolition**

2.4.4.1 Data sources and inventory input

The system solution with an air-to-water heat pump is in this study based on an analysis published in the Swiss Ecoinvent report No.6-X, made by Thomas Heck in 2007 [33]. As is the case in the study by Heck, the air-to-water heat pump is based on data of the model Genius, produced by Hoval. The power on this heat pump is 10 kW, which is large for a passive house. The installed power should have been about 5-6 kW instead, but the difference in terms of material input is assumed to be small. The manufacture is assumed located in Newark, England.

The refrigerant used in the study is R – 134a (or HFC – 134a) which is the technical name on 1,1,1,2-Tetrafluorethan (CH_2FCF_3). The amount of refrigerant for these kinds of heat pumps lies around the amount of 0.49 kg/kW [33]. Due to the leakage of refrigerant emissions, there is a loss into the air that has to be replenished. In this study a loss of 6 percent is used, with an uncertainty SD_g^2 of 1.7 [33].

As was the case for the solar collector system; also the heat pump system is based on a 600l tank delivered by Jenni Energietechnik AG with production in Burgdorf, Switzerland. The transport distance is calculated by the assumption that the water tank is produced in Hokksund, Norway. This is the place where the Norwegian manufacture of hot water tanks, OSO Hot Water, is located.

The life time expectancy of a heat pump is regarded as 15- 20 years [33]. In this analysis is 20 years assumed for the heat pump and 25 years for the water tank. The hydronic pipe system is assumed to last during the whole life time of 50 years.

The radiators, hydronic pipes and the hot water thank included is the same as used in the solar collector system, Stord Passive S2, described in chapter 2.4.3.1. The inventory is presented in appendix 7.4.2. Appendix 7.1 illustrates a possible installation of where the pipes and radiators connected to the heat pump can be installed in the house. The basic materials for the heat pump can be studied in appendix 7.4.3.2. Further inventory input of the system is presented in appendix 7.4.3.

2.4.4.2 The heat pump system

A regular heat pump system consists of a capacitor, a reducing valve, an evaporator and a compressor. See Figure 2.20.

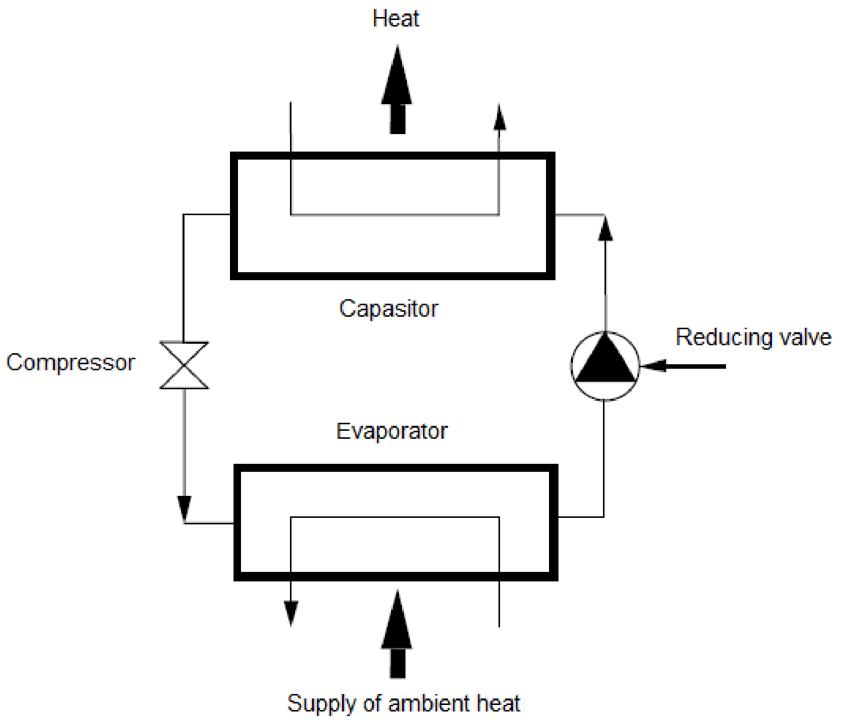


Figure 2.20: The components of the heat pump

First the liquid goes into an evaporator where it turns into steam. Evaporation occurs because the working fluid has a low pressure, and thus a low boiling point temperature. The environment is now hotter than the steam, and the steam will then get heat from its surroundings.

The compressor then sucks in the cold vapor and compresses it. When a gas is compressed, the temperature of the gas increases. The gas is further led into a capacitor where it condenses into liquid again, because it is warmer than the surroundings and thus produces heat. After this, the liquid goes through a reducing valve where the pressure is reduced and the liquid has a low temperature again.

The most common heat pumps currently receive energy from the outdoor air, groundwater, seawater, soil or rock. There is a distinction between direct and indirect heat pump systems. A direct construction has heat exchangers that transfer heat directly, like a so-called air-to-air heat pump does. An indirect system usually transmits the heat to a central heating system, in an air-to-water or water-to-water heat pump.

The air-to-water heat pump model by Hoval is illustrated in Figure 2.21.

Figure 2.21: The air-to-water heat pump model by Hoval [34].

2.4.4.3 *Energy output and efficiency of the heat pump system*

When talking about the energy performance of a heat pump, there are some basic parameters. First of all, the Seasonal Performance Factor (SPF), says something about the heat pump annual performance [33]. The factor is calculated by the yearly amount of energy - in the form of the heat it supplies, Q_{yr} - divided by the amount of electricity that is supplied to power the heat pump, W_{yr}. See formula 2.20. The performance of a heat pump varies through the year and the SFP factor take into account all the energy supplied and used during the year, both in the hot summer and cold winter periods.

The factor can vary between 1.5 and 4, where for example a factor of 2 halves the energy use and the factor of 4 saves 75 percent energy. High annual efficiency or SFP thus provides a good economy.

2.20

$$SPF = \frac{Q_{yr}}{W_{yr}}$$

Another factor that says something about the ratio of the change in heat supply in proportion to the supplied work is the COP factor, or the Coefficient of Performance factor [33]. The factor shows the proportion of heating capacity, Q, to active energy input, W, per time unit. See formula 2.21.

2.21
$$COP = \frac{Q}{W}$$

The theoretical maximum of the COP, that is the COP of an ideal heat pump, can be calculated by the temperature of the heat source, T_U, and the temperature generated by heat in the heat pump, T_N, as can be seen in formula 2.22.

2.22
$$COP_{\max,id} = \frac{T_N}{T_N - T_U} = \left(1 - \frac{T_U}{T_N}\right)^{-1}$$

A heat pump work more efficient the lower the temperature on the delivered heat is. See the graph in Figure 2.22. A heat distribution system in a house with 35-40 ^{0}C (low temperature system) allows a better COP value than a system with higher temperatures.

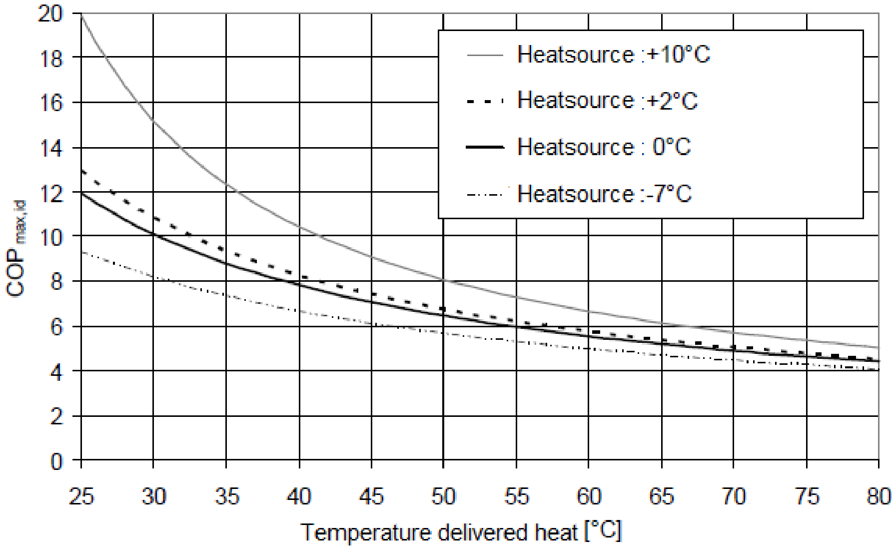


Figure 2.22: The COP value for an ideal heat pump and its connection with the temperature on the delivered heat [33].

The efficiency η_{hp} is then the ratio between the actual and the theoretical maximal COP value as shown in equation 2.23.

2.23
$$\eta_{hp} = \frac{COP}{COP_{\max,id}}$$

The efficiency is not constant during the heat pumps operational time, but can vary with about 15 percent because of the variation of the input parameters T_U and T_N [33].

2.4.4.4 Characteristics of the heat pump

Input parameters regarding the heat pump can be studied in Table 2.15. The choice of SFP factor is based on the recommended production efficiency which is presented in Table 1.8.

Table 2.15: Rating figures including defrosting losses based on air temperature 2 °C / heating water 35 °C. *The technical data are not model specific but are based on mean values.

The heat pump system - facts		
Type:	Air-water	
Manufacturer:	Hoval	
Model:	Genius	
Dimensions		
Width	1,2	m
Depth	0,75	m
Height	1,625	m
Weight	290	kg
Technical data *		
Heating Capacity	10,25	kW
Heat distribution (Low temp system)	40/50	°C
SFP factor	2,3	-

The pump are said to work at low temperatures, down to about -15 °C [34]. However, at low temperatures the heat pump works less efficiently, and during periods when the outside temperature is low the need for warmth is especially great. Therefore is the heat pump equipped with a small supplementary heating unit, which serves to deal with periods of peak demand.

2.4.4.1 Differentiating between energy sources – Stord Passive S3

For this heating solution it is assumed that 75 percent of the total heat needed for hot water and space heat are covered by the heat pump, while the rest is compensated with direct electrical heating. The division in each year will vary, but this allocation was the one recommended as a mean by researchers working on heat pump issues in Norway [35]. This will also satisfy the energy requirement from the passive house standard said by formula 1.1. Appendix 7.3.3 shows the results of the calculation using the formula.

Figure 2.23 shows the division of energy sources to net energy demand for heating, ventilation included. 40 percent of this amount is energy delivered by the heat pump.

Figure 2.24 illustrate the total electricity delivered to the system, compared to the amount of renewable heat pump energy. The electricity needed for the heat pump is based on the recommended production efficiency of 2.3 which is presented in Table 1.8.

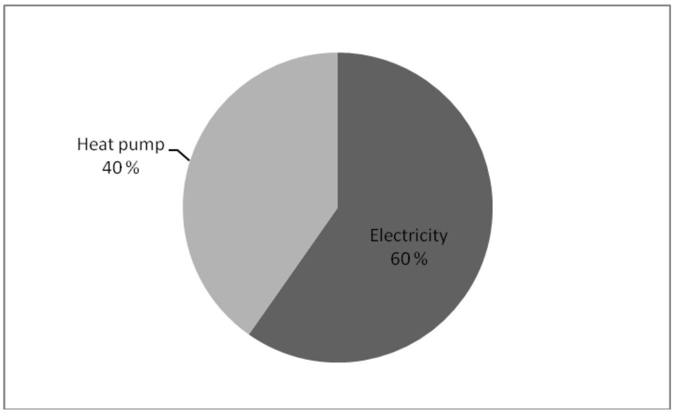


Figure 2.23: Illustration of the division of net heat demand with ventilation included for Stord Passive S3.

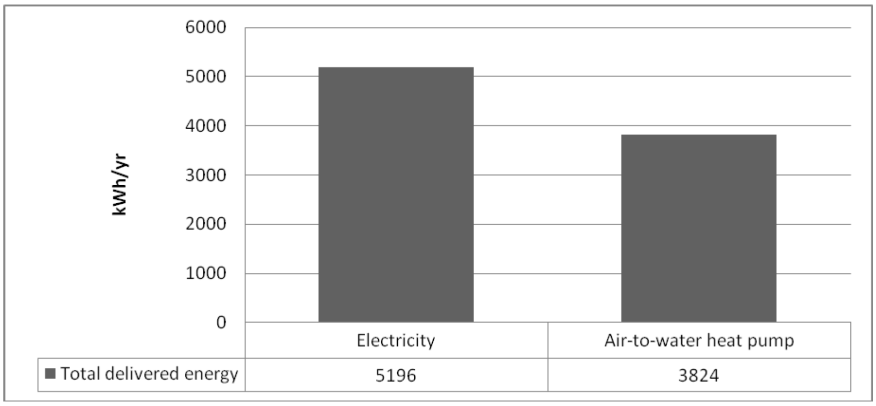


Figure 2.24: Annual delivered energy divided between the energy sources for Stord Passive S3

2.4.5 Costs related to the heating systems

2.4.5.1 Estimated costs of the renewable energy solutions

The costs of the installation and investments of the different heating systems can vary a lot. Enova, which is the state's own agency to promote environmentally friendly restructuring of energy and develop viable markets for efficient and environmentally friendly energy solutions, has done some estimations that can be used as reasonable prices on the renewable alternatives.

All costs presented in this chapter includes taxes, if not otherwise is explained.

- **The solar collector system**

Enova expects that a complete solar collector system will be around 30 000 kr and up [36]. It is assumed a total cost of 40 000 kr in this study, installation included.

- **The heat pump system**

  A good air –to- water heat pump normally costs 60 000-130 000 kr according to Enova [37]. According to the firm Midt-Norge VVS AS it is assumed a price of 96 000 kr for the heat pump model Bosch EHP AW, 6kW. Together with consultation and installation costs of 37 000 kr, the total amount reaches 133 000 kr.

- **The wood stove**

  A stove costs from 4 000 kr and up, according to Enova [38]. The stove used in the LCA analysis has an investment price of 10 000kr [22] and this is will also be the the price used in the calculations.

  The price of a chimney delivered by Nordpeis can be calculated with a program presented on their webpage [22]. This was found to be about 20 000 kr.

  The effective price of fire wood may vary during the year. It is a little bit more expensive in the winter. The oven's efficiency and the moisture content are also important factors for the effective wood price. According to Enova is the effective price of a cord of wood normally around 50-55 øre/ kWh in a clean-burning wood stove [38]. In this analysis is the price set to 1 660 kr per cord, which gives an effective energy price of 52 øre/ kWh [38].

2.4.5.2 Economical support from Enova

Enova can support up to 20 percent of the cost of energy installations in buildings if renewable energy is installed. The goal of Enova is that their support should only be a trigger, so the agency does not provide support beyond this proportion. The investment costs for air-to-air heat pumps are considered by Enova as so low that subsidies are necessary to spur investment, but they do support pellet stoves and boilers, geothermal and water based heat pumps, and solar collectors [39].

In the study it is assumed that 6 000 kr is given for the investment of a solar collector, 4 000 kr for the central heating system and 10 000 kr for the air-to-water heat pump [39].

2.4.5.3 Hydronic pipe system and hot water tank

The costs of a full installation of a central heating system can vary a lot, from about 100 to 1000 kr/m^2. The firm Midt-Norge VVS AS has estimated costs on a hydronic pipe system with two radiators, and heating in the bathroom floors suiting the exact case study of Stord Passive. The total price given is 29 000 kr, installing costs included.

The price of the hydronic heating based hot water tank is assumed on the basis of prices presented on the webpage of OSO Hot Water. A hot water tank of this type can vary from about 11 000 kr to 18 750 kr. In this study it is assumed a cost of 15 000 kr.

2.4.5.4 Electrical heating with panel heaters

A panel heater with a capacity of 1000 W can typically cost from 700 – 1500 kr, dependent of design and material input. In this study a cost of 1000 kr is assumed for the heater of 1000W, 800 kr for the heaters of 600W and 700 kr for the heaters of 400 W.

For electrical heating of hot water a tank of 200 l with capacity 2 kW was chosen in the LCA. The suggested retail price for such a tank is 6500kr [40]. Installation cost is believed to be 2000 kr.

The electrical installation is not taken into account because this is needed for the electricity specific needs in all of the system solutions.

2.4.5.5 The electricity price

Electricity prices in the Nordic market are based on supply and demand. The power companies send offers of purchases, and the spot price is determined by this for each hour the next day. The customers of the power companies can then choose between different ways to calculate the force of the price they pay for, where the two main categories are fixed-price contracts and spot price deals.

In a fixed-price contract, power price is determined for a contract period of for example one or two years. This will provide more predictable costs for the customer, but you risk having to pay more than if you choose a spot based product. The spot price based deal follow price fluctuations in the market with varying resolution, from hours to months. In addition, you must pay a charge that represents what the power company profits.

The price of electricity varies greatly throughout the year. See Figure 2.25.

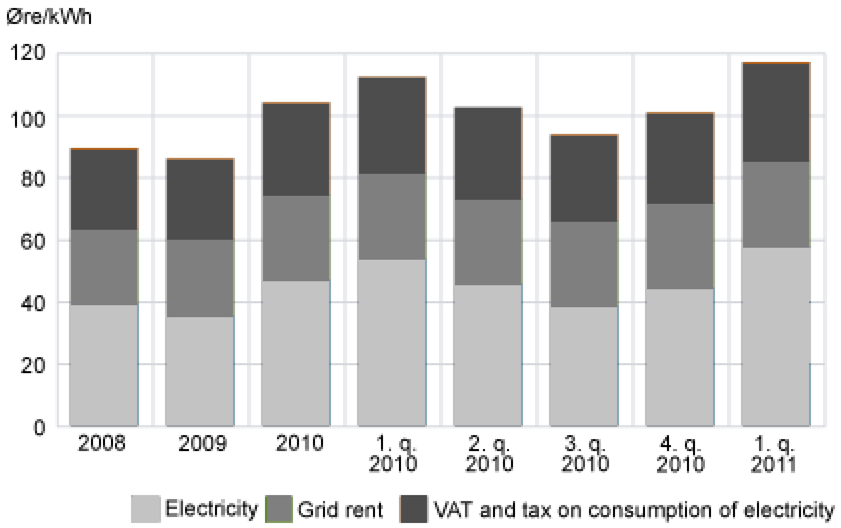


Figure 2.25: Electricity prices, grid rent and taxes for households, quarterly [41].

The price of electricity is three-parted and consist of;
- Electricity
- Grid rent
- Government charges

The grid rent for single-family homes consists of two joints: a fixed component and an energy component. The fixed component consists of a cost per year, while the energy component is the price per kWh used.

The average private economic price of electricity was for 2010 in excess of around 1 kr per kwh. This is higher than the average price for the previous three years, where the average price ranged between 75 and 90 øre/ kWh. In 2011 it has grown considerably in the first quarter.

The price of the electricity will vary a lot during the life time of the building, but for simplicity reasons it is assumed to be the same in the 50 year period. For this study the price of 1.1 kr per kWh is chosen as reference price.

2.4.5.6 The costs of the construction

Nordbohus AS has given the total assumed costs of building the two houses. Projected cost for Stord TEK 07 is 1 529 128 kr, ventilation system included.

If a passive house is to be built, this will entail increased construction costs due to extra costs for better components and technical solutions, and expertise in the individual projects. The additional costs of building a new house of passive standard today varies. Typical numbers are between 1000-2000 kr/m^2 or 3-6 percent extra construction costs [42]. Nordbohus AS has given a projected cost for the wooden construction of 1 668 996 kr for Stord Passive, which is about 9 percent more than Stord TEK 07. Maintenance costs during the 50 year life cycle are assumed to be about the same for the two constructions, and are not taken into account in the economical comparison.

2.5 Ventilation

A good ventilation system helps to maintain comfort and healthy indoor air quality in the building. In addition to removing particulate matter and other pollutants from indoor air ventilation, it is important to limit the humidity that can cause condensation and moisture damage.

The most energy-efficient ventilation system that is recommended today is balanced ventilation together with a high degree of heat recovery. This is also the most used ventilation system in the current projects of the building company, Nordbohus AS. This kind of system is also chosen for the two houses of this study. The heat recovery of the chosen system is 80 percent.

2.5.1 Mechanical balanced ventilation

A ventilation system is said to be balanced if it has the same amount of exhaust air going out and fresh air delivered. This is accomplished using electric fans. Normally, 60-90 percent of the heat extracted is preserved using a heat exchanger, making the supply air need less preheating. The system requires that the property is otherwise tight, so that all the venting takes place in a controlled form through channels and not through gaps in windows or through vents in the walls [43].

Regulations of the Planning and Building Act [6] sets requirements for the building's total heat loss figures. Efficient heat recovery of exhaust air is the single measure that is said to reduce heat demand in a building the most. In homes with balanced ventilation the requirement may be met by the installation of a heat exchanger efficiency by at least 70 percent [43]. For passive houses, it is a requirement of an efficiency of at least 75 percent, and preferably more than 80 percent [4].

Demand management is also important when it comes to energy use by venting. Ventilation in a building should be adjusted based on when it is most activity in the building. Good management is essential to reduce energy consumption.

It is also important to choose and design the ventilation system with the lowest possible energy to the fans. In low-energy housing it is common to claim that the fan power measured with SFP's should be better than 2.0 kW/ (m^3/s). Similarly, the requirement for a passive house is 1.6 kW/ (m^3/s). Low SFP figures are achieved by the use of flow-optimized design of the unit and duct system, with a small pressure drop and as short channels as possible, and use of energy-efficient fan motors [20].

As when it comes to heat recovery system, there are several types to choose between. A rotating heat recovery system is the one chosen in this study and is seen as the system which is most efficient at current stage.

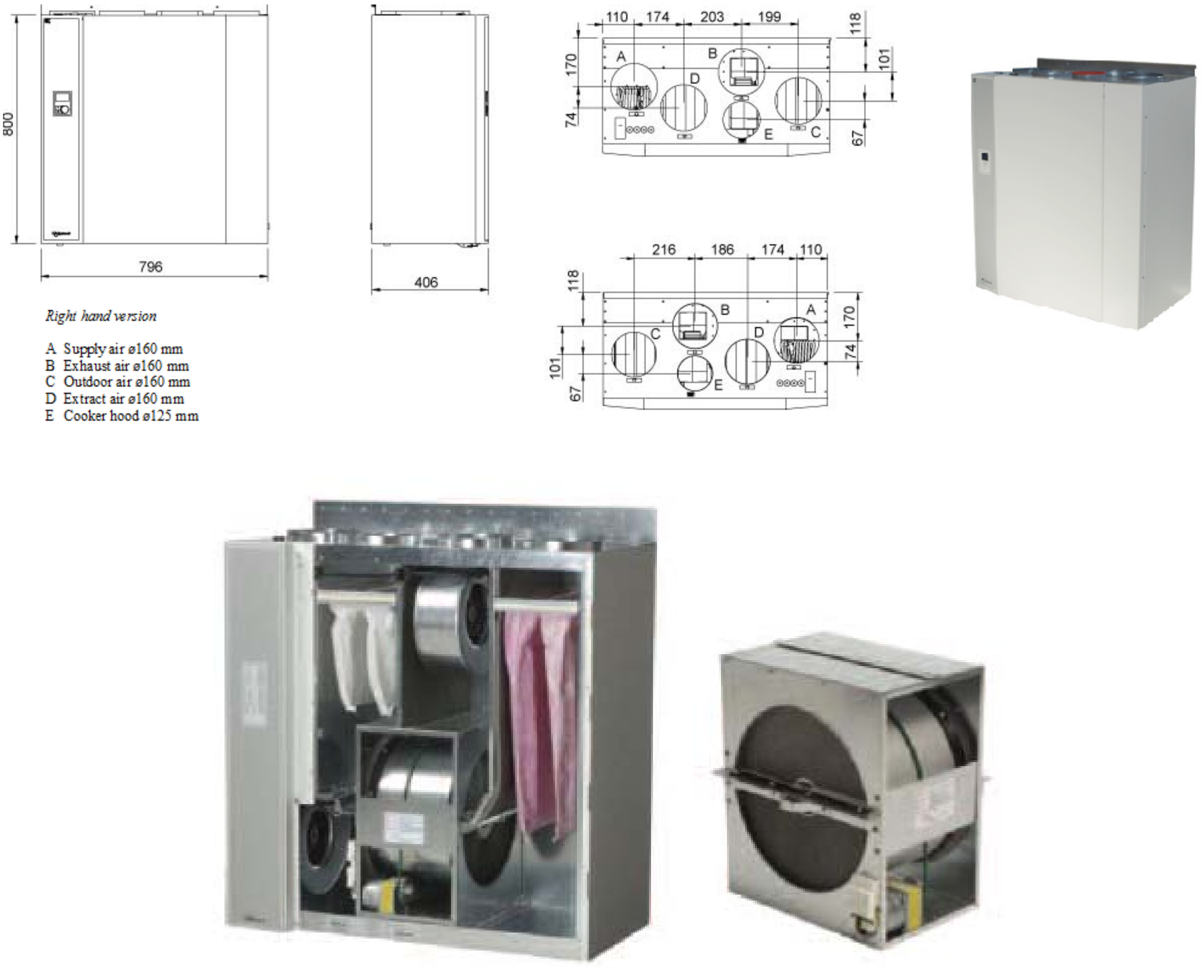


Figure 2.26: Balanced ventilation with a rotating heat recovery unit, model VR 400 DCV/B L (Systemair/Villavent) [20, 44].

2.5.1.1 Rotating heat recovery system

Figure 2.26 shows the ventilation unit with a rotary heat exchanger. The rotor, which is usually aluminum, is heated by the exhaust air, and this heat is released back to the cold incoming outdoor air [20]. Rotary heat exchangers can reach an efficiency of approximately 75 percent to over 85 percent and are used both in small decentralized units and in large central units.

The benefits of rotating recyclers are several. It has stable high temperature efficiency even in the coldest periods of the year, and is therefore well suited to cold regions of the country. For rotating recyclers with efficiency above 80 percent there will also be possible to survive without a heat battery, making the unit slightly more affordable and reduce the pressure loss in the unit [20].

In warm periods, the desired supply air temperature is regulated by regulating the rotational speed on the rotor. In very hot periods it can act as a cooling exchanger, but the effect of this is relatively small in a Norwegian climate.

Overall, the rotating recyclers will in most cases be a very good choice for low-energy and passive houses, especially in cold inland regions due to its high efficiency at low temperatures.

2.5.2 Data source and inventory input

It was not easy to find exact data on a balanced ventilation system with all the components required. The analysis is therefore based on a product declaration given by Systemair on the model VR 400 DCV/B L where amounts of materials are given as a percentage of the total mass, included with large uncertainties. The analysis will therefore consider three different scenarios. The model is the one presented in Figure 2.26.

The printed circuit board, filters and cables are included components taken from the inventory of Ecoinvent, while the rest of the material input is based on mean figures and uncertainties based on the declaration. An uncertainty analysis is performed and presented with the results in chapter 3. Appendix 7.2 shows the product declaration which the inventory input is based on and appendix 7.4.4.2 presents the final inventory.

The Ecoinvent process “Steel product manufacturing, average metal working/RER U” is included to take into account the resources needed to bend and work with the steel cover.

The air is assumed to be distributed in pipes made of steel. The whole system, including the unit and the pipes are assumed to have a lifetime of 25 years and that in a 50 year perspective is a need of two systems.

Appendix 7.4.4.1 shows the total input regarding the ventilation system over the 50 year life cycle.

2.5.2.1 Maintenance

According to the user manual of the VR 400 [45], maintenance of the model should normally be performed 3 - 4 times a year. Apart from check and cleaning of the different components the supply and extract filter must be changed 1-2 times per year. In the analysis it is assumed that the filters are changed ones a year

2.5.2.2 Disposal

The ventilation unit is complex and contains of many different components and materials. The assumed treatment of the unit is based on a combination of statistical data from the Norwegian waste management and a modification of the Ecoinvent process called “Disposial, ventilation equipment, decentralized, 180-250 m^3/h/U”.

2.5.3 Characterisitics of the chosen ventilation system

VR 400 DCV/B is designed for installation in laundry room, storeroom or cupboard, and can ventilate an area up to about 200 m^2. The unit is double skinned, fully insulated and with complete control functions, high efficiency rotating heat exchanger, thermostat operated re-heater battery and filters. Energy efficient fans with EC motors will reduce energy consumption for transportation of ventilation air by about 50 percent compared to traditional AC motors. Modern technology gives a low SFP factor as well as constant airflow and balance between extract and supply air [44].

The model is promised to have a constant airflow and balance between extract and supply, and it changes automatically to summer operation where no heat recovery is needed.

3 Results

The results are presented with the same short names as stated before; Stord TEK 07 is the conventional building with a heating system based on electricity and fire wood, while Stord Passive S1, S2 and S3 are the passive house energy solutions. Stord Passive S1 is based on electricity and fire wood, Stord Passive S2 is the solar collector system and Stord Passive S3 is the heat pump system.

3.1 Impact potential and cumulative energy of the heating system solutions

3.1.1 Impact potential of the heating system solutions

The results of the life cycle analysis is based on a midpoint view, which distributes the emissions in to different impact categories of potential damage. It is chosen to use the hierarchic perspective on the distribution. The hierarchic perspective is seen as the consensus model and is the one which is most encountered in scientific models.

Table 3.1 shows the impact potential of the different heating system solutions and Figure 3.1 illustrates normalized numbers of these to see the relative importance of each category. A description of the different impact categories was given in chapter 2.2.2.

Table 3.1: Total impact potential of the heating system solutions over the 50 year life cycle.

	Stord TEK 07	*Stord Passive S1*	*Stord Passive S2*	*Stord Passive S3*	*Unit*
Climate change	127845	83234	67080	70324	*kg CO2 eq*
Human toxicity	24488	15950	15007	13394	*kg 1,4-DB eq*
Photochemical oxidant formation	299	187	156	131	*kg NMVOC*
Particulate matter formation	193	125	108	93	*kg PM10 eq*
Ionising radiation	163104	107530	83509	74839	*kg U235 eq*
Terrestrial acidification	439	287	240	208	*kg SO2 eq*
Freshwater eutrophication	1	1	1	1	*kg P eq*
Marine eutrophication	94	59	50	41	*kg N eq*
Terrestrial ecotoxicity	95	60	45	40	*kg 1,4-DB eq*
Freshwater ecotoxicity	143	96	150	109	*kg 1,4-DB eq*
Marine ecotoxicity	280	186	249	197	*kg 1,4-DB eq*
Water depletion	1484	960	757	671	*m3*
Metal depletion	17301	11859	16216	14112	*kg Fe eq*

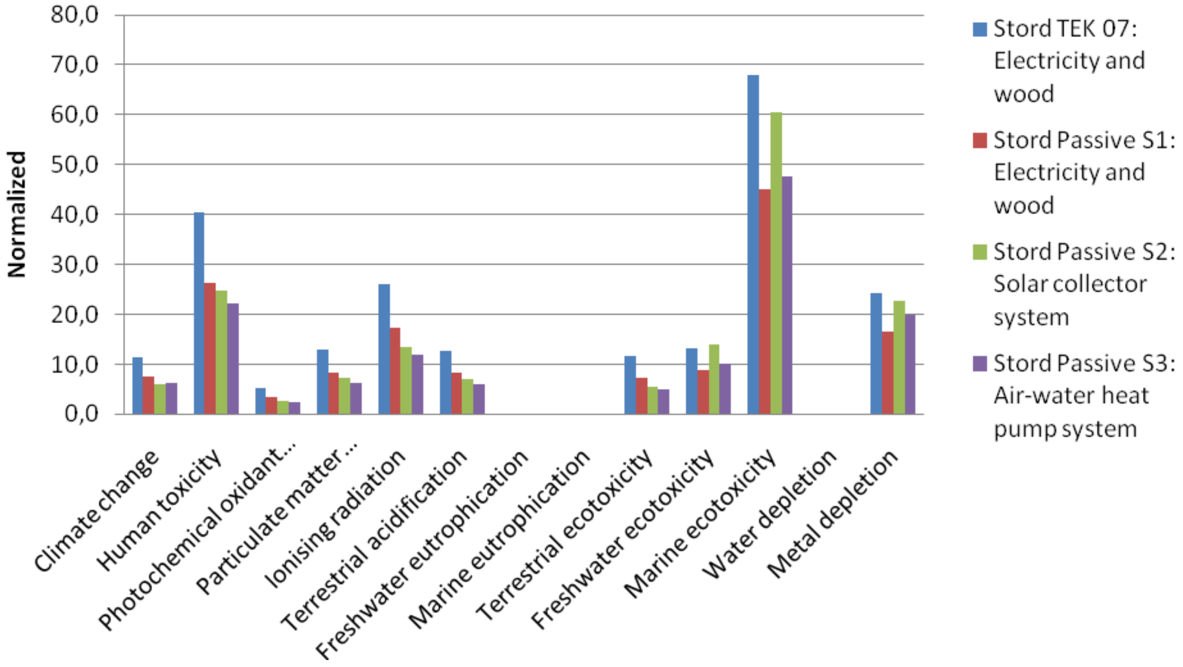
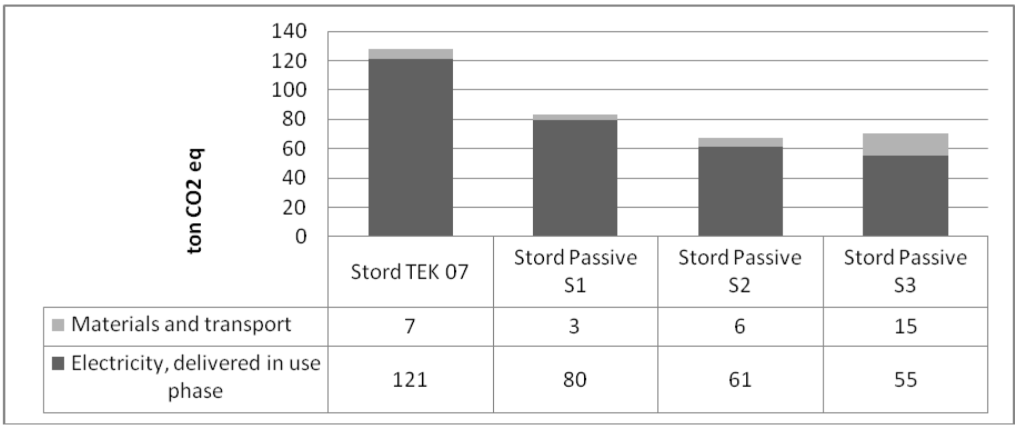


Figure 3.1: Normalized presentation of the impact potential of the heating system solutions.

As can be seen in Table 3.1 and Figure 3.1, the largest impact on each of the categories except "Freshwater ecotoxicity" is by the alternative Stord TEK 07. Stord Passive S1, the passive house solution with the same traditional heating system, is the alternative with the second largest impacts in every category except "Freshwater ecotoxicity", "Marine ecotoxicity" and "Metal depletion". When excluding these categories, the solar collector alternative, Stord Passive S2, and the heat pump solution, Stord Passive S3, is the winning alternatives due to overall lower emission outputs. Stord Passive S2 has relatively large impacts in these three categories, with the overall largest amount in the category "Freshwater ecotoxicity".

In Figure 3.1 are "Freshwater eutrophication", "Marine eutrophication" and "Water depletion" all reduced to zero, illustrating that their amount of outputs are not important compared to the emission output in other categories. Less emphasis can therefore be taken on these categories.

The impact category which stands out as the category with largest impacts in all categories is "Marine ecotoxicity", but also "Human impact" and "Metal depletion" have large relative emission impacts.



	Stord TEK 07	Stord Passive S1	Stord Passive S2	Stord Passive S3
■ Materials and transport	7	3	6	15
■ Electricity, delivered in use phase	121	80	61	55

Figure 3.2: Emission output causing climate change due to the heating system solutions over the 50 year life cycle.

Figure 3.2 compare the total amount of CO_2 eq from each of the solutions. The figure shows that an amount of 67 ton CO_2 eq from the solar collector alternative, Stord Passive S2, has a slightly better outcome than the heat pump alternative, Stord Passive S3, with its 70 ton of CO_2 eq. Stord TEK 07, with the total amount of 128 ton CO_2 eq, has about twice as high potential of “Climate change” as the two renewable energy solutions.

Figure 3.3 illustrates the percentage output of emissions for each heating system solution, showing the relative importance in each impact category of importance. In this figure and in Figure 3.2, an allocation is done between the material and transport input and the energy delivered to the system in the use phase.

The categories “Freshwater ecotoxicity”, “Marine ecotoxicity” and “Metal depletion” are all having large contributions due to the input of materials and transport, but the rest of the categories have output mainly contributed by delivered electricity.

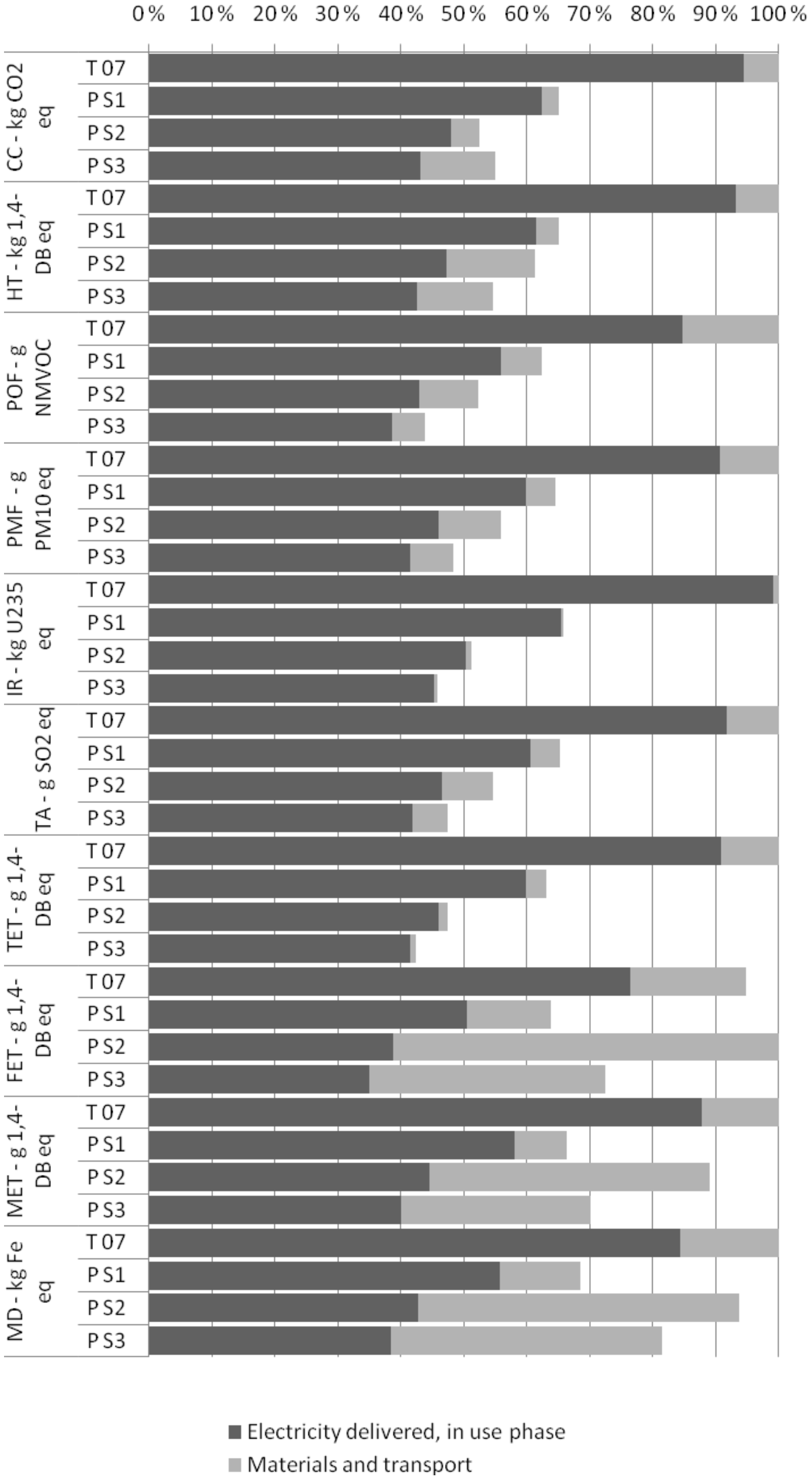
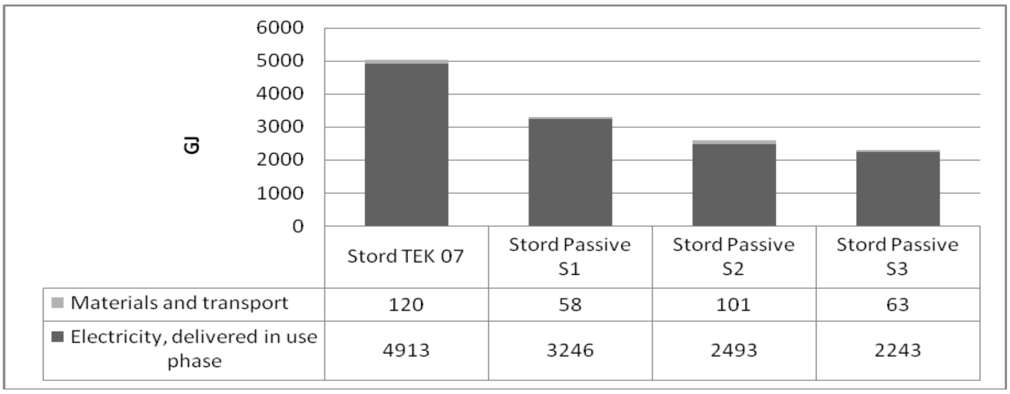


Figure 3.3: Comparison of the heating systems presenting a division between delivered electricity and materials/transport.

3.1.2 Cumulative energy of the heating system solutions

Figure 3.4 shows the primary energy cumulated by the different heating systems. Most of the contribution in each heating system is done by the delivered electricity.

Table 3.2 shows the allocation of the cumulated energy on different energy sources and Figure 3.5 illustrates this. The results must be seen in the light of Table 2.7, where the division between energy sources in the Nordic electricity mix was presented.



	Stord TEK 07	Stord Passive S1	Stord Passive S2	Stord Passive S3
■ Materials and transport	120	58	101	63
■ Electricity, delivered in use phase	4913	3246	2493	2243

Figure 3.4: Total cumulated primary energy for the different systems over the 50 year life cycle.

Table 3.2: Cumulative energy of the heating system solutions over the 50 year life cycle.

Cumulated energy

Unit: Giga Joule, GJ

	Stord TEK 07	***Stord Passive S1***	***Stord Passive S2***	***Stord Passive S3***
Non renewable, fossil	1536	995	807	703
Non-renewable, nuclear	1695	1118	868	778
Renewable, biomass	460	304	236	211
Renewable, wind, solar, geothermal	37	25	19	17
Renewable, water	1305	862	664	597
Total	*5033*	*3303*	*2594*	*2306*

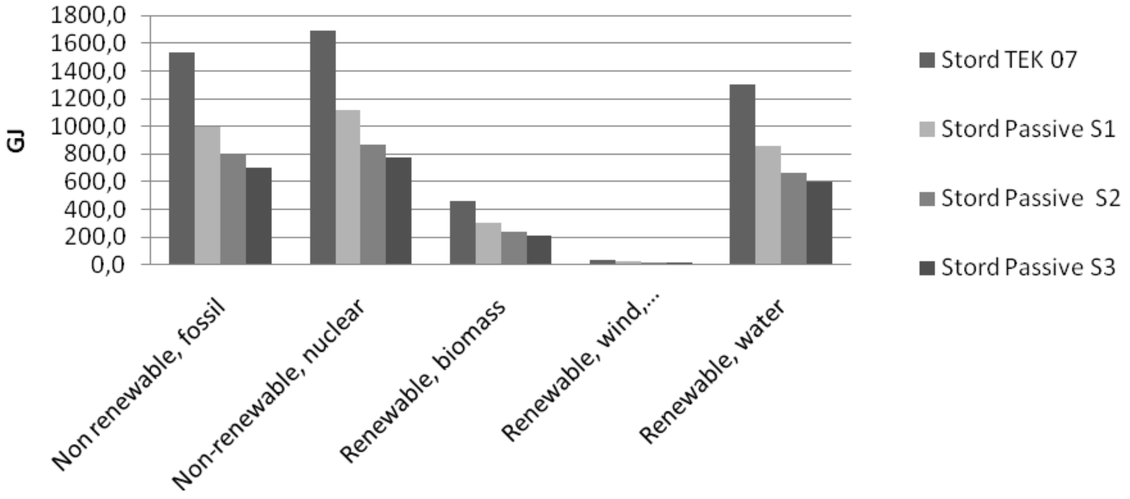


Figure 3.5: The cumulative energy demand in each of the heating system solutions over the 50 year life cycle.

3.2 Cost calculations on the heating system solutions

Table 3.3 shows the total costs, presented as present value, of implementing the different heating system solutions. Figure 3.6 and Figure 3.7 show an illustration of the costs, without and with building costs included, respectively.

If seeing the heating systems separately without the building costs, the heating system of Stord TEK 07 is the most expensive alternative, with a total cost of a little less than 383 000 kr. With slightly lower expenses comes the heat pump system, Stord Passive S3, while Stord Passive S2 comes out as the most economical valuable alternative at a price of about 245 500 kr.

If the building costs are included will the alternative Stord Passive S3 surpass Stord TEK 07 with a total cost of about 2 029 300 kr. The best outcome is now Stord Passive S2 with a total cost of about 1 898 000 kr, slightly less than the houses with standard Norwegian heating systems, Stord TEK 07 and Stord Passive S1.

Table 3.3: The costs of implementing the heating system solutions over the 50 year life cycle.

	Stord TEK 07	*Stord Passive S1*	*Stord Passive S2*	*Stord Passive S3*
Energy, investment costs	48839	46914	92381	237572
Energy, annual expenses	333987	198639	136492	122791
Total energy costs	**382826**	**245553**	**228873**	**360363**
Building, investment costs	1529128	1668996	1668996	1668996
Total	**1911954**	**1914549**	**1897869**	**2029359**

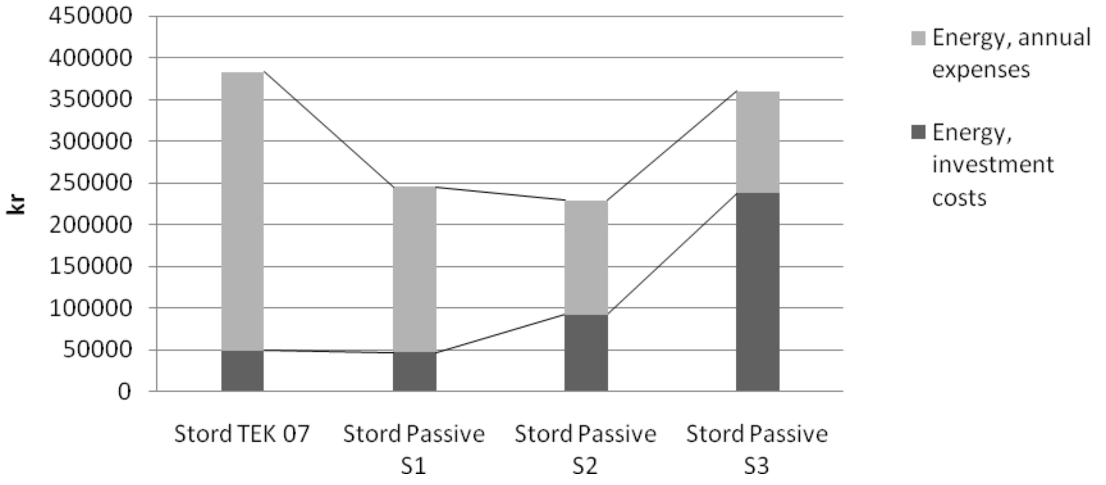


Figure 3.6: Illustration of the costs of implementing the heating system solutions over the 50 year life cycle.

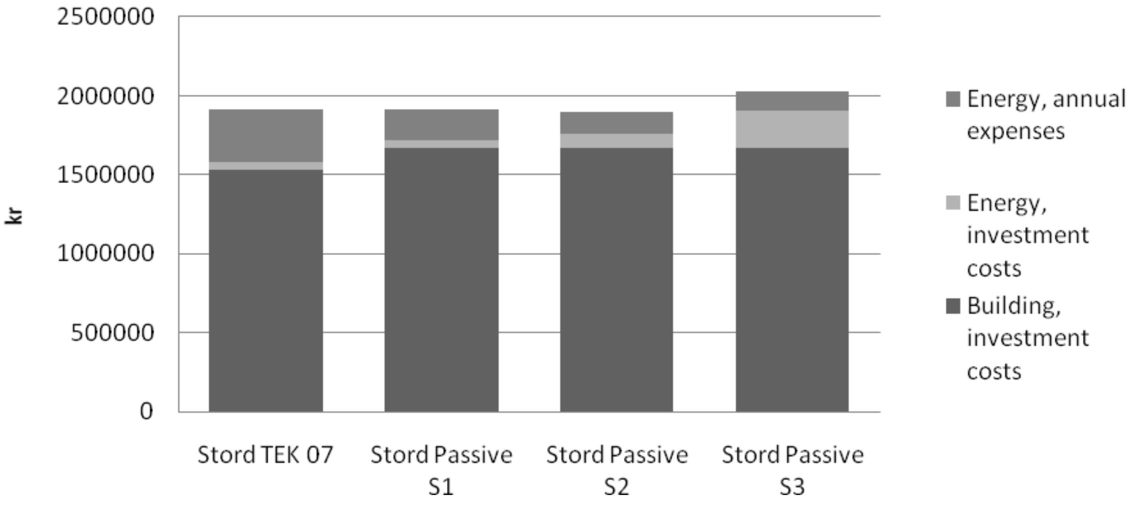


Figure 3.7: The costs of implementing the heating system solutions over the 50 year life cycle, including building costs.

3.3 Summary of the results regarding the heating system solutions

The most important results of the calculations regarding the heating system solutions are gathered in Table 3.4. In this table are the results presented as unit per square meter. The bold blue numbers are the lowest alternative in each row, and the bold, red are the largest and least favorable ones.

Table 3.5 show the percentage higher emission outputs of the standard alternatives of electricity and fire wood, compared to the two renewable energy alternatives. See Table 3.6 for the comparison of the two renewable heating system solutions.

Table 3.4: Overview of the results regarding the heating system solutions (unit/m^2).

	Stord TEK 07	*Stord Passive S1*	*Stord Passive S2*	*Stord Passive S3*	*Unit/m2*
Impact potential, midpoint					
Climate change	**684**	445	**359**	376	*kg CO2 eq*
Human toxicity	**131**	85	80	**72**	*kg 1,4-DB eq*
Photochemical oxidant formation	**2**	1	1	**1**	*kg NMVOC*
Particulate matter formation	**1**	1	1	**0**	*kg PM10 eq*
Ionising radiation	**872**	575	447	**400**	*kg U235 eq*
Terrestrial acidification	**2**	2	1	**1**	*kg SO2 eq*
Terrestrial ecotoxicity	**1**	0	0	**0**	*kg 1,4-DB eq*
Freshwater ecotoxicity	1	**1**	**1**	1	*kg 1,4-DB eq*
Marine ecotoxicity	**1**	**1**	1	1	*kg 1,4-DB eq*
Metal depletion	**93**	**63**	87	75	*kg Fe eq*
Cumulative primary energy	**27**	18	14	**12**	*MJ eq*
Costs of the energy system	**2047**	1313	**1224**	1927	*kr*
Total costs, incl. building	10224	10238	**10149**	**10852**	*kr*

Table 3.5: The percentage share of higher emissions and energy use of Stord TEK 07 and Stord Passive S1 compared to the renewable energy solutions.

	% more in ST 07 than SP S1	*% more in ST 07 than SP S2*	*% more in ST 07 than SP S3*	*% more in SP S1 than SP S2*	*% more in SP S1 than SP S3*
Impact potential, midpoint					
Climate change	35	48	45	19	16
Human toxicity	35	39	45	6	16
Photochemical oxidant format	38	48	56	16	30
Particulate matter formation	35	44	52	14	25
Ionising radiation	34	49	54	22	30
Terrestrial acidification	35	45	53	16	27
Terrestrial ecotoxicity	37	53	58	25	33
Freshwater ecotoxicity	33	-5	24	-57	-14
Marine ecotoxicity	34	11	30	-34	-6
Metal depletion	31	6	18	-37	-19
Cumulative primary energy	34	48	54	21	30

Table 3.6: The percentage share of more emissions and primary energy use of Stord Passive S2 compared to Stord Passive S3.

	% more in SP S2 than SP S3
Impact potential, midpoint	
Climate change	-5
Human toxicity	11
Photochemical oxidant format	16
Particulate matter formation	13
Ionising radiation	10
Terrestrial acidification	13
Terrestrial ecotoxicity	11
Freshwater ecotoxicity	27
Marine ecotoxicity	21
Metal depletion	13
Single score, endpoint	-1
Cumulative primary energy	11

3.4 The ventilation system

3.4.1 Impact potential and cumulated energy of the ventilation system

Table 3.7 shows the emission output of the ventilation system divided on ventilation units, electricity during use phase and the rest which includes the distribution system, changing air filters for maintenance and transport of the components. As was mentioned in chapter 2.5.2, it is a great deal of uncertainty regarding the material input in the ventilation unit. Table 3.7 is therefore presenting three different scenarios of the emission outputs. "*Ventilation units*" is the middle way, "*Ventilation units, at lowest*" is best case scenario and "*Ventilation units, at largest*" is the worst case.

Table 3.8 presents the total emission output of the different scenarios.

Table 3.7: Impact potential of the ventilation system over the 50 year life cycle.

Impact category	*Ventilation units*	*Ventilation units, at lowest*	*Ventilation units, at largest*	*Distribution system, air filters and transport*	*Electricity during use phase, Stord TEK 07*	*Electricity during use phase, Stord Passive*	*Unit*
Climate change	850	350	1349	176	15312	13518	*kg CO2 eq*
Human toxicity	298	143	453	32	2889	2550	*kg 1,4-DB eq*
Photochemical oxidant formation	3	1	5	1	32	28	*kg NMVOC*
Particulate matter formation	2	1	3	0	22	20	*kg PM10 eq*
Ionising radiation	274	90	459	65	20476	18076	*kg U235 eq*
Terrestrial acidification	5	2	9	1	51	45	*kg SO2 eq*
Freshwater eutrophication	0	0	0	0	0	0	*kg P eq*
Marine eutrophication	1	0	1	0	10	9	*kg N eq*
Terrestrial ecotoxicity	0	0	0	0	11	10	*kg 1,4-DB eq*
Freshwater ecotoxicity	7	3	10	0	15	13	*kg 1,4-DB eq*
Marine ecotoxicity	9	4	14	1	31	28	*kg 1,4-DB eq*
Water depletion	11	4	18	1	175	155	*m3*
Metal depletion	1090	481	1699	26	1848	1632	*kg Fe eq*

Table 3.8: Total impact potential of the different ventilation scenarios over the 50 year life cycle.

	Stord TEK 07			***Stord Passive***			
Impact category	*Ventilation system*	*Ventilation system, at lowest*	*Ventilation system, at largest*	*Ventilation system*	*Ventilation system, at lowest*	*Ventilation system, at largest*	*Unit*
Climate change	16337	15838	16837	14543	14043	15042	*kg CO2 eq*
Human toxicity	3219	3064	3375	2881	2726	3036	*kg 1,4-DB eq*
Photochemical oxidant formation	36	34	38	32	30	34	*kg NMVOC*
Particulate matter formation	25	24	26	22	21	23	*kg PM10 eq*
Ionising radiation	20815	20630	21000	18415	18231	18600	*kg U235 eq*
Terrestrial acidification	58	54	61	52	48	55	*kg SO2 eq*
Freshwater eutrophication	0	0	0	0	0	0	*kg P eq*
Marine eutrophication	11	11	12	10	10	11	*kg N eq*
Terrestrial ecotoxicity	11	11	11	10	10	10	*kg 1,4-DB eq*
Freshwater ecotoxicity	22	19	25	20	17	23	*kg 1,4-DB eq*
Marine ecotoxicity	41	36	46	37	33	42	*kg 1,4-DB eq*
Water depletion	187	180	194	167	160	174	*m3*
Metal depletion	2964	2355	3573	2747	2138	3356	*kg Fe eq*

In the normalized comparison in Figure 3.8, Freshwater eutrophication", "Marine eutrophication" and "Water depletion" are all reduced to zero, illustrating that their amount of outputs are not important compared to the emission output in other categories.

As can be seen in the table and in Figure 3.8, it is a varying outcome of the impact potential for the three scenarios. Figure 3.9 shows the potential of "Climate change" of the three scenarios. The difference between the best and worst scenario for both of the case studies is about one ton CO_2 eq. The middle way gives 16.3 ton of CO_2 eq for the Stord TEK 07 building, and 14.5 ton CO2 eq for Stord Passive. The middle way scenario is the one used as the basic scenario in further simulation results.

"Marine ecotoxicity" is the category with the largest importance in Figure 3.8, but also "Human toxicity" and "Metal depletion" have relatively large emission output.

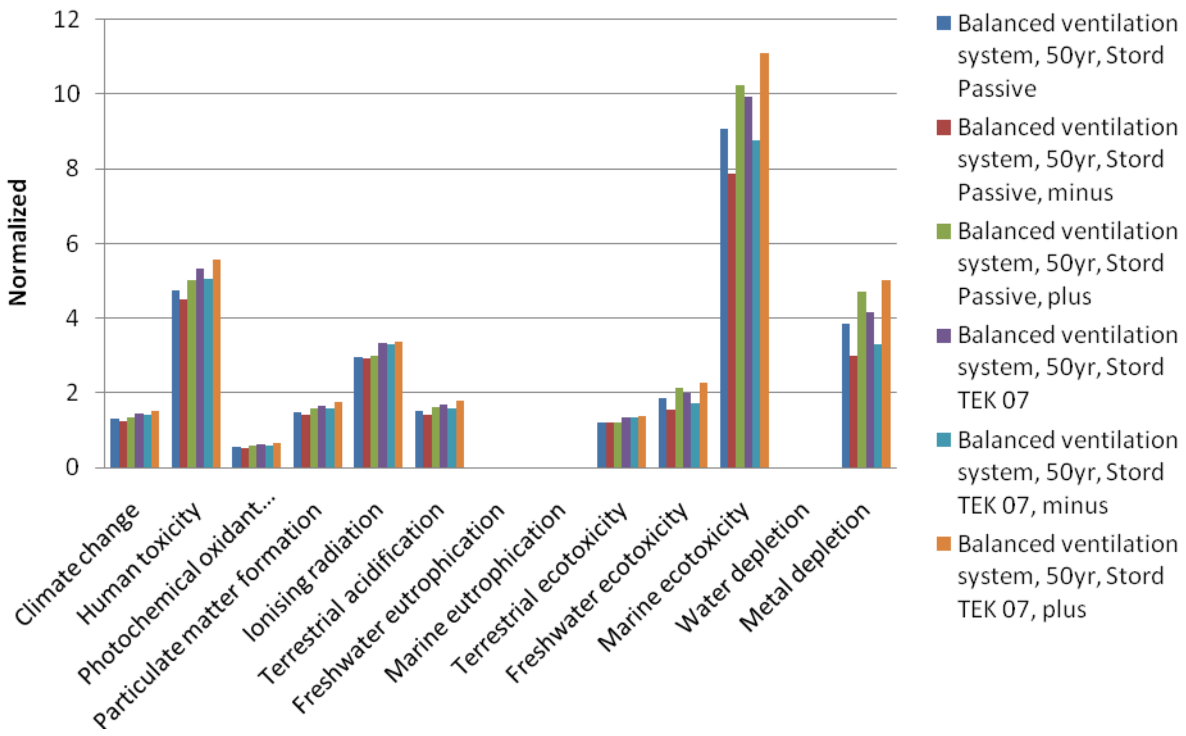
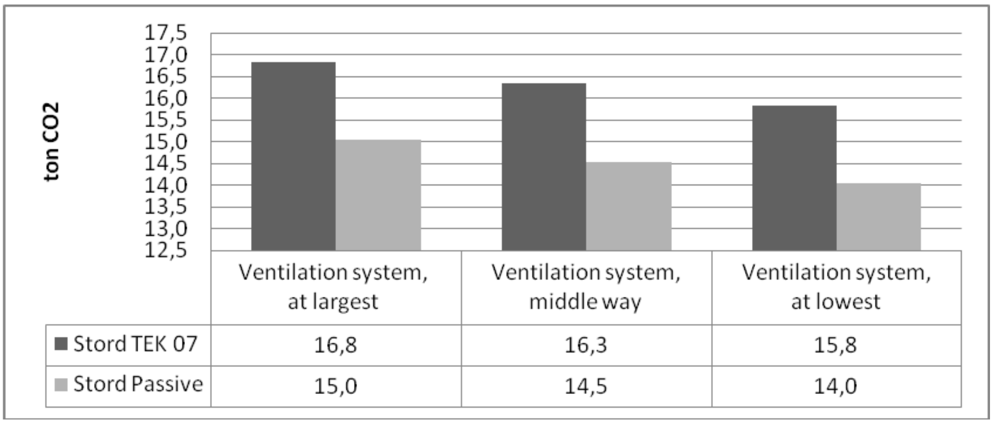


Figure 3.8: Normalized illustration of the impact potential due to the ventilation system for the three scenarios seen over the 50 year life cycle.



	Ventilation system, at largest	Ventilation system, middle way	Ventilation system, at lowest
■ Stord TEK 07	16,8	16,3	15,8
■ Stord Passive	15,0	14,5	14,0

Figure 3.9: Climate change potential of the three scenarios due to the ventilation system over the 50 year life cycle.

Figure 3.10 presents the percentage allocation between the output due to electricity delivered to the system in the use phase and the remaining part which is caused by material and transport. Both impact categories and accumulated energy, named CE, is presented in this graph. About 93-94 percent of the CO_2 eq. output is due to delivered electricity and 97 percent of accumulated energy. Also here have the material and transport input larger relevance in the categories "Freshwater ecotoxicity", "Marine ecotoxcity" and "Metal depletion", than in the rest of the categories.

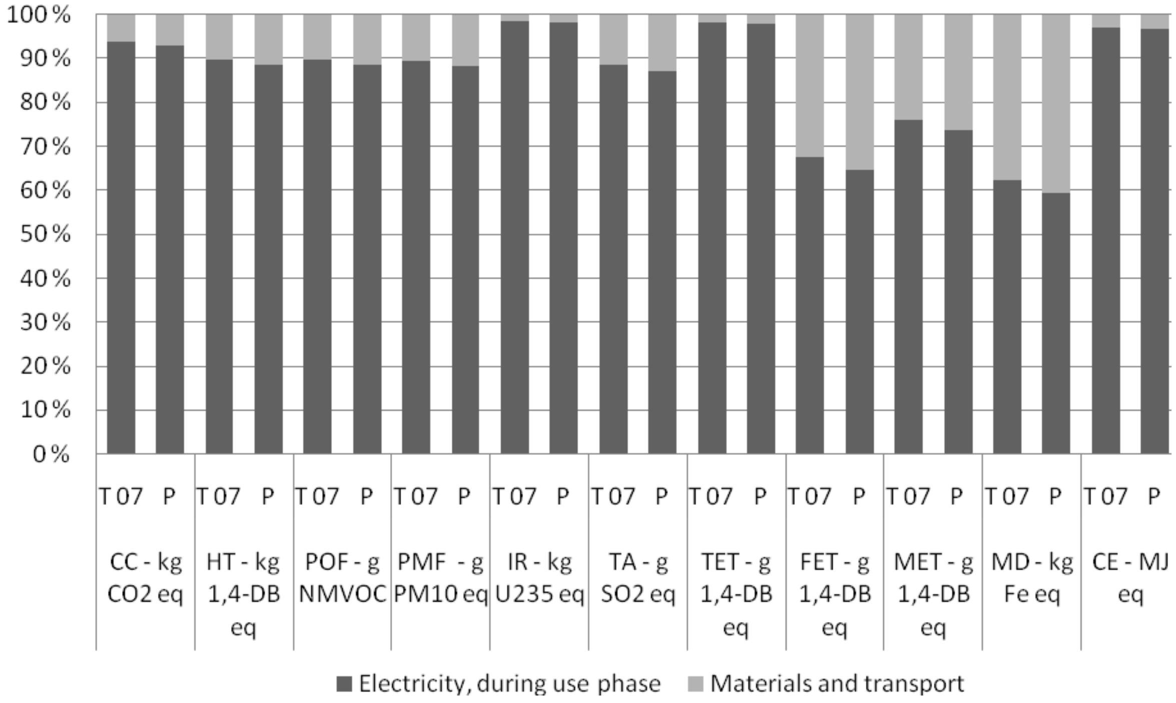


Figure 3.10: Percentage division between the impact potential due to delivered electricity and the rest of the system.

Table 3.9 presents the cumulated primary energy due to the ventilation system over the 50 year life cycle divided on different energy sources. This must be seen in the light of the chosen electricity mix, presented in Table 2.7. Figure 3.11 shows an illustration of the numbers. Appendix 7.5 can be studied to see the net energy use divided on energy sources for the two cases.

Table 3.9: Cumulated energy due to the ventilation system over the 50 year life time.

Cumulated energy

Unit: Giga Joule, GJ

	Ventilation system, Stord TEK 07	***Ventilation system, Stord Passive***
Non renewable, fossil	195	174
Non-renewable, nuclear	216	191
Renewable, biomass	59	52
Renewable, wind, solar, geothermal	5	4
Renewable, water	166	146
Total	*641*	*568*

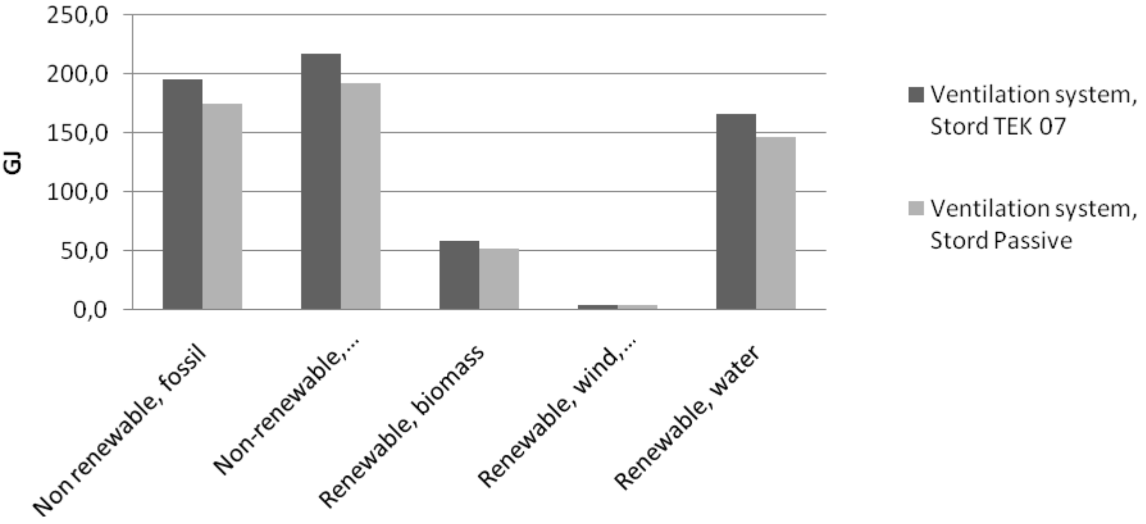


Figure 3.11: Cumulated primary energy due to the ventilation system over the 50 year life time.

3.4.2 The effect of heat recovery in the heating and climate system

When studying the emission output from the ventilation system it is important to see the positive effect of the heat recovery which makes the need for space heating lower.

The effect of heat recovery is presented in Table 3.10 and Table 3.11, assuming that the 80 percent higher energy need is covered by electricity.

Table 3.10: Net emission output of the impact categories for Stord TEK 07.

Impact category	*Materials and transport*	*Use*	*Effect of heat recovery*	***Net emissions***
Climate change	1025	15312	-83215	-66877
Human toxicity	330	2889	-15701	-12481
Photochemical oxidant formation	4	32	-174	-139
Particulate matter formation	3	22	-121	-96
Ionising radiation	339	20476	-111277	-90462
Terrestrial acidification	7	51	-277	-220
Freshwater eutrophication	0	0	-1	-1
Marine eutrophication	1	10	-56	-44
Terrestrial ecotoxicity	0	11	-59	-48
Freshwater ecotoxicity	7	15	-79	-58
Marine ecotoxicity	10	31	-170	-128
Water depletion	12	175	-952	-765
Metal depletion	1116	1848	-10045	-7081

Table 3.11: Net emission output of the impact categories for Stord Passive.

Impact category	*Materials and transport*	*Use*	*Effect of heat recovery*	***Net emissions***
Climate change	1025	13518	-26799	-12256
Human toxicity	330	2550	-5056	-2176
Photochemical oxidant formation	4	28	-56	-24
Particulate matter formation	3	20	-39	-17
Ionising radiation	339	18076	-35837	-17421
Terrestrial acidification	7	45	-89	-38
Freshwater eutrophication	0	0	0	0
Marine eutrophication	1	9	-18	-8
Terrestrial ecotoxicity	0	10	-19	-9
Freshwater ecotoxicity	7	13	-26	-6
Marine ecotoxicity	10	28	-55	-17
Water depletion	12	155	-307	-140
Metal depletion	1116	1632	-3235	-488

Figure 3.12 is showing an illustration of the “Climate change” category for both houses. When it comes to the net cumulated energy, both Stord TEK 07 and Stord Passive have negative outcomes. See Table 3.12 and Figure 3.13 for the results.

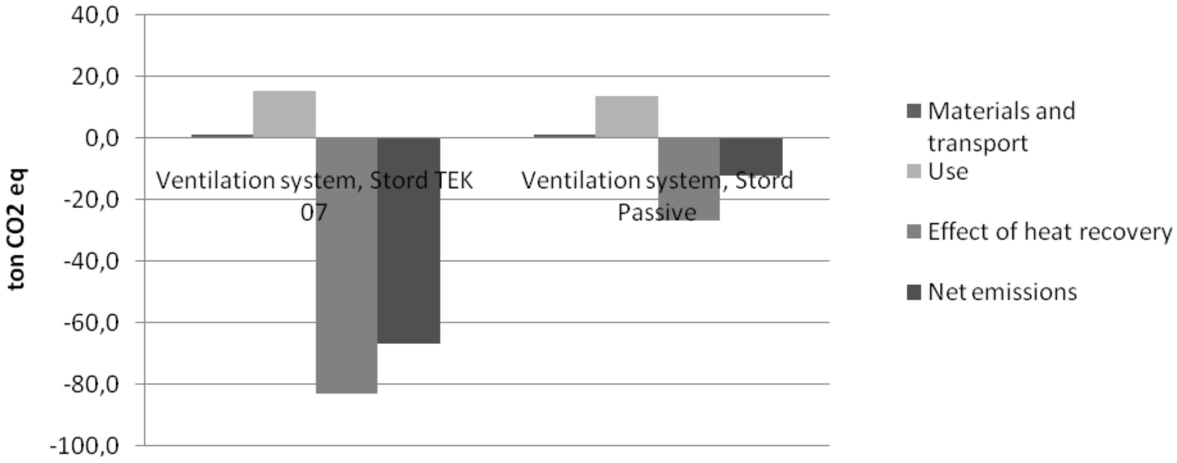


Figure 3.12: Climate change potential due to the ventilation system including the heat recovery over the 50 year life cycle.

Table 3.12: Net cumulated primary energy of the ventilation system for the 50 year life cycle.

Net cumulated primary energy

Unit: Giga Joule, GJ

	Ventilation system	*Effect of heat recovery*	*Net emissions*
Ventilation system, Stord TEK 07	641	-2486	-1845
Ventilation system, Stord Passive	568	-801	-232

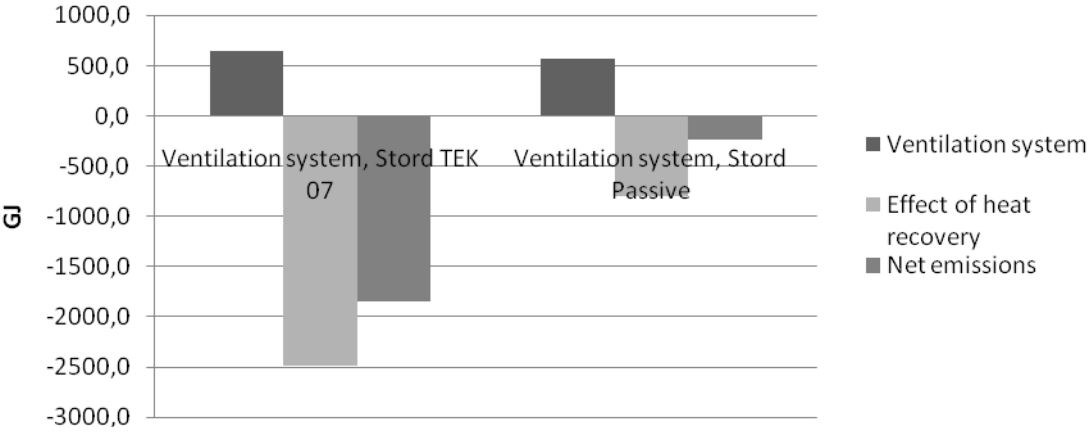


Figure 3.13: Net cumulated primary energy of the ventilation system for the 50 year life cycle.

Figure 3.14 and Figure 3.15 illustrates the intersection between the amount of CO_2 output and accumulated energy from materials, transport and use and the positive gain given from different percentages of heat recovery. The heat recovery is than seen to have a net positive impact in the conventional house Stord TEK 07 at an efficiency of about 15 percent and at about 42 percent in the passive house, Stord Passive.

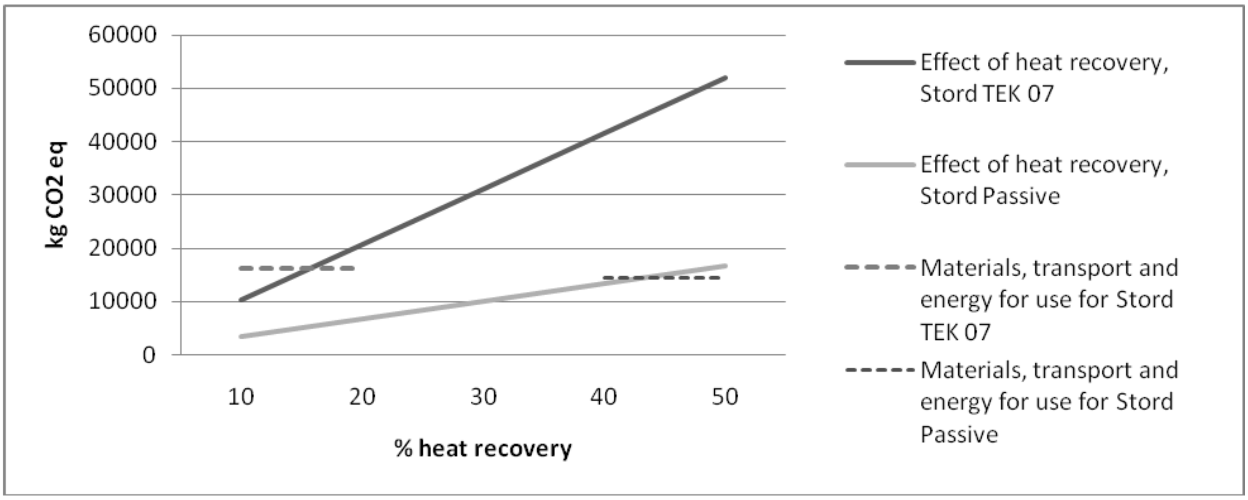


Figure 3.14: Illustration of the intersection between the CO_2 emission output from materials and use compared to the gain of heat recovery.

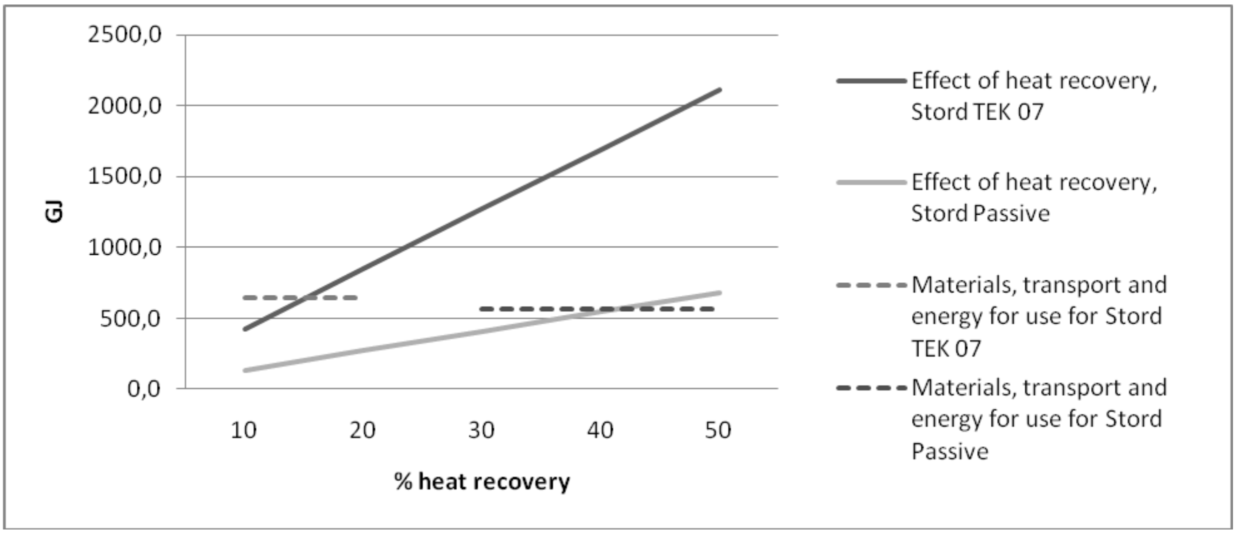


Figure 3.15: Illustration of the intersection between the CO_2 emission output from materials and use compared to the gain of heat recovery.

4 Discussion

The aim of this study was to determine the level of environmental impact and primary energy resulting from demands placed on residential ventilation and heating systems; a conventional residential house built to the 2007 Norwegian building code with a standard heating system was compared against three technology scenarios used in a passive house of the equivalent size. An economical evaluation of the heating systems was also done.

4.1 Evaluation of the results

4.1.1 The heating systems

The most important results of the calculations regarding the heating system solutions are gathered in Table 3.4. In this table are the results presented as unit per square meter. The bold blue numbers are the lowest alternative in each row, and the bold, red are the largest and least favorable ones.

As can be seen in the table, the alternative with the best outcome in most rows is Stord Passive S3, the air-water heat pump solution. With the amount of 376 kg CO_2 eq/ m^2, it got some larger potential of ”Climate change” than the solar collector alternative with 359 CO_2 eq/ m^2. In the categories “Freshwater ecotoxicity”, “Marine ecotoxicity” and “Metal depletion” it is beaten by another alternative, Stord Passive S1. The point where the heat pump alternative is coming out as the worst choice is at the total costs. Air-water heat pumps are expensive and have lower lifetime than the other technical solutions. Together with the extra price of the passive house building, this gets the most expensive alternative.

Stord TEK 07 is the clearly loosing alternative, with largest numbers in most of the categories, both when it comes to impacts, energy and costs of the heating system. The output related to climate change is 684 CO_2 eq/ m^2 and is then the clearly worst heating solution in this category. This alternative is also more expensive than both Stord Passive S1 and Stord Passive S2 when the building expenses is taken into account, which all together makes this alternative to the least favorable.

The cheapest heating system solution is Stord Passive S1, which has both low investments costs and annual expenses. The big drawback with this alternative is that it emits much more than the renewable alternatives.

Table 3.5 shows the percentage higher emission outputs of the standard alternatives of electricity and fire wood, compared to the two renewable energy alternatives. Considering impacts related to ”Climate change”, Stord TEK 07 has 47.5 and 45 percent higher output than the renewable energy solutions of Stord Passive S2 and S3, respectively. The accumulated energy is also almost twice as large as in the renewable solutions. Also installing a standard Norwegian heating system in a passive house, as done in Stord Passive S1, cause large improvements. The total of 34-35 percent lower CO_2 eq output and use of accumulated primary energy is a good improvement.

See Table 3.6 for a comparison of the two renewable heating system solutions. The solar collector alternative, Stord Passive S2, has some larger impacts than the heat pump alternative, but 4.8 percent lower CO_2 eq output. In the category “Freshwater ecotoxicity” the solar collector alternative has large impacts, not only compared to Stord Passive S3, but also compared to all other alternatives. This is mainly because of the output of Nickel (ion) due to delivered electricity to the system and the use of chromium steel, both in the collectors and water tank.

In Figure 3.2 and Figure 3.3 the impacts are presented with a division between delivered electricity during the use phase and input of material and transport. It is evident that the emission outcome of the life cycle is much due to the amounts of electricity to the different systems. Figure 4.1 shows the amount of delivered electricity in the use phase over the 50 year life cycle.

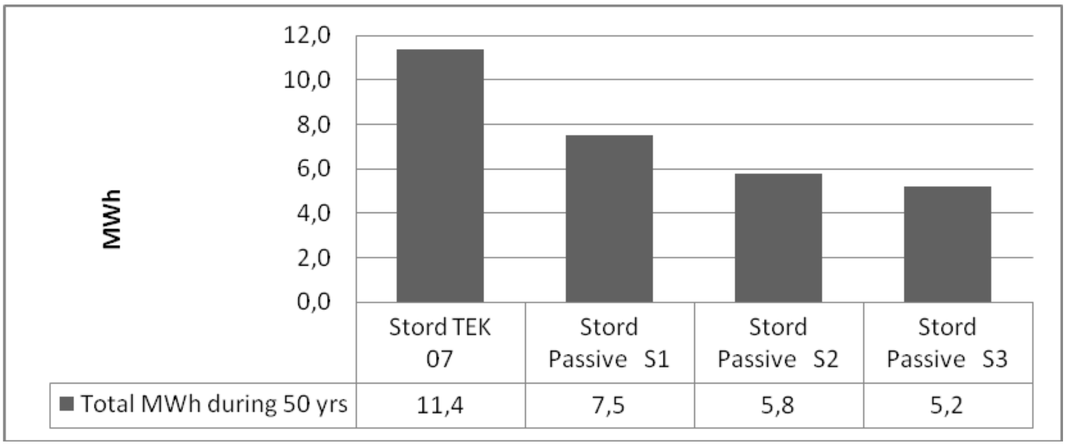


Figure 4.1: Delivered electricity for hot water and space heating for the different system solutions over the 50 year life cycle.

For the potential of ”Climate change” is the amount of emissions due to electricity over 75 percent for all the alternatives. The effect of materials and transport is largest for the heat pump solution Stord Passive S3. One reason for this is that in this alternative technical equipment has a lower life time and must be changed more often. Another more important factor is that in this heating system need large material inputs of polluting refrigerants, as discussed further later in this chapter.

Stord Passive S2 and S3 have larger shares of emissions due to materials and transport, than to the alternatives based on electricity and wood seen over the life cycle. Especially “Freshwater ecotoxicity”, “Metal depletion” and “Marine ecotoxicity” are impact potential categories with large shares of the emission output due to the input of materials and transport. Nevertheless, it is interesting to see that despite the fact of a much larger input of materials and a transport length all the way from Great Britain, the renewable heating systems is the alternatives which seem to be the most environmentally friendly.

Focusing on “Marine ecotoxicity”, the overall emission output is large for all alternatives. In Figure 3.1 is this category the one with largest relative importance. For Stord TEK 07, the main emission contributor to this category is the use of copper and nickel while using electricity. A large degree of these kinds of metals is used in the electrical distribution network. The same emission source is the reason for the impacts connected to Stord Passive S1. Also in Stord Passive S2 is nickel and copper the largest emission sources, but not only because of the use of electricity. Copper is an important material input in the vacuum collectors. The use of chromium steel in both the collectors and in the water tank is also making a noticeable contribution.

Another category with great relative importance in Figure 3.1 is “Human impact”. Arsenic, Phosphorus, Lead and Manganese are the main emission outputs in this category. These are mainly emitted by the use of electricity because of the direct use of different kinds of polluting energy sources and material inputs to the grid system, but also the use of copper and steel as material input to the different systems are making contributions.

Figure 3.4 shows the primary energy cumulated by the different heating systems. A clearly connection to the delivered electricity is evident. Stord TEK 07 is the heating system solution with highest use of primary energy and the two systems based on renewable energy are not surprising the least energy intensive alternatives. The heat pump solution, Stord Passive S3, uses slightly less energy than the solar collector alternative.

Table 3.2 shows the division of the cumulated energy on different energy sources and Figure 3.5 illustrates this. This table must be seen in the light of Table 2.7 where the percentage allocation of the energy sources of the Nordic electricity production. It must be mentioned that the energy related to the use of wood in the heating system solutions Stord TEK 07 and Stord Passive S1 are not counted for as cumulated energy in the simulation.

As was stated in the introduction, 22 percent of the final energy consumption is related to the residential building stock. The results of this study show that by accomplish the goal of reducing the need of net energy for space heating by 68 percent, from 9306 kWh/yr to 2997 kWh/yr, makes big differences according to the need of delivered electricity and the amount of overall impacts through the life cycle of a heating system. Comparing the standard Norwegian heating system consisting of electricity and fire wood for the two different frames of construction, shows that the emission outputs and primary energy need could be dramatically reduced. Going further, focusing on renewable energy sources in the passive house, the result shows about half of the emissions than the conventional house with the standard heating structure.

Nevertheless, the results must be seen in the light of that the materials included in the construction of the building are not considered. When the extra amounts of materials due to the construction of a tight and tick walled passive house is included, the study may give other results.

Considering economy, it is in this study shown that building a passive house with a standard Norwegian heating system has about the same price as building a conventional house with the same heating system. As can be studied in Table 3.4, Stord TEK 07 has a total cost of 10 224 kr/m^2, while Stord Passive S1 has the amount of 10 238 kr/m^2. The renewable energy solution based on solar collectors is the most economical favorable alternative with a cost of 10 149 kr/m^2. The other renewable system based on an air-water heat pump is the most expensive solution with 10 852 kr/m^2.

Seeing the costs of the latter heating system together with the rest of the expenses when building a new house, the extra amount of costs may be valued in other positive ways. An important factor is the uncertainty factor associated by delivery of electricity and its associated costs in the future. Installing a hydronic heating system makes the consumer less dependent on one energy source, which means that the energy safety is higher. The consumer can always choose the energy source that is easily accessible, cheapest and most environmentally friendly. When the hydronic pipe system is installed, it is possible to utilize renewable energy sources such as biomass, solar, geothermal and district heating, which makes the system energy-flexible. A central heating system like this can use environmentally friendly and renewable energy sources that would not otherwise have been used.

Comfort is another issue. A problem with electric heating is that the panel heaters allow dust particles burning and churning up. The dust is unpleasant for asthma and allergy sufferers. When using hydronic heating similar dust problems will not occur, and is therefore recommended by the Norwegian Asthma and Allergy Association [46].

When discussing advantages and disadvantages on different kinds of technologies, the whole picture must be taken into account. Though the emission output is important in an environmental matter, an emphasis must also be taken in considering the material input to a system, in terms of possible resource scarcity. As mentioned, the type of solar collector considered in this study contains 2.8 kg copper/m^2. Lack of new mines and lower grade ore mean copper could become scarcer in the years to come. Before putting the large degree of copper in a solar collector, we should be sure that this is a sustainable way of using this resource, before valuing it as a renewable energy system.

Another issue is the use of refrigerants in the heat pump system. Though the heat pumps are environmentally friendly in the way they are making buildings use less electricity, there has been another problem related to the refrigerant. Hydro fluorocarbons or 'HFCs' have been increasingly used in the last decade or so as an alternative to ozone damaging CFCs in refrigeration systems [47]. Unfortunately, though they provide an effective alternative to CFCs which is now banned under the Montreal Protocol, they can also be powerful greenhouse gases with long atmospheric lifetimes. A problem connected to this is the large amount of polluting waste ending up on the landfill, today and in the future, the more popular the heat pumps become.

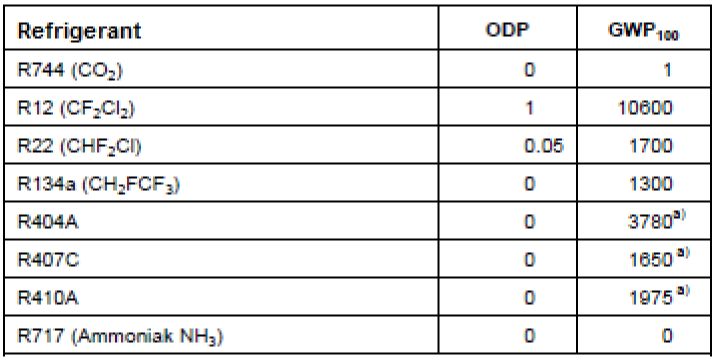
The three main HFCs are HFC-23, HFC-134a and HFC152a, with HFC-134a being the most widely used refrigerant and the one used in this study. It has a life time of 14 years and since 1990, when it was almost undetectable, concentrations of HFC-134a have risen massively[47].

The amount of refrigerant for the kind of heat pumps used in the study lies around 0.49 kg/kW [33]. This is a factor of 1.6 higher than a comparable brine water heat pump [33]. Due to the leakage loss of the refrigerant going out in the air, it has to be refilled periodically. Loosing 6 percent per year of the fully loaded heat pump of 3 kg refrigerant fluid makes a loss of 7.32 10^{-6} kg/MJ giving a total output to the atmosphere of 9 kg over the life time of 50 years for the heat pump alternative, Stord Passive S3.

Table 4.1 gives an indication of the potential of global warming due to the refrigerant. HFC-134a is a blending of 4 percent R404A and 52 percent R407C which together makes a total Global Warming Potential, or GWP_{100}, of 1300. The GWP_{100} is the global warming potential over 100 years and is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount heat trapped by a similar mass of carbon dioxide.

The amount of HFC-134a emitted to the atmosphere by Stord Passive S3 is then causing about 11.8 ton CO_2 eq, 17 percent of the total emission output related to the “Climate change” potential.

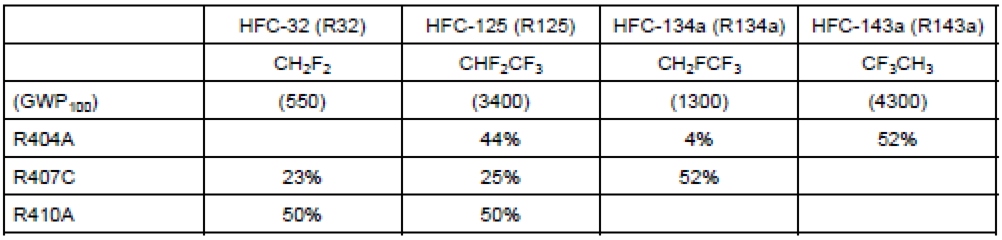
Table 4.1: The Ozon Depletion Potential (ODP) and Global Warming Potential (GWP_{100}) of refrigerants [33].



Refrigerant	ODP	GWP_{100}
R744 (CO_2)	0	1
R12 (CF_2Cl_2)	1	10600
R22 (CHF_2Cl)	0.05	1700
R134a (CH_2FCF_3)	0	1300
R404A	0	$3780^{a)}$
R407C	0	$1650^{a)}$
R410A	0	$1975^{a)}$
R717 (Ammoniak NH_3)	0	0

a) GWP_{100} from R404A, R407C and R410A is calculated by Table 8.6

Table 4.2: The composition of the common refrigerant blends R404A, R407C and R410A and Global Warming Potential (GWP_{100}) of the HFC-components [33].



	HFC-32 (R32)	HFC-125 (R125)	HFC-134a (R134a)	HFC-143a (R143a)
	CH_2F_2	CHF_2CF_3	CH_2FCF_3	CF_3CH_3
(GWP_{100})	(550)	(3400)	(1300)	(4300)
R404A		44%	4%	52%
R407C	23%	25%	52%	
R410A	50%	50%		

The capacity of 10 kW of the heat pump is large compared to the low amount of heat needed to a passive house. The amounts of materials may be less choosing a smaller pump, but it is assumed that the extra amounts do not change the results much.

Since the refrigerant has a large influence on the emission outcome related to the climate change potential, the choice of refrigerant is important. A model with less capacity does not necessarily emit less CO_2 eq. According to Midt-Norge VVS, the popular model Bosch EHP 6 AW with a capacity of 6 kW is using 2.5 kg R407C. Loosing 6 percent to the atmosphere gives an emission output of 6.16 10^{-6} kg/MJ giving a total output to the atmosphere of 7.5 kg over the life time of 50 years. As presented in the table, R407C corresponds to 1 650 GWP_{100}, which in total gives a CO_2 output of about 12.4 ton, which is a bit more than what was the resulting amount in this study when the capacity was assumed larger.

All together, seeing the heating systems in a life cycle perspective, the benefit of using less and cleaner electricity is clear. Anyway, when reading the results an emphasis must be pointed on the uncertainty of the study, which is discussed further in chapter 4.3. It must also be remembered that the electricity mix used is the Nordic one. The Norwegian mix, which is mainly based on the renewable energy source water power, has much lower emission output per kWh than the Nordic mix, resulting in larger share of emission outputs related to the production phase of the heating systems. This will be discussed further in chapter 4.2.1.

4.1.2 The balanced ventilation system

When evaluating the ventilation system, three scenarios were studied. The system was based on an uncertain declaration given by a ventilation system supplier. In terms of climate change potential, the difference between the best and worst scenario for both of the case studies is about one ton CO_2 eq. See Table 3.8. The middle way gives a result of 16.3 ton of CO_2 eq for the Stord TEK 07 building, and 14.5 ton CO2 eq for Stord Passive.

As is shown through Figure 3.8, the impact category “Marine ecotoxicity” is also here the category with largest relative importance of impact. The same reason as was the case for the heating systems is also valid for the ventilation system. Copper polluted to the air and nickel (ion) emitted to water are the most polluting substances. This is much due to delivered electricity, but also to the material input in the production of the unit.

As was the case for the heating systems, also for the ventilation system is the electricity delivered during use phase the main contributor to the emission output. Figure 3.10 presents the percentage allocation between the output due to electricity delivered to the system in the use phase of the building and the remaining part which is caused by material and transport. Less than 10 percent of the “Climate change” potential is due to the latter inputs, but contributes with about 40 percent of the “Metal depletion” and over 30 percent of the emissions in the impact category “Freshwater ecotoxicity”. When it comes to accumulated primary energy, about 97 percent is due to delivered electricity in the use phase.

When studying a ventilation system with an efficient heat exchanger, it is important to take into account the benefit of the heat recovery. Table 4.3 presents net energy need for space heating with and without the 80 percent heat recovery. The larger the heating need in the building is, the larger is the amount of extra electricity that must be delivered to the building.

Table 4.3: Annual net energy need for space heating with and without 80 percent heat recovery.

	Stord TEK 07 (kWh/yr)	*Stord Passive (kWh/yr)*
With 80% heat recovery	9306	2997
Without 80% heat recovery	13324	4386

The results, taken into account the effect of heat recovery, are presented in Table 3.11 and Table 3.12. It is assumed that the 80 percent higher energy need is covered by electricity. All net emissions are negative in both tables, earning more the higher the delivered energy need for the system is. Figure 3.13 is showing an illustration of the “Climate change” category for both houses. Heat recovery totally compensates for the harmful environmental impacts that arise from the manufacture, maintenance and operation of the ventilation unit. The total amount of about 67 ton CO_2 eq. for Stord TEK 07 and more than 12 ton CO_2 eq. for Stord Passive is avoided using the heat recovery.

The accumulated energy as presented in Table 3.13 and Figure 3.14. Also here is the gain of heat recovery larger for the house which uses the most energy, Stord TEK 07. The accumulated energy gain is 1.8 GJ for Stord TEK 07 and 0.2 GJ for Stord Passive.

Figure 3.14 and Figure 3.15 illustrates the intersection between the amount of CO_2 output and accumulated energy from materials, transport and use and the gain given from different percentages of heat recovery. The heat recovery is than seen to have a net positive impact in the conventional house Stord TEK 07 at an efficiency of about 15 percent and at about 42 percent in the passive house, Stord Passive. The result of gain at about 15 percent for the conventional house is the same result as was accomplished by Mikko Nyman and Carey J. Simonson which studied two types of ventilation systems installed in a residential house in 2004 [48].

It must be noticed that the effect of heat recovery is based on that the extra heating need is to be covered by electricity. The reason for this is that this was seen as the most realistic heating source substitute. The extra heating need may have been covered by other less polluting energy sources and the gain would then have been lower.

4.2 Choice of inventory input

4.2.1 The choice of electricity mix for the user phase

It can be discussed whether it was right to use the Nordic instead of the Norwegian or European electricity mix, in the use phase of the building.

The emission outputs due to the mean European kWh is much larger than to both the Nordic and Norwegian one. First of all, when it comes to potential of ”Climate change”, there is a sizeable difference. In the Ecoinvent database, the Nordic mix (NORDEL) has an overall output of 0.21 kg CO_2 eq/kWh, while the European production (RER) has an output of 0.56 kg CO_2 eq/kWh. In comparison, the Norwegian mix (NO) has only 0.017 kg CO_2 eq/kWh. The latter is because of the Norwegian electricity production has a share of 98.5 percent renewable water power, as was presented in Table 2.7, chapter 2. Figure 4.2 shows the effect on outputs related to ”Climate change” on each heating system due to the choice of electricity mix.

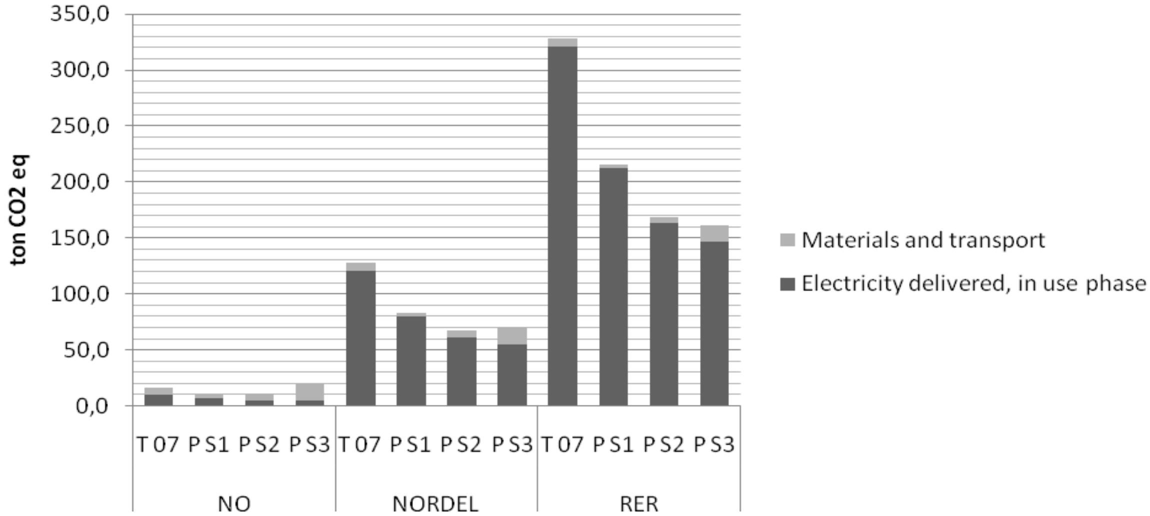


Figure 4.2: Comparison of “Climate change” potential choosing European electricity mix (RER) instead of Nordic mix (NORDEL).

As can be seen in the figure, when the Norwegian electricity mix is used, the share of emission output due to materials and transport is getting much larger, resulting in the heat pump solution Stord Passive S3 to be the loosing alternative in terms of largest CO_2 eq output.

Figure 4.3 shows a comparison of one kWh of the Nordic (NORDEL) versus the European (RER) and Norwegain (NO) electricity mix. Many of the impact categories are shown to have a huge dissimilarity between the three. Especially "Marine ecotoxicity" points out with substantial gaps.

The choice of electricity mix in life cycle assessments concerning products with connection to the Norwegian grid is highly discussed. The question is how large impacts should be pointed on the Norwegian consumer, living in a country which mainly produces renewable energy. The reason for the choice of Nordic electricity mix in this study is that Norway is a part of a Nordic electricity market and this mix is therefore considered more accurate in terms of the current and future state of the Norwegian electricity status.

Another issue is that the electricity mix will change dramatically the next 50 years, which makes the uncertainty regarding the emission outputs larger. To be able to cope with these dilemmas, the Norwegian research center on zero emission buildings, ZEB, has recently made new CO_2 factors based on future scenarios [49]. The results are not official yet, but can be used in later studies.

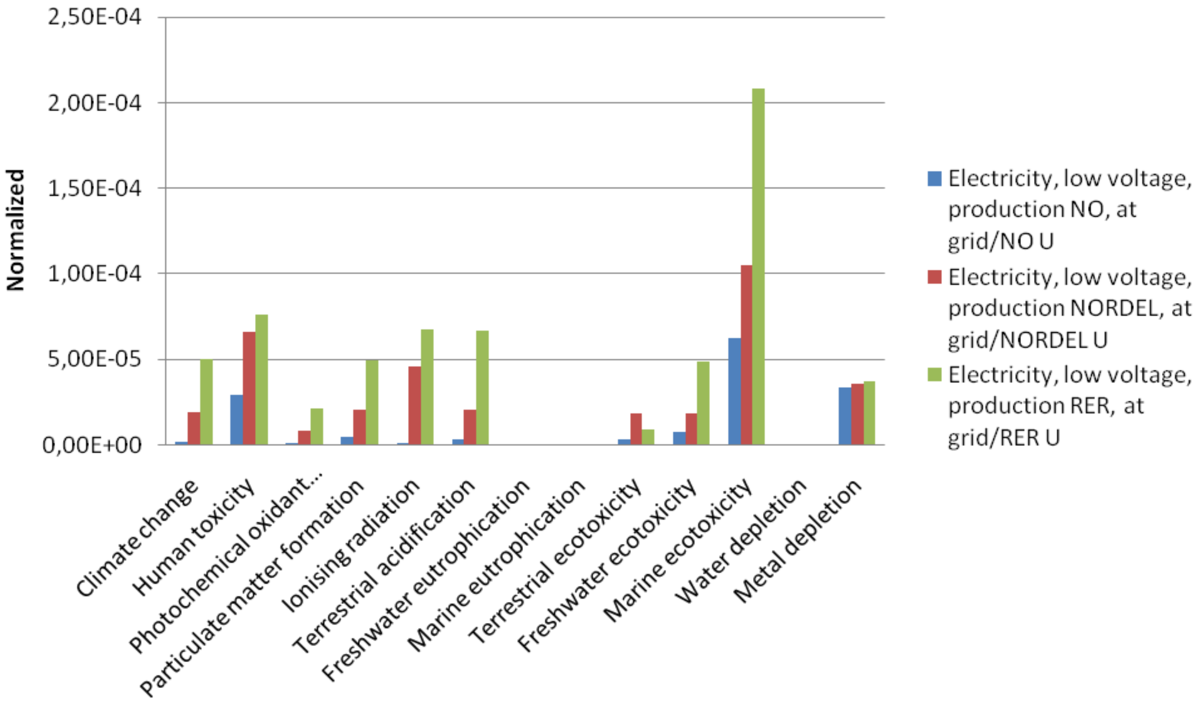


Figure 4.3: A normalized comparison of 1 kWh Norwegian (NO), Nordic (NORDEL) and European (RER) electricity mix.

4.2.2 The size of the solar collector system

There are several parameters that affect the solar thermal energy output from a solar collector plant. Especially important is it to figure out the most efficient number of collectors and of second interest is it to place the collectors in right angle against the sun.

When considering the numbers of collectors in alternative Stord Passive S2, several simulations with the software Polysun were done. There was a decision that had to be taken if two or three collectors were to be chosen. The extra energy output from a third collector must be compared to the extra energy and material input in making the extra solar collector. Simulating a system with three collectors gave the result of 23 percent more delivered energy output to the system than for two collectors with the same tilt of 30 degree. This extra amount of energy output is considered to be large enough to make the assumption that it is beneficial to choose three collectors instead of two, and was the recommended choice of Polysun.

The user manual to the simulation program presents an optimal angle of 44 degree in the city of Oslo, lying at latitude 59.5 degree [28]. The latitude of Stord is 59.8 degree, so this tilt will also suit the case of this study. The slope of 30 degree was nevertheless chosen in this study so that the collectors could be mounted on the slope of the roof. The effect of choosing 30 degree instead of 45 degree can be studied further in Figure 4.4 which show the solar thermal energy output from both of them. The difference between the two is that the 45 degree angle will in total give 5 percent more energy resulting in some larger energy output in the winter months when the energy need is at its highest.

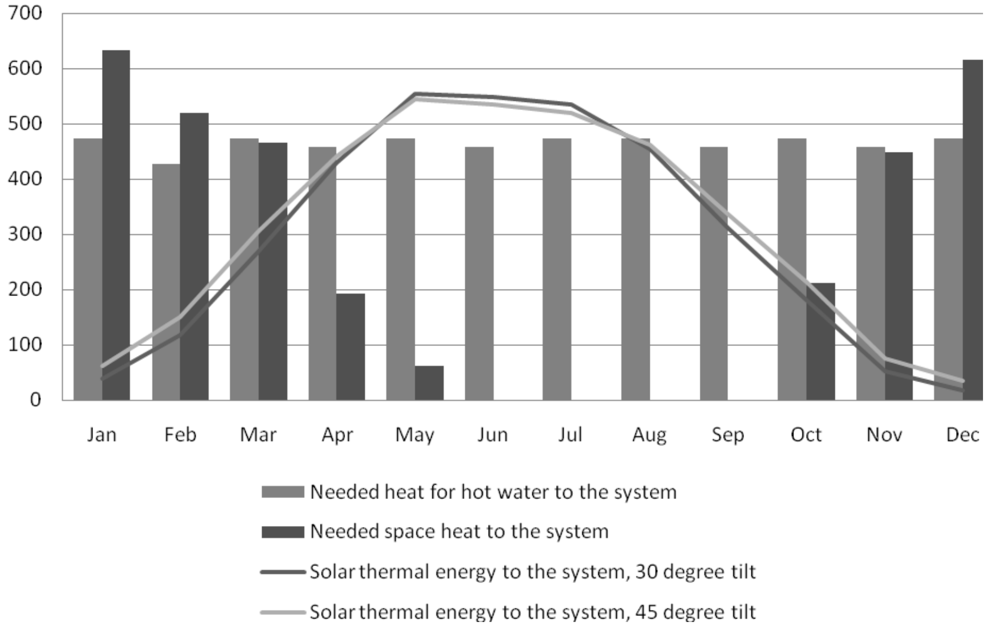


Figure 4.4: Solar thermal energy to the system comparing an angle of 30 degree with 45 degree.

4.3 Uncertainty

4.3.1 Uncertainties regarding data sources and inventory input

The largest uncertainties in the study analyzing energy and climate systems over a life cycle of 50 years, is due to the technical developments which is unknown at present day. Each year new technical improvements are done, making the efficiencies of a system better, the service life longer, resulting in other material inputs and lower energy use.

The changing times does not only concern the material inputs, but is also crucial to the economical status. Price and development are often strongly dependent on each other, making the two parameters difficult to predict in a 50 year perspective. There will always be considerable uncertainty in the provision of additional costs and the calculated energy savings. Especially important to mention is it that the annual price of the electricity will vary to a big extent during the life time. Nobody knows what the future will bring, if it will be a lack or a surplus of the energy sources, making the electricity price go up or down. Another changing parameter is the discount rate which also is crucial for the profitability calculation.

As already discussed in chapter 4.2.1, the production mix of electricity during the 50 year life cycle is to a high extent uncertain and is much due to future developments. What way the developments are turning is also concerning the degree of recycling for the different material inputs. A higher share of material and energy recovering will lower the overall emission output of the life cycle, making the outcome of the analysis different.

Another big uncertainty is the role of the residents. The amount of net energy used by a family varies to a great extent, depending on the degree of regulation, in addition to what extent the energy efficient thinking within the family is. This also affects the amounts of net energy covered by the different heating systems. The heating systems based on electricity and wood has a 60/40 allocation in this study, but this division is largely dependent on the actors living in the residence. This also concerns the heat pump system. The assumption of 75 percent cover of net heat demand can be both higher and less, depending on the users and the climate conditions. The fact that an air based heat pump may not work under - 15 degree may play a role, but is assumed to have little importance at this location where the mean temperature is 7.4 degree and the lowest mean temperature is more than zero. The assumption of 75 percent is therefore assumed to be rather low, than high. The energy need in the passive house is so low that the possibility of 100 percent covering can be reasonable some of the years.

The uncertainty regarding the usable energy from the solar collector is also an important parameter to mention. The solar energy outcome is calculated based on mean values in the municipally Stord, and may vary to a large extent during the years. Through the 50 year life cycle it is nevertheless assumed that these dissimilarities are counterbalanced.

Stoves and fireplaces may be appropriate solutions in a passive house, but requires good regulation of the heat distribution [20]. Because of the tight structure of a passive house, there is a possibility of overheating the building resulting in loss of energy. This loss of energy is hard to predict and are therefore neglected. The same applies to the possible need of cooling, especially in the summer.

Uncertainties on a lower level are the assumptions taken of how the heating systems are composed. The renewable energy alternatives Stord Passive S2 and S3 are assumed to be using the same type of distribution system consisting of pipes and components making the hydronic system in the building function. The amount of materials may vary for two systems like this, but the difference is neglected.

The material input to the pipes is assumed on the basis of what was assumed in the study of the solar collector done by Jungbluth [25], which was analyzing a regular one-family house. The amounts of steel and copper in the case studies analyzed in this study may be less, but is assumed to not vary too much from what was the case in the study done by Jungbluth.

The environmental profiles of the energy and climate systems are based on simplified systems with estimated material types and quantities. Production process estimates were based on available processes in the Ecoinvent database and the estimated materials used in the systems. The systems were modeled with as much detail as possible to provide a good basis of comparison for the scenarios. Nevertheless, there may be differences between the assumed process inputs based on European mean values got from the Ecoinvent database and how the components in a Norwegian standard home actually are produced.

Other variables that may influence the environmental performance related to heating and ventilation systems are the quality of the systems in terms of production and installation errors. Another factor is the thermal quality of outer construction of the dwelling, which affects energy use, and then again the emission outputs from the system [50].

4.3.2 Uncertainty regarding the impact categories

The categories are only showing *potentially* impact.There are big uncertainties regarded the different impact categories and how the impact will be in real life. Especially the category “Human toxicity” is uncertain to a large extent. The characterization models regarding the influence of metals on ecotoxicity contain flaws regarding the time they are present in ecosystems and in what form, which determines if they are harmful or beneficial. Therefore the results of the ecotoxicity impact categories have a higher level of uncertainty [50]. However, despite the fact that the impact categories are uncertain, it is still possible to compare system alternatives.

Further description about uncertainties of the ReCiPe method and how it distributes the output and impacts to the different impact potential catergories, are beyond the scope of this study. It can be studied further in the ReCiPe method description [15].

4.4 Closure

To fulfill the discussion of the primary energy use and environmental impacts for the different heating system alternatives, the effect of the materials used in the construction phase of the two houses must be included. The trends presented by the results of this study are still valid to make a conclusion of a positive environmental benefit of building a passive house using renewable energy technology and ventilation with a high degree of heat recovery. The use phase of a building turns out as an energy intensive phase in the buildings life cycle, which results in huge emission outputs.

Traditionally, the building sectors main argument in choosing one solution instead of another has been economical benefits. Marked studies made recently on how buyers think in the process of selecting a house is way more complex than this. Comfort, energy safety, environmental benefits, flexibility and higher sales value is some other important arguments of the house buyer of today [20].

5 Conclusion

The life cycle assessment of different heating systems studying a conventional house, Stord TEK 07 and three passive house versions of the same building, shows that the environmental gain of building a passive house is large compared to the conventional residential building, using the same heating system based on electricity and fire wood. In terms of potential of ”Climate change”, the improvements are 34-35 percent lower in terms of CO_2 eq output and use of accumulated primary energy.

Going further, choosing a renewable alternative like installing a solar collector system or a air-water heat pump, the gain becomes even bigger, resulting in almost half the output of CO_2 eq than in the conventional house with the standard Norwegian heating system. The renewable solutions do not have to be more expensive than the conventional one, seen over the entire life cycle, but the investment costs are somewhat higher.

For all heating systems the main emission contributions are due to the amount of delivered electricity in the use phase. Input of materials and transport in the production phase are of minor importance.

Focusing on the ventilation, a balanced ventilation system with 80 percent heat recovery has large environmental benefits due to the installation of an efficient heat exchanger, causing the recovered heat. The energy consumption and potential harmful emissions resulting from the electrical energy used by fans during the 50 year life cycle far exceed the environmental impacts that result from manufacture and transportation of the ventilation unit. The study revealed that a heat-recovery system must have efficiency greater than 15 percent to achieve reductions concerning output of CO_2-eq and use of primary energy for Stord TEK 07; this requirement increases to 42 percent in houses built to the passive house standard house, Stord Passive.

5.1 Suggestions for further work

Many alternative heating systems could have been chosen and analyzed in this study. There are especially one alternative that would be an interesting fourth alternative for the passive house; Installing a heat pump and solar collectors together. Another solution of interest is to analyze a system based on a geothermal heat pump. These have longer technical life time than the air-water pumps and can also easily be used for cooling in the hot summer months. Also several scenarios focusing on different choices done by the actors would have been an interesting expansion of the study.

What would also have been interesting is to see different possible heating systems for Stord TEK 07, especially renewable ones.

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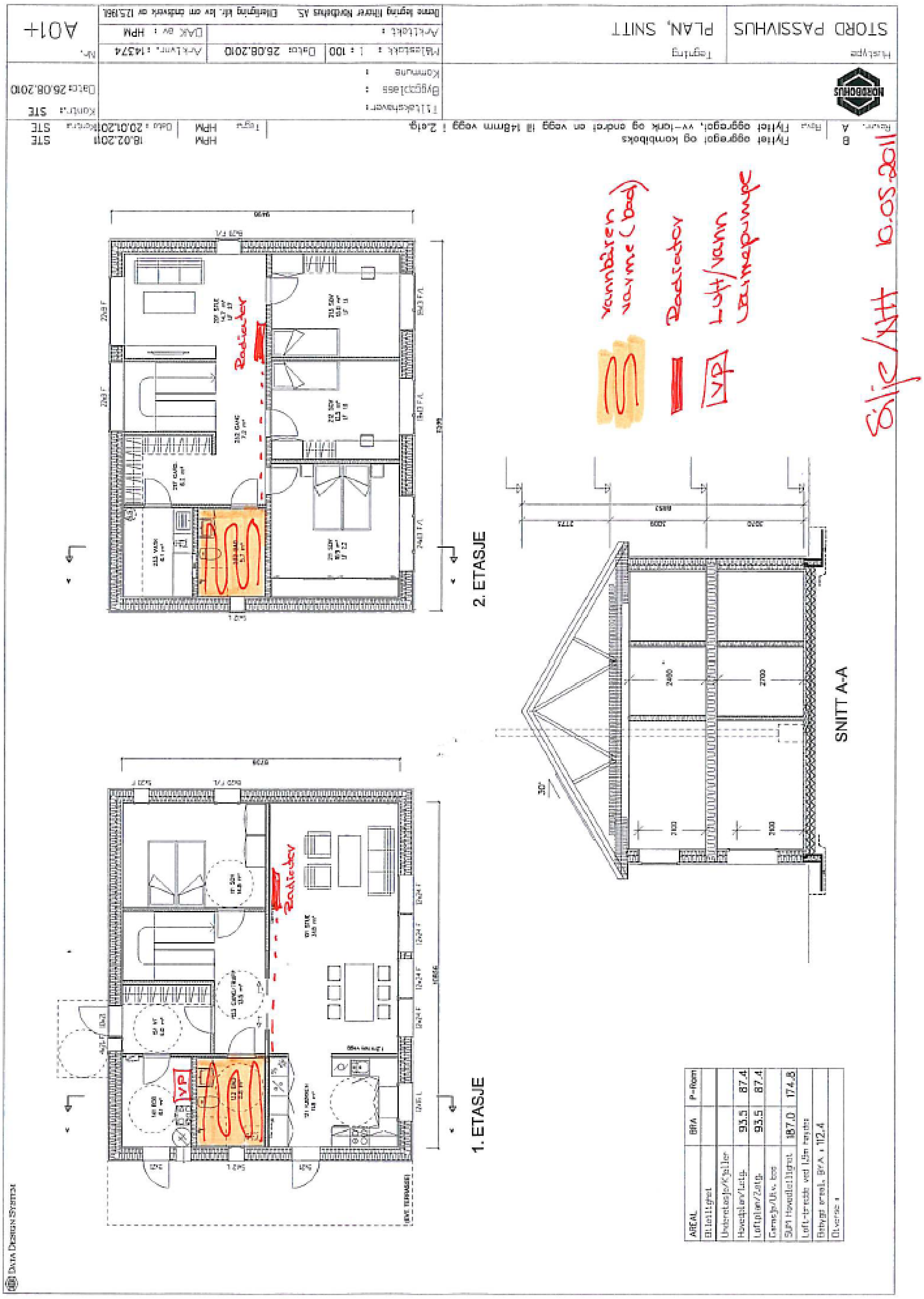
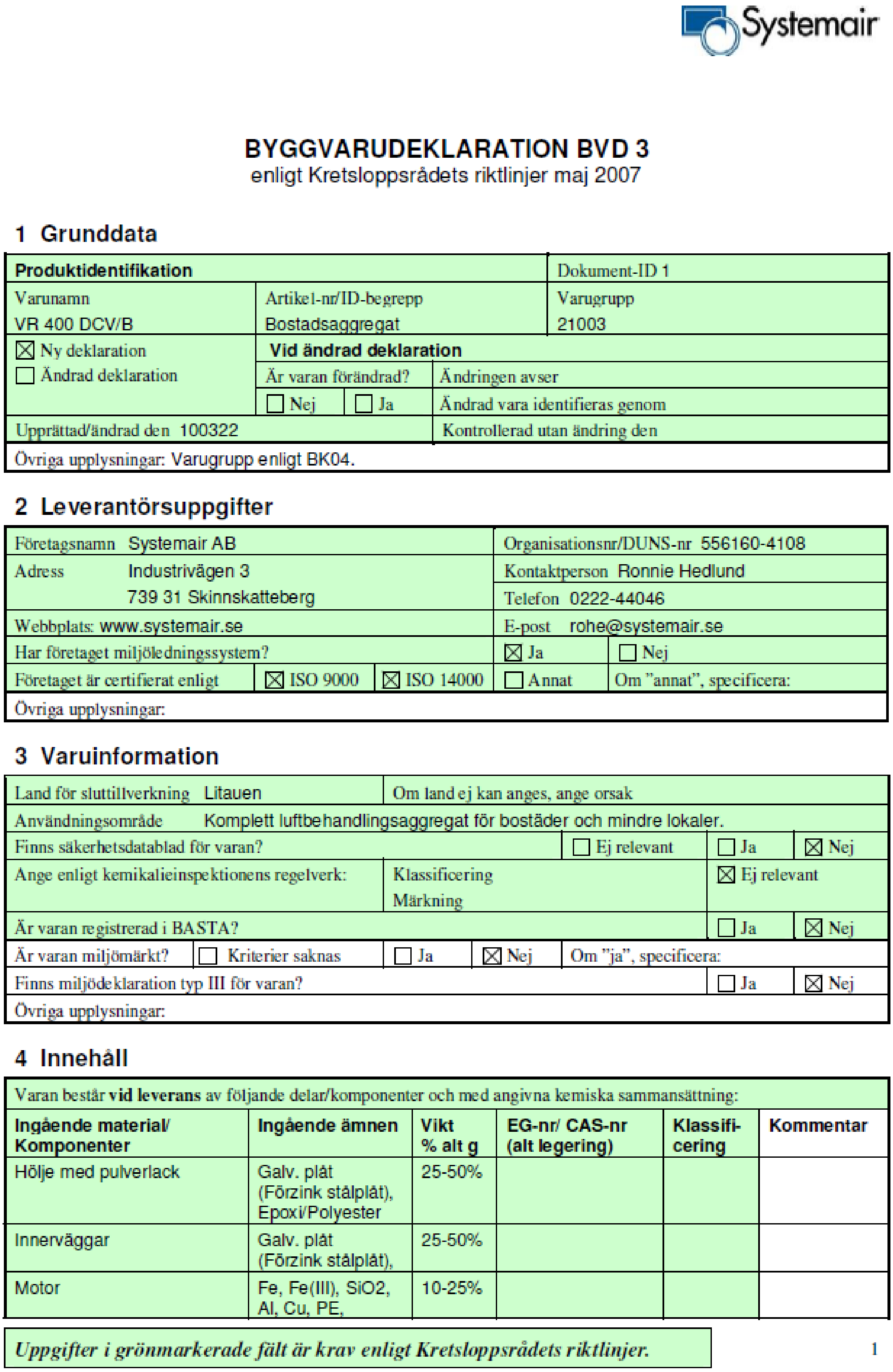
7 Appendix

7.1 Illustration of a possible installation of the distribution system in Stord Passive



7.2 Part of product declaration, Systemair ventilation unit



Systemair

BYGGVARUDEKLARATION BVD 3

enligt Kretsloppsrådets riktlinjer maj 2007

1 Grunddata

Produktidentifikation			Dokument-ID 1
Varunamn VR 400 DCV/B	Artikel-nr/ID-begrepp Bostadsaggregat		Varugrupp 21003
☒ Ny deklaration ☐ Ändrad deklaration	**Vid ändrad deklaration**		
	Är varan förändrad?	Ändringen avser	
	☐ Nej ☐ Ja	Ändrad vara identifieras genom	
Upprättad/ändrad den 100322		Kontrollerad utan ändring den	
Övriga upplysningar: Varugrupp enligt BK04.			

2 Leverantörsuppgifter

Företagsnamn Systemair AB			Organisationsnr/DUNS-nr 556160-4108	
Adress Industrivägen 3 739 31 Skinnskatteberg			Kontaktperson Ronnie Hedlund Telefon 0222-44046	
Webbplats: www.systemair.se			E-post rohe@systemair.se	
Har företaget miljöledningssystem?			☒ Ja	☐ Nej
Företaget är certifierat enligt	☒ ISO 9000	☒ ISO 14000	☐ Annat	Om "annat", specificera:
Övriga upplysningar:				

3 Varuinformation

Land för sluttillverkning Litauen	Om land ej kan anges, ange orsak			
Användningsområde Komplett luftbehandlingsaggregat för bostäder och mindre lokaler.				
Finns säkerhetsdatablad för varan?		☐ Ej relevant	☐ Ja	☒ Nej
Ange enligt kemikalieinspektionens regelverk:	Klassificering Märkning		☒ Ej relevant	
Är varan registrerad i BASTA?			☐ Ja	☒ Nej
Är varan miljömärkt? ☐ Kriterier saknas	☐ Ja	☒ Nej	Om "ja", specificera:	
Finns miljödeklaration typ III för varan?			☐ Ja	☒ Nej
Övriga upplysningar:				

4 Innehåll

Varan består **vid leverans** av följande delar/komponenter och med angivna kemiska sammansättning:

Ingående material/ Komponenter	**Ingående ämnen**	**Vikt % alt g**	**EG-nr/ CAS-nr (alt legering)**	**Klassificering**	**Kommentar**
Hölje med pulverlack	Galv. plåt (Förzink stålplåt), Epoxi/Polyester	25-50%			
Innerväggar	Galv. plåt (Förzink stålplåt),	25-50%			
Motor	Fe, Fe(III), SiO2, Al, Cu, PE,	10-25%			

Uppgifter i grönmarkerade fält är krav enligt Kretsloppsrådets riktlinjer.

1

	Glasfiber, Si				
Fläkthjul	PA6.6, Fe, Glasfiber	1-2,5%			
Motorkabel	PVC, Cu	<1%			
Växlarpaket (roterande)	Al	2-10%			
Rotormotor + remhjul	Al, Fe, Cu, PA6.6, PE, Neopren, Al	2-10%			
Element	Rostfritt AISI3161	2-10%			
Inloppsrör	Galv.plåt	1-2,5%			
Isolering (glasull)	Glas, Bakelit, Mineralolja	2-10%			
Isolering mellanvägg och frontlucka	PE	1-2,5%			
Kretskort m. komponenter	Epoxy, Cu, Al, Sn, Fe, C, Ti, Ag, Au, SiO2	<1%			
Styrkort i dörr	Epoxy, Cu, Al, Sn, Fe, C, Ti, Ag, Au, SiO2	<1%			
Sladdställ	PVC, Cu, EPR	<1%			
Kablage	PVC, Cu	<1%			
Filter (Tilluft)	Al, PP, EPDM	<1%			
Filter (Frånluft)	Al, Akryl, EPDM	<1%			
Vibrationsdämpare	NR	<1%			
Termostat	Rostfritt stål, Fe, Keramik	<1%			
Tätningsmassa (Fix All)	Hybridpolymer (MS)	<1%			
Övrigt (skruv, popnit, genomföring, tätningslist, drivrem, borstlist)	Fzb, AL/AC, TPE, EPDM, Polyuretan, PP	1-2,5%			

Övriga upplysningar:

Om varans kemiska sammansättning är annan efter inbyggnad än vid leverans, anges innehållet i den **färdiga inbyggda varan** här. Om innehållet är oförändrat lämnas inga uppgifter i nedanstående tabell.

Ingående material / Komponenter	Ingående ämnen	Vikt % alt g	EG-nr/ CAS-nr (alt legering)	Klassifi-cering	Kommentar

Övriga upplysningar:

5 Produktionsskedet

Resursutnyttjande och miljöpåverkan under produktion av varan redovisas på ett av följande sätt:

☐ 1) Inflöden (råvaror, insatsvaror, energi mm) för den registrerade varan till **tillverkningsenheten**, och utflöden (emissioner och restprodukter) därifrån, d v s från "grind till grind".

☐ 2) Samtliga inflöden och utflöden från utvinning av råvaror till färdig produkt d v s "vagga till grind".

☐ 3) Annan avgränsning. Ange vad:

Redovisningen avser enhet av varan	☐ Redovisad vara	☐ Varans varugrupp	☐ Varans tillverkningsenhet

Ange **råvaror och insatsvaror** som använts vid tillverkning av varan		☐ Ej relevant
Råvara/insatsvara	Mängd och enhet	Kommentar

7.3 Calculations of formula 1.1

Formula:

$E_{part,\ el} + E_{part,\ oil} + E_{part,\ gas} < Et - 0.5 *Qw,nd$

7.3.1 Stord Passive S1: Electrical panel heaters and a woodstove (all numbers in kWh)

Et	*0.5 *Qw,nd*	*Et – 0.5 *Qw,nd*	*Epart, el*
15251	2786	12465	14202,6

7.3.2 Stord Passive S2: Solar collector system (all numbers in kWh/yr).

Et	*0.5 *Qw,nd*	*Et – 0.5 *Qw,nd*	*Epart, el*
15251	2786	12465	12458,1

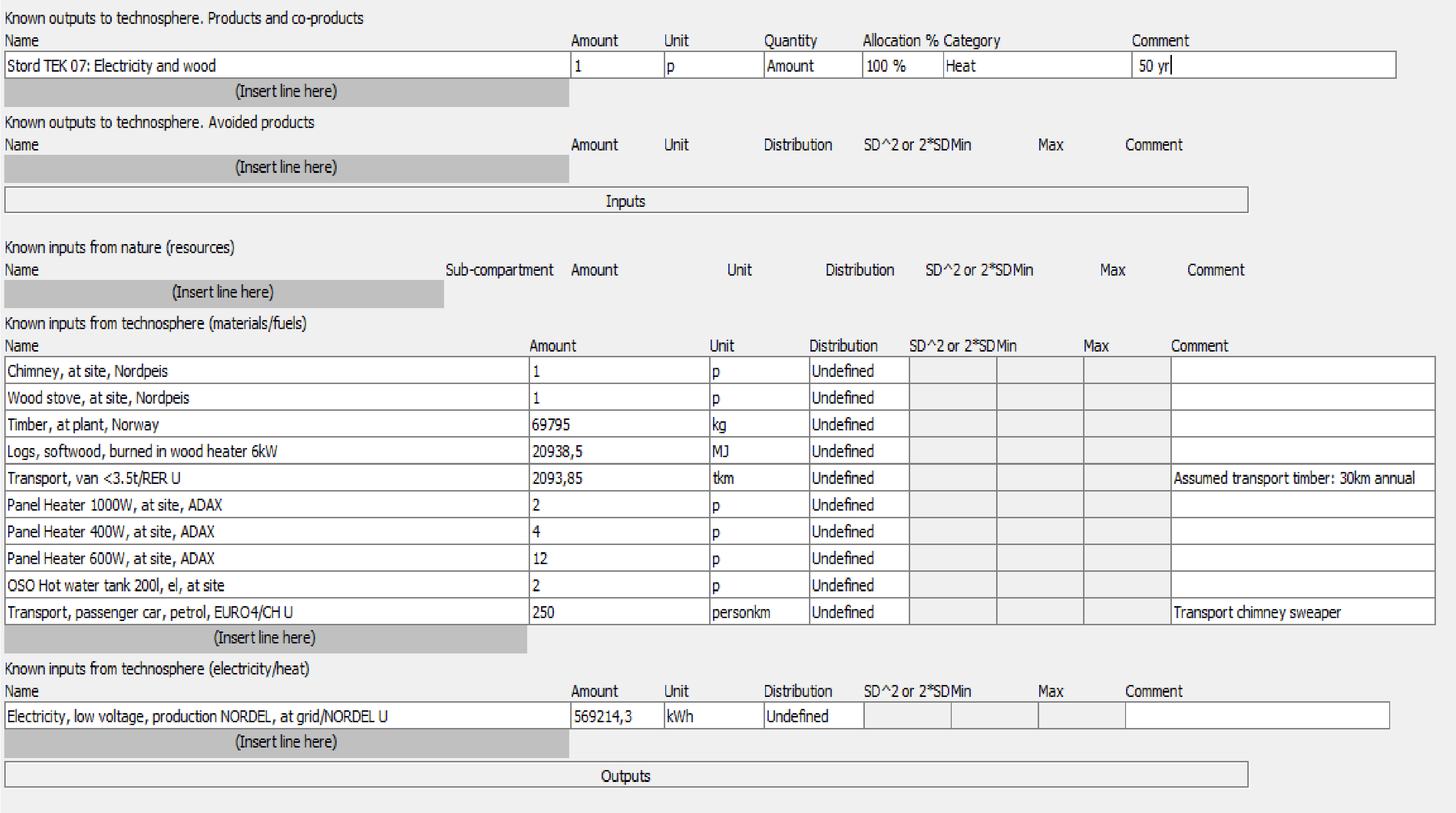
7.3.3 Stord Passive S3: Air -to- water heat pump system (all numbers in kWh/yr).

Et	*0.5 *Qw,nd*	*Et – 0.5 *Qw,nd*	*Epart, el*
15251	2786	12465	11878,30

7.4 Inventory

7.4.1 Stord TEK 07 and Stord Passive S1: Electricity and wood

7.4.1.1 Total system, Stord TEK 07



Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Category	Comment
Stord TEK 07: Electricity and wood	1	p	Amount	100 %	Heat	50 yr
(Insert line here)						

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Known inputs from technosphere (materials/fuels)

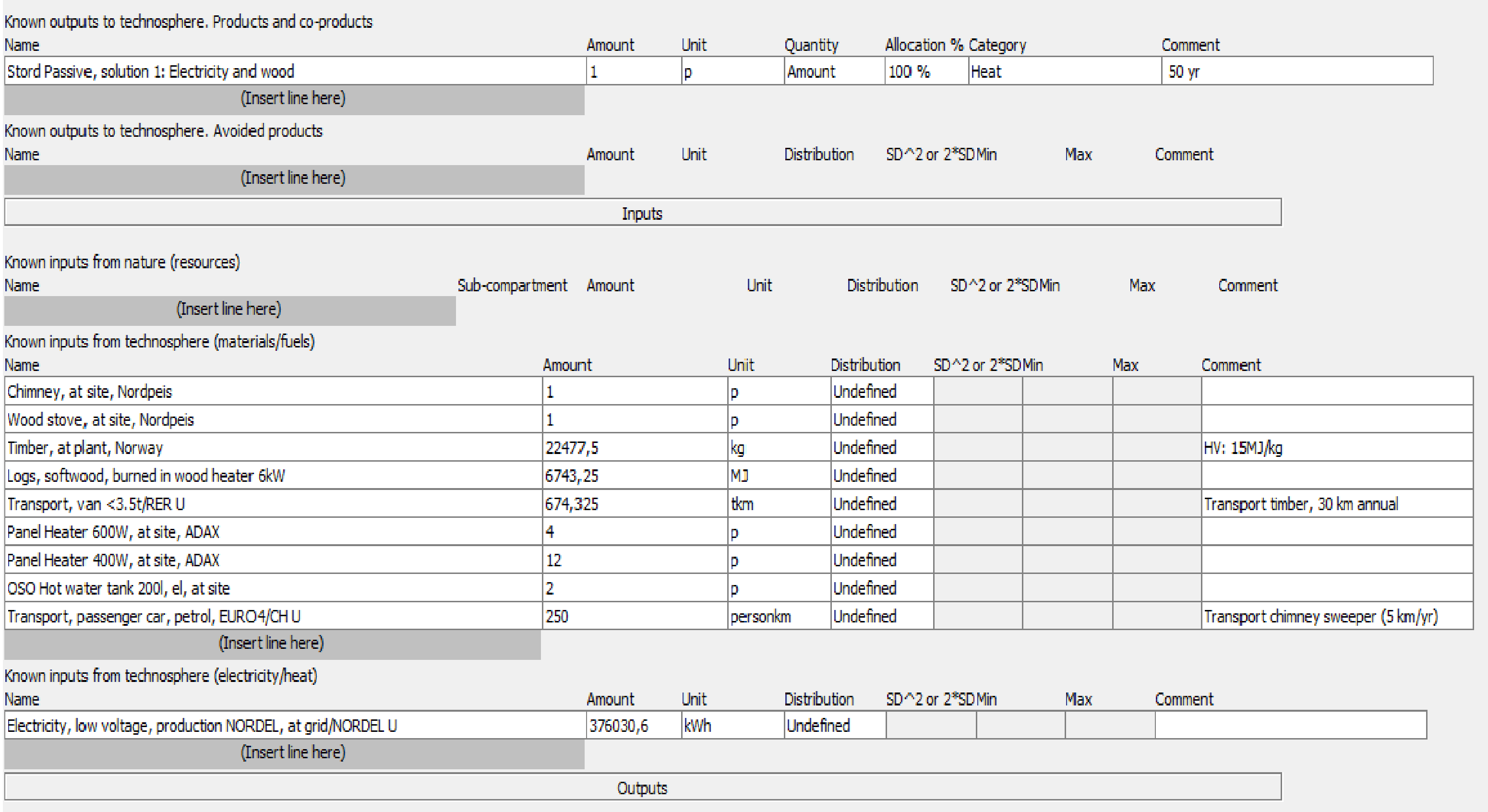
Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Chimney, at site, Nordpeis	1	p	Undefined				
Wood stove, at site, Nordpeis	1	p	Undefined				
Timber, at plant, Norway	69795	kg	Undefined				
Logs, softwood, burned in wood heater 6kW	20938,5	MJ	Undefined				
Transport, van <3.5t/RER U	2093,85	tkm	Undefined				Assumed transport timber: 30km annual
Panel Heater 1000W, at site, ADAX	2	p	Undefined				
Panel Heater 400W, at site, ADAX	4	p	Undefined				
Panel Heater 600W, at site, ADAX	12	p	Undefined				
OSO Hot water tank 200l, el, at site	2	p	Undefined				
Transport, passenger car, petrol, EURO4/CH U	250	personkm	Undefined				Transport chimney sweaper
(Insert line here)							

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Electricity, low voltage, production NORDEL, at grid/NORDEL U	569214,3	kWh	Undefined				
(Insert line here)							

Outputs

7.4.1.2 Total system, Stord Passive S1



Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Category	Comment
Stord Passive, solution 1: Electricity and wood	1	p	Amount	100 %	Heat	50 yr
(Insert line here)						

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Known inputs from technosphere (materials/fuels)

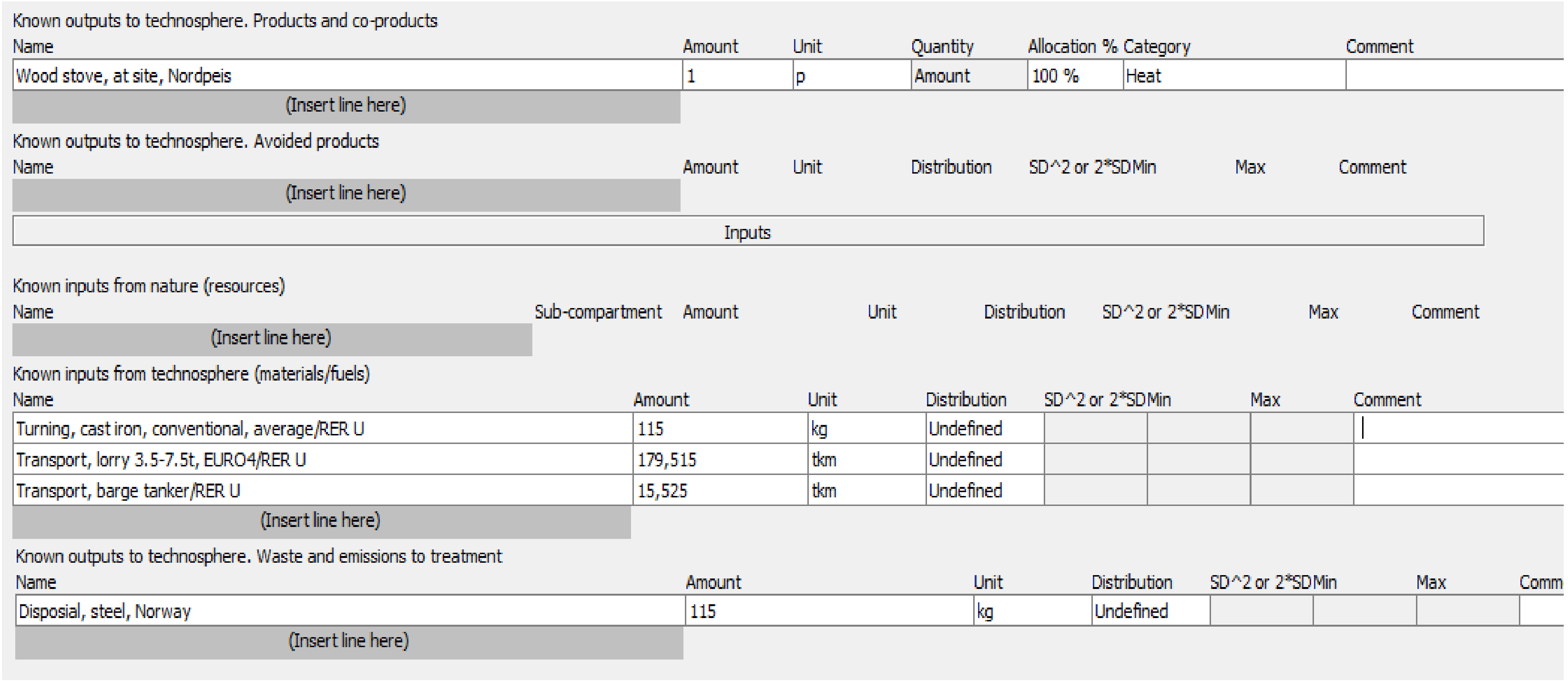
Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Chimney, at site, Nordpeis	1	p	Undefined				
Wood stove, at site, Nordpeis	1	p	Undefined				
Timber, at plant, Norway	22477,5	kg	Undefined				HV: 15MJ/kg
Logs, softwood, burned in wood heater 6kW	6743,25	MJ	Undefined				
Transport, van <3.5t/RER U	674,325	tkm	Undefined				Transport timber, 30 km annual
Panel Heater 600W, at site, ADAX	4	p	Undefined				
Panel Heater 400W, at site, ADAX	12	p	Undefined				
OSO Hot water tank 200l, el, at site	2	p	Undefined				
Transport, passenger car, petrol, EURO4/CH U	250	personkm	Undefined				Transport chimney sweeper (5 km/yr)
(Insert line here)							

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Electricity, low voltage, production NORDEL, at grid/NORDEL U	376030,6	kWh	Undefined				
(Insert line here)							

Outputs

7.4.1.3 Wood stove



Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Category	Comment
Wood stove, at site, Nordpeis	1	p	Amount	100 %	Heat	
(Insert line here)						

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

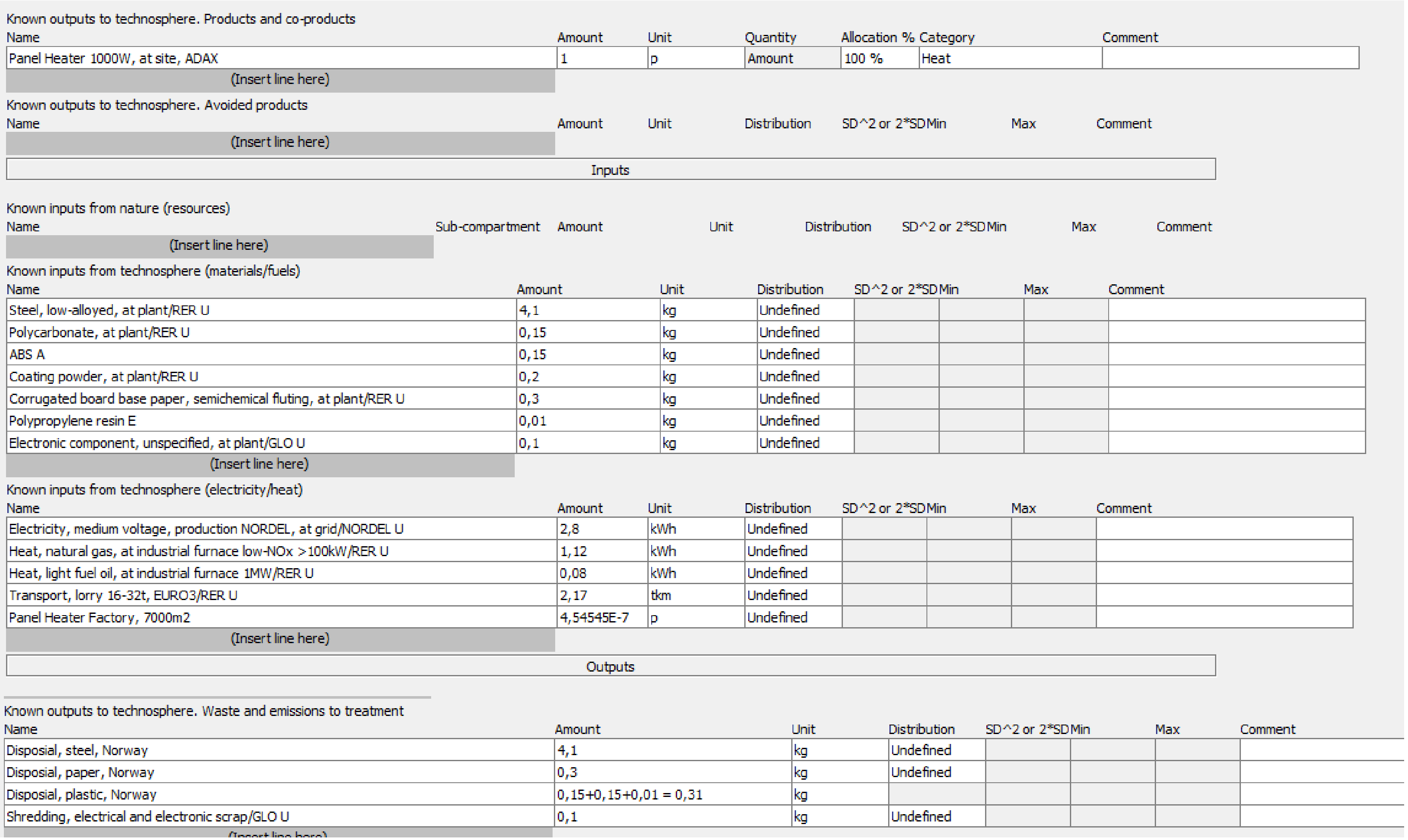
Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Turning, cast iron, conventional, average/RER U	115	kg	Undefined				
Transport, lorry 3.5-7.5t, EURO4/RER U	179,515	tkm	Undefined				
Transport, barge tanker/RER U	15,525	tkm	Undefined				
(Insert line here)							

Known outputs to technosphere. Waste and emissions to treatment

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comm
Disposial, steel, Norway	115	kg	Undefined				
(Insert line here)							

7.4.1.4 Panel heater, 1000W



Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Category	Comment
Panel Heater 1000W, at site, ADAX	1	p	Amount	100 %	Heat	
(Insert line here)						

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Steel, low-alloyed, at plant/RER U	4,1	kg	Undefined				
Polycarbonate, at plant/RER U	0,15	kg	Undefined				
ABS A	0,15	kg	Undefined				
Coating powder, at plant/RER U	0,2	kg	Undefined				
Corrugated board base paper, semichemical fluting, at plant/RER U	0,3	kg	Undefined				
Polypropylene resin E	0,01	kg	Undefined				
Electronic component, unspecified, at plant/GLO U	0,1	kg	Undefined				
(Insert line here)							

Known inputs from technosphere (electricity/heat)

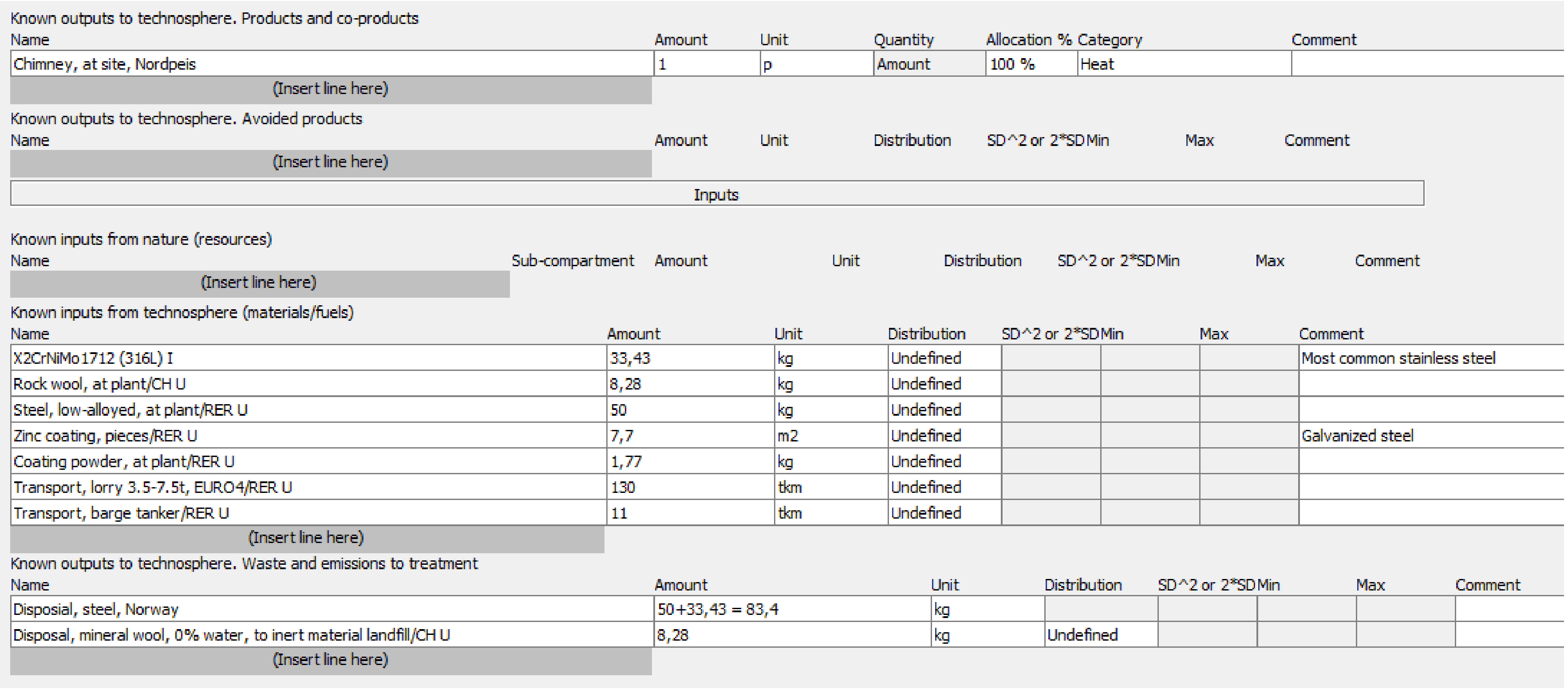
Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Electricity, medium voltage, production NORDEL, at grid/NORDEL U	2,8	kWh	Undefined				
Heat, natural gas, at industrial furnace low-NOx >100kW/RER U	1,12	kWh	Undefined				
Heat, light fuel oil, at industrial furnace 1MW/RER U	0,08	kWh	Undefined				
Transport, lorry 16-32t, EURO3/RER U	2,17	tkm	Undefined				
Panel Heater Factory, 7000m2	4,54545E-7	p	Undefined				
(Insert line here)							

Outputs

Known outputs to technosphere. Waste and emissions to treatment

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Disposal, steel, Norway	4,1	kg	Undefined				
Disposal, paper, Norway	0,3	kg	Undefined				
Disposal, plastic, Norway	0,15+0,15+0,01 = 0,31	kg					
Shredding, electrical and electronic scrap/GLO U	0,1	kg	Undefined				
(Insert line here)							

7.4.1.5 Chimney



Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Category	Comment
Chimney, at site, Nordpeis	1	p	Amount	100 %	Heat	
(Insert line here)						

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

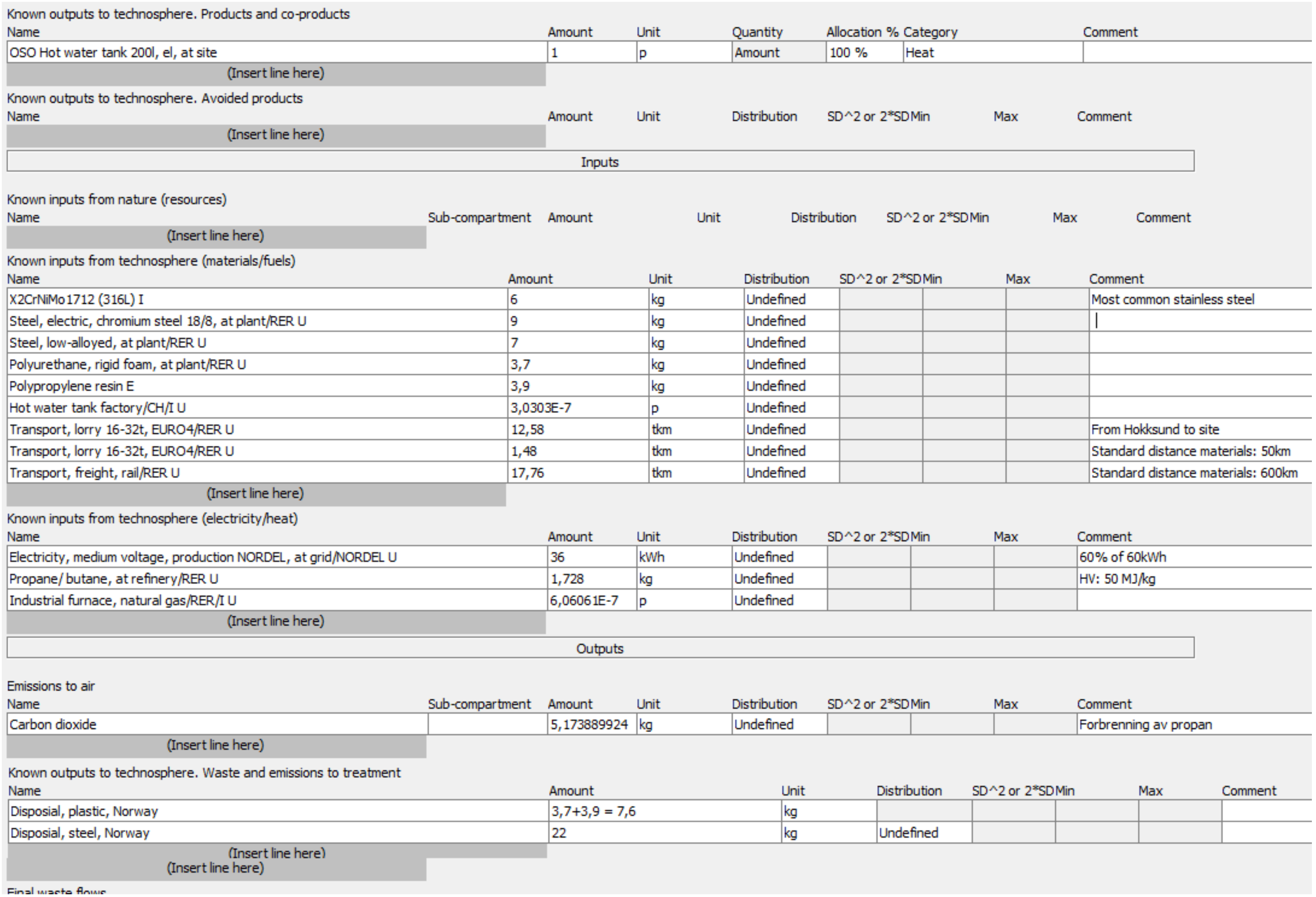
Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
X2CrNiMo1712 (316L) I	33,43	kg	Undefined				Most common stainless steel
Rock wool, at plant/CH U	8,28	kg	Undefined				
Steel, low-alloyed, at plant/RER U	50	kg	Undefined				
Zinc coating, pieces/RER U	7,7	m2	Undefined				Galvanized steel
Coating powder, at plant/RER U	1,77	kg	Undefined				
Transport, lorry 3.5-7.5t, EURO4/RER U	130	tkm	Undefined				
Transport, barge tanker/RER U	11	tkm	Undefined				
(Insert line here)							

Known outputs to technosphere. Waste and emissions to treatment

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Disposial, steel, Norway	50+33,43 = 83,4	kg					
Disposal, mineral wool, 0% water, to inert material landfill/CH U	8,28	kg	Undefined				
(Insert line here)							

7.4.1.6 Hot water tank, electric



Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Category	Comment
OSO Hot water tank 200l, el, at site	1	p	Amount	100 %	Heat	
(Insert line here)						

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
X2CrNiMo1712 (316L) I	6	kg	Undefined				Most common stainless steel
Steel, electric, chromium steel 18/8, at plant/RER U	9	kg	Undefined				|
Steel, low-alloyed, at plant/RER U	7	kg	Undefined				
Polyurethane, rigid foam, at plant/RER U	3,7	kg	Undefined				
Polypropylene resin E	3,9	kg	Undefined				
Hot water tank factory/CH/I U	3,0303E-7	p	Undefined				
Transport, lorry 16-32t, EURO4/RER U	12,58	tkm	Undefined				From Hokksund to site
Transport, lorry 16-32t, EURO4/RER U	1,48	tkm	Undefined				Standard distance materials: 50km
Transport, freight, rail/RER U	17,76	tkm	Undefined				Standard distance materials: 600km
(Insert line here)							

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Electricity, medium voltage, production NORDEL, at grid/NORDEL U	36	kWh	Undefined				60% of 60kWh
Propane/ butane, at refinery/RER U	1,728	kg	Undefined				HV: 50 MJ/kg
Industrial furnace, natural gas/RER/I U	6,06061E-7	p	Undefined				
(Insert line here)							

Outputs

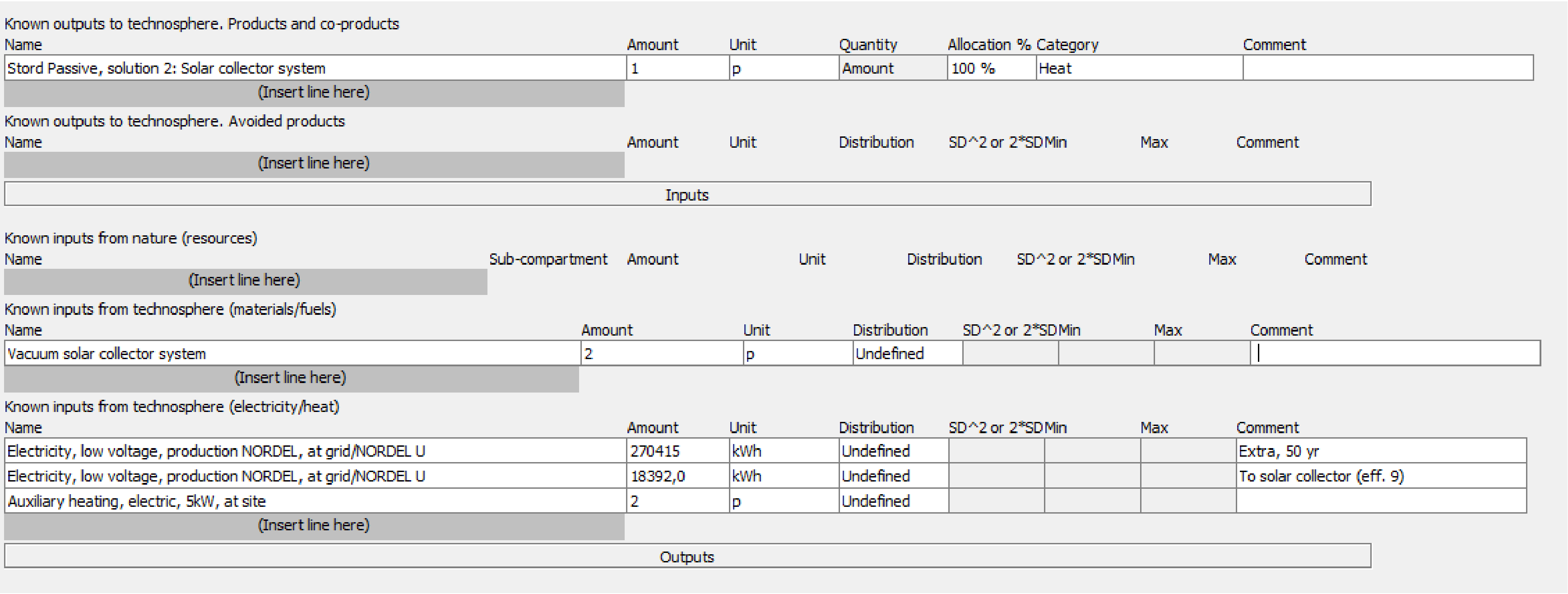
Emissions to air

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Carbon dioxide		5,173889924	kg	Undefined				Forbrenning av propan
(Insert line here)								

Known outputs to technosphere. Waste and emissions to treatment

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Disposial, plastic, Norway	3,7+3,9 = 7,6	kg					
Disposial, steel, Norway	22	kg	Undefined				
(Insert line here)							
(Insert line here)							

7.4.2 Stord Passive S2: Solar collector system



Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Category	Comment
Stord Passive, solution 2: Solar collector system	1	p	Amount	100 %	Heat	
(Insert line here)						

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Known inputs from technosphere (materials/fuels)

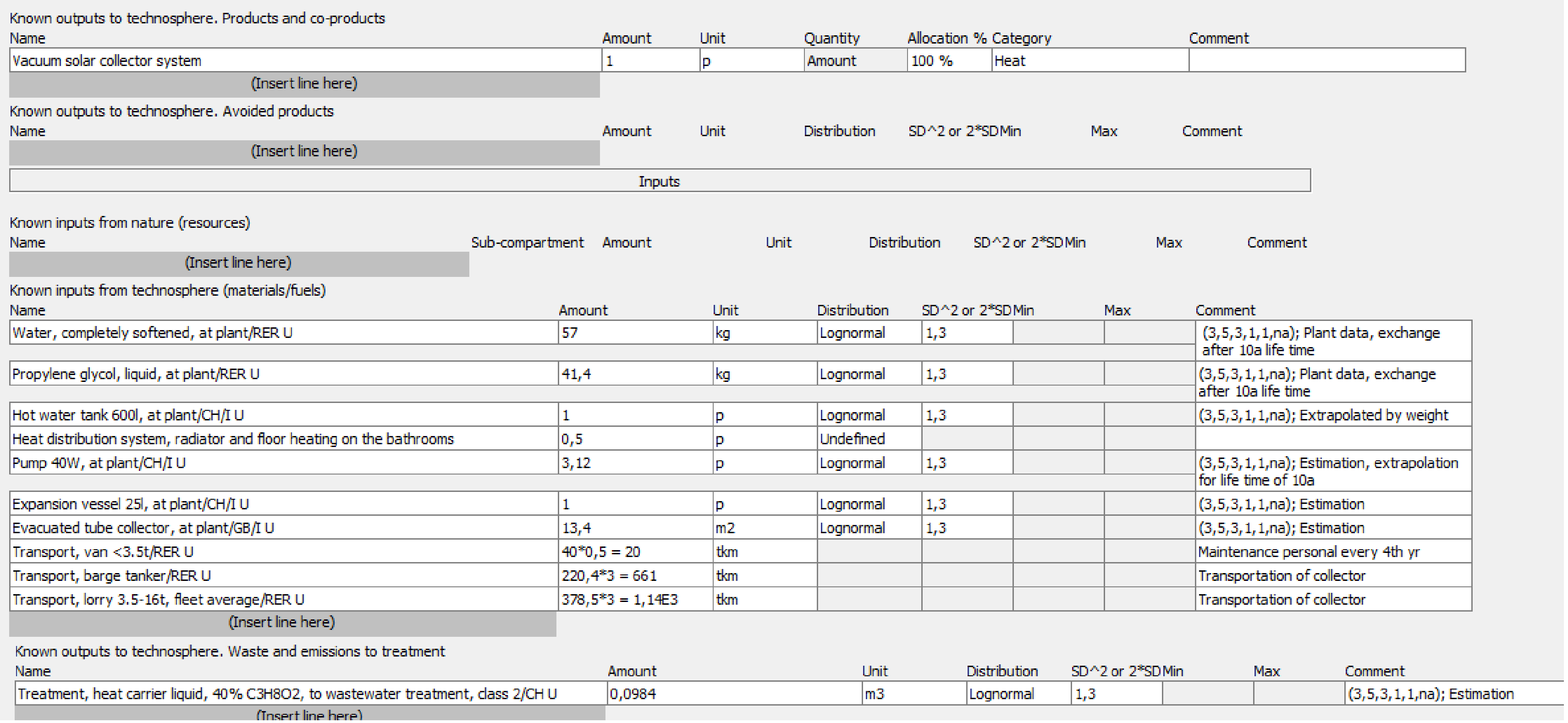
Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Vacuum solar collector system	2	p	Undefined				
(Insert line here)							

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Electricity, low voltage, production NORDEL, at grid/NORDEL U	270415	kWh	Undefined				Extra, 50 yr
Electricity, low voltage, production NORDEL, at grid/NORDEL U	18392,0	kWh	Undefined				To solar collector (eff. 9)
Auxiliary heating, electric, 5kW, at site	2	p	Undefined				
(Insert line here)							

Outputs

7.4.2.1 Vacuum solar collector system



Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Category	Comment
Vacuum solar collector system	1	p	Amount	100 %	Heat	
(Insert line here)						

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SDMin	Max	Comment
(Insert line here)						

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SDMin	Max	Comment
(Insert line here)							

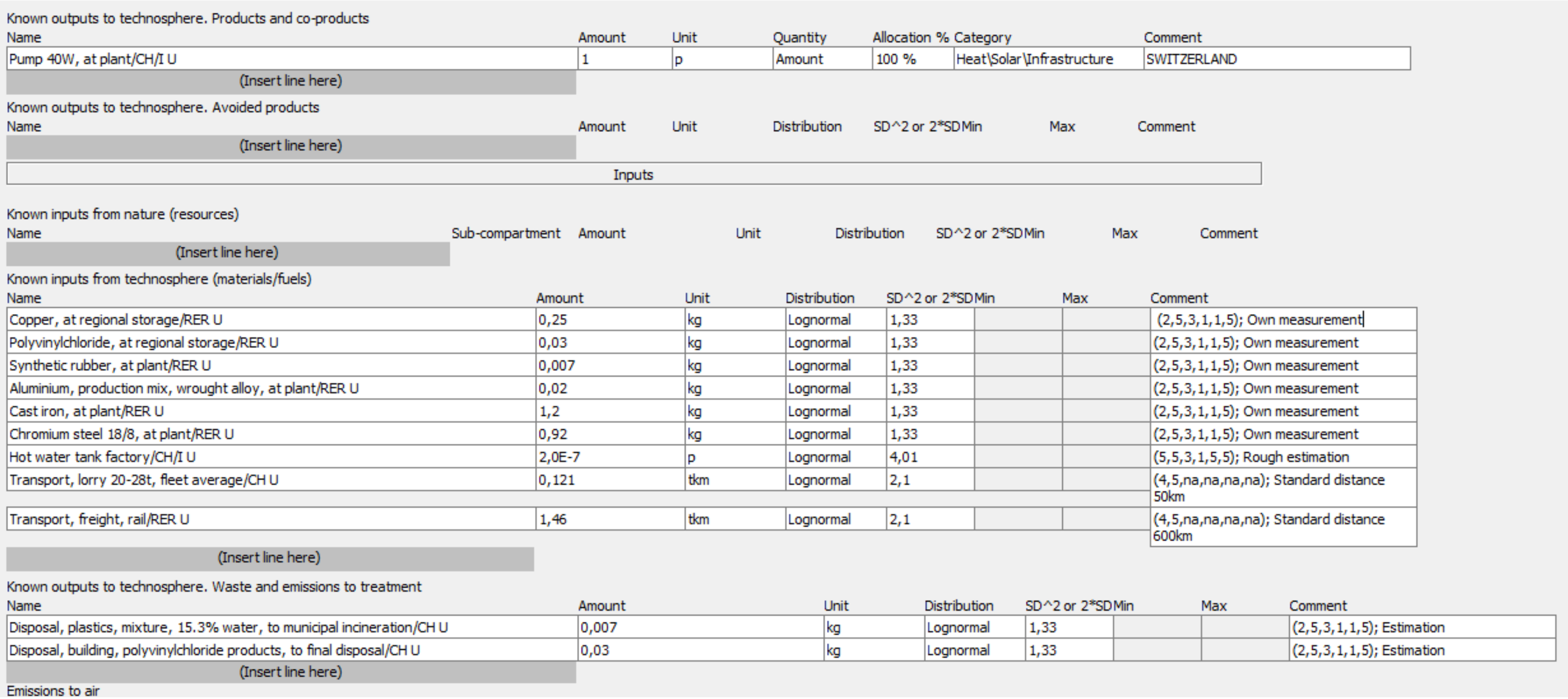
Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SDMin	Min	Max	Comment
Water, completely softened, at plant/RER U	57	kg	Lognormal	1,3			(3,5,3,1,1,na); Plant data, exchange after 10a life time
Propylene glycol, liquid, at plant/RER U	41,4	kg	Lognormal	1,3			(3,5,3,1,1,na); Plant data, exchange after 10a life time
Hot water tank 600l, at plant/CH/I U	1	p	Lognormal	1,3			(3,5,3,1,1,na); Extrapolated by weight
Heat distribution system, radiator and floor heating on the bathrooms	0,5	p	Undefined				
Pump 40W, at plant/CH/I U	3,12	p	Lognormal	1,3			(3,5,3,1,1,na); Estimation, extrapolation for life time of 10a
Expansion vessel 25l, at plant/CH/I U	1	p	Lognormal	1,3			(3,5,3,1,1,na); Estimation
Evacuated tube collector, at plant/GB/I U	13,4	m2	Lognormal	1,3			(3,5,3,1,1,na); Estimation
Transport, van <3.5t/RER U	40*0,5 = 20	tkm					Maintenance personal every 4th yr
Transport, barge tanker/RER U	220,4*3 = 661	tkm					Transportation of collector
Transport, lorry 3.5-16t, fleet average/RER U	378,5*3 = 1,14E3	tkm					Transportation of collector
(Insert line here)							

Known outputs to technosphere. Waste and emissions to treatment

Name	Amount	Unit	Distribution	SD^2 or 2*SDMin	Min	Max	Comment
Treatment, heat carrier liquid, 40% C3H8O2, to wastewater treatment, class 2/CH U	0,0984	m3	Lognormal	1,3			(3,5,3,1,1,na); Estimation
(Insert line here)							

7.4.2.2 Pump 40W



Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Category	Comment
Pump 40W, at plant/CH/I U	1	p	Amount	100 %	Heat\Solar\Infrastructure	SWITZERLAND
(Insert line here)						

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Copper, at regional storage/RER U	0,25	kg	Lognormal	1,33			(2,5,3,1,1,5); Own measurement
Polyvinylchloride, at regional storage/RER U	0,03	kg	Lognormal	1,33			(2,5,3,1,1,5); Own measurement
Synthetic rubber, at plant/RER U	0,007	kg	Lognormal	1,33			(2,5,3,1,1,5); Own measurement
Aluminium, production mix, wrought alloy, at plant/RER U	0,02	kg	Lognormal	1,33			(2,5,3,1,1,5); Own measurement
Cast iron, at plant/RER U	1,2	kg	Lognormal	1,33			(2,5,3,1,1,5); Own measurement
Chromium steel 18/8, at plant/RER U	0,92	kg	Lognormal	1,33			(2,5,3,1,1,5); Own measurement
Hot water tank factory/CH/I U	2,0E-7	p	Lognormal	4,01			(5,5,3,1,5,5); Rough estimation
Transport, lorry 20-28t, fleet average/CH U	0,121	tkm	Lognormal	2,1			(4,5,na,na,na,na); Standard distance 50km
Transport, freight, rail/RER U	1,46	tkm	Lognormal	2,1			(4,5,na,na,na,na); Standard distance 600km
(Insert line here)							

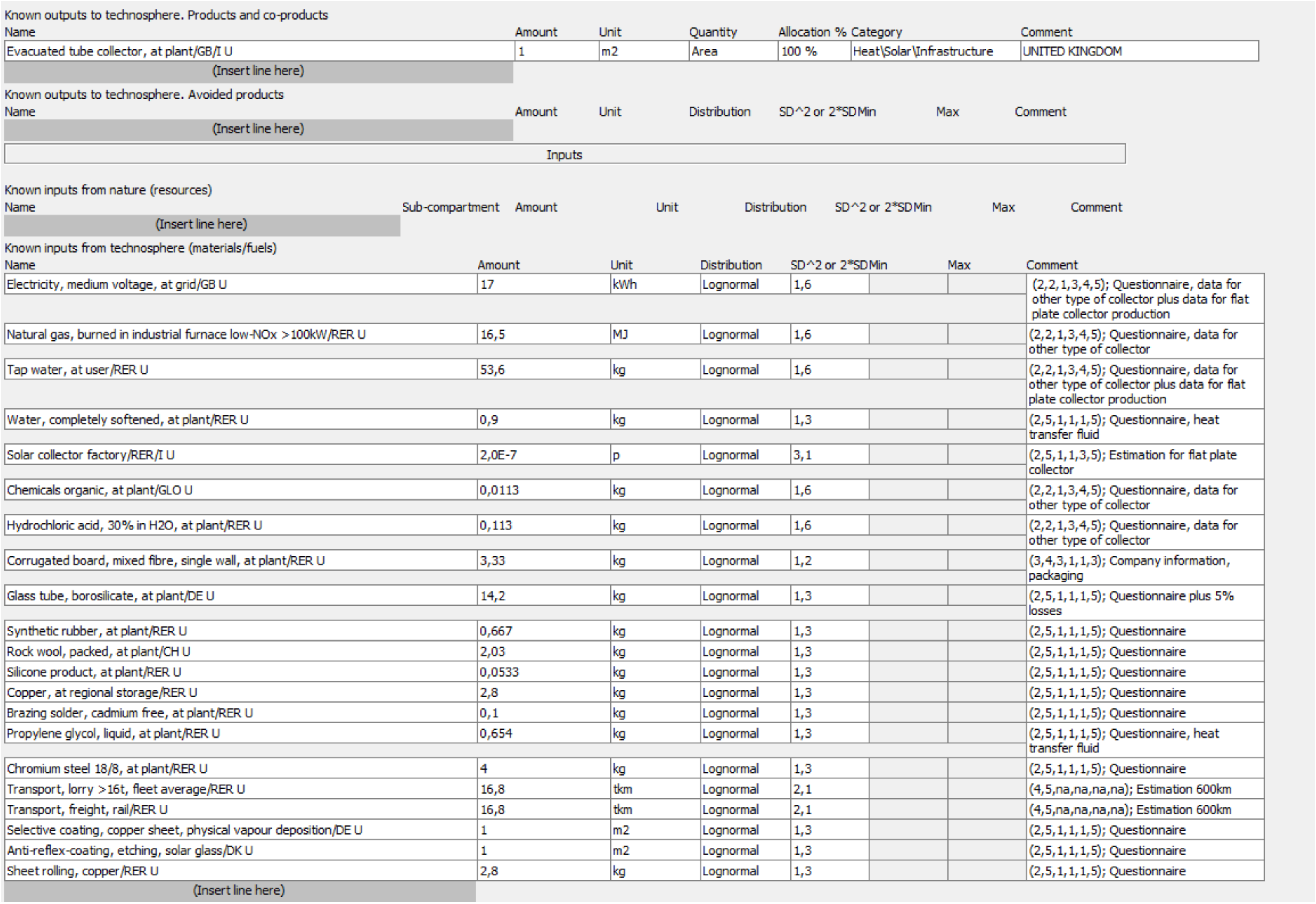
Known outputs to technosphere. Waste and emissions to treatment

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Disposal, plastics, mixture, 15.3% water, to municipal incineration/CH U	0,007	kg	Lognormal	1,33			(2,5,3,1,1,5); Estimation
Disposal, building, polyvinylchloride products, to final disposal/CH U	0,03	kg	Lognormal	1,33			(2,5,3,1,1,5); Estimation
(Insert line here)							

Emissions to air

7.4.2.3 Evacuated cube collector

Input



Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Category	Comment
Evacuated tube collector, at plant/GB/I U	1	m2	Area	100 %	Heat\Solar\Infrastructure	UNITED KINGDOM
(Insert line here)						

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

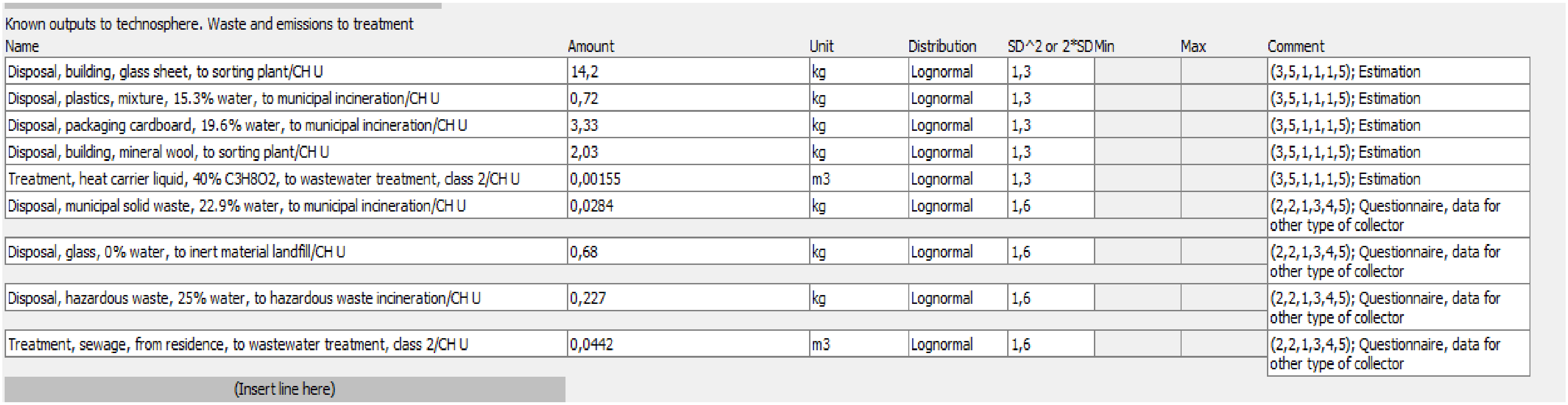
Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Electricity, medium voltage, at grid/GB U	17	kWh	Lognormal	1,6			(2,2,1,3,4,5); Questionnaire, data for other type of collector plus data for flat plate collector production
Natural gas, burned in industrial furnace low-NOx >100kW/RER U	16,5	MJ	Lognormal	1,6			(2,2,1,3,4,5); Questionnaire, data for other type of collector
Tap water, at user/RER U	53,6	kg	Lognormal	1,6			(2,2,1,3,4,5); Questionnaire, data for other type of collector plus data for flat plate collector production
Water, completely softened, at plant/RER U	0,9	kg	Lognormal	1,3			(2,5,1,1,1,5); Questionnaire, heat transfer fluid
Solar collector factory/RER/I U	2,0E-7	p	Lognormal	3,1			(2,5,1,1,3,5); Estimation for flat plate collector
Chemicals organic, at plant/GLO U	0,0113	kg	Lognormal	1,6			(2,2,1,3,4,5); Questionnaire, data for other type of collector
Hydrochloric acid, 30% in H2O, at plant/RER U	0,113	kg	Lognormal	1,6			(2,2,1,3,4,5); Questionnaire, data for other type of collector
Corrugated board, mixed fibre, single wall, at plant/RER U	3,33	kg	Lognormal	1,2			(3,4,3,1,1,3); Company information, packaging
Glass tube, borosilicate, at plant/DE U	14,2	kg	Lognormal	1,3			(2,5,1,1,1,5); Questionnaire plus 5% losses
Synthetic rubber, at plant/RER U	0,667	kg	Lognormal	1,3			(2,5,1,1,1,5); Questionnaire
Rock wool, packed, at plant/CH U	2,03	kg	Lognormal	1,3			(2,5,1,1,1,5); Questionnaire
Silicone product, at plant/RER U	0,0533	kg	Lognormal	1,3			(2,5,1,1,1,5); Questionnaire
Copper, at regional storage/RER U	2,8	kg	Lognormal	1,3			(2,5,1,1,1,5); Questionnaire
Brazing solder, cadmium free, at plant/RER U	0,1	kg	Lognormal	1,3			(2,5,1,1,1,5); Questionnaire
Propylene glycol, liquid, at plant/RER U	0,654	kg	Lognormal	1,3			(2,5,1,1,1,5); Questionnaire, heat transfer fluid
Chromium steel 18/8, at plant/RER U	4	kg	Lognormal	1,3			(2,5,1,1,1,5); Questionnaire
Transport, lorry >16t, fleet average/RER U	16,8	tkm	Lognormal	2,1			(4,5,na,na,na,na); Estimation 600km
Transport, freight, rail/RER U	16,8	tkm	Lognormal	2,1			(4,5,na,na,na,na); Estimation 600km
Selective coating, copper sheet, physical vapour deposition/DE U	1	m2	Lognormal	1,3			(2,5,1,1,1,5); Questionnaire
Anti-reflex-coating, etching, solar glass/DK U	1	m2	Lognormal	1,3			(2,5,1,1,1,5); Questionnaire
Sheet rolling, copper/RER U	2,8	kg	Lognormal	1,3			(2,5,1,1,1,5); Questionnaire
(Insert line here)							

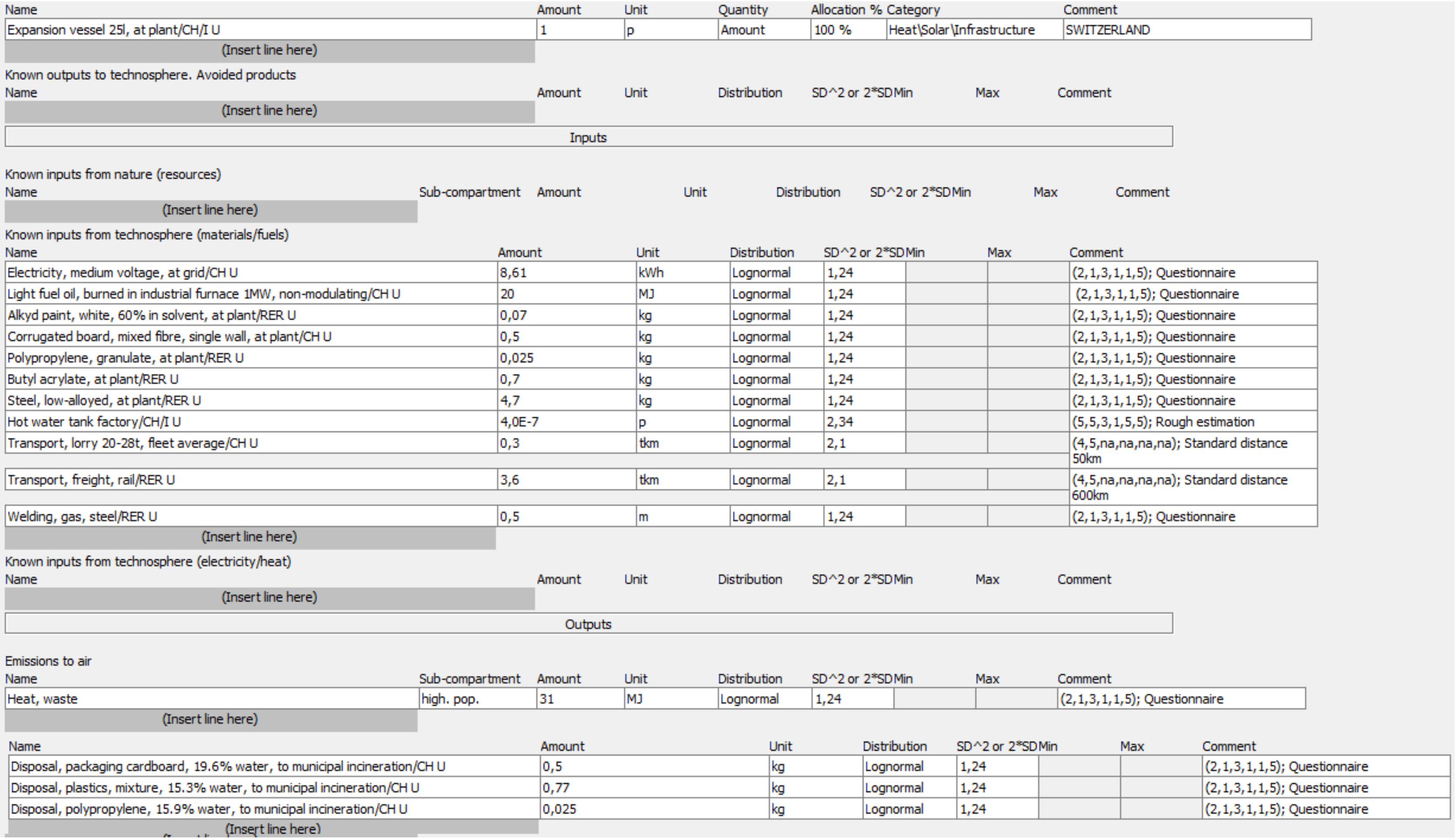
Disposial



Known outputs to technosphere. Waste and emissions to treatment

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Disposal, building, glass sheet, to sorting plant/CH U	14,2	kg	Lognormal	1,3			(3,5,1,1,1,5); Estimation
Disposal, plastics, mixture, 15.3% water, to municipal incineration/CH U	0,72	kg	Lognormal	1,3			(3,5,1,1,1,5); Estimation
Disposal, packaging cardboard, 19.6% water, to municipal incineration/CH U	3,33	kg	Lognormal	1,3			(3,5,1,1,1,5); Estimation
Disposal, building, mineral wool, to sorting plant/CH U	2,03	kg	Lognormal	1,3			(3,5,1,1,1,5); Estimation
Treatment, heat carrier liquid, 40% C3H8O2, to wastewater treatment, class 2/CH U	0,00155	m3	Lognormal	1,3			(3,5,1,1,1,5); Estimation
Disposal, municipal solid waste, 22.9% water, to municipal incineration/CH U	0,0284	kg	Lognormal	1,6			(2,2,1,3,4,5); Questionnaire, data for other type of collector
Disposal, glass, 0% water, to inert material landfill/CH U	0,68	kg	Lognormal	1,6			(2,2,1,3,4,5); Questionnaire, data for other type of collector
Disposal, hazardous waste, 25% water, to hazardous waste incineration/CH U	0,227	kg	Lognormal	1,6			(2,2,1,3,4,5); Questionnaire, data for other type of collector
Treatment, sewage, from residence, to wastewater treatment, class 2/CH U	0,0442	m3	Lognormal	1,6			(2,2,1,3,4,5); Questionnaire, data for other type of collector

7.4.2.4 Expansion vessel



Name	Amount	Unit	Quantity	Allocation %	Category	Comment
Expansion vessel 25l, at plant/CH/I U	1	p	Amount	100 %	Heat\Solar\Infrastructure	SWITZERLAND
(Insert line here)						

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Electricity, medium voltage, at grid/CH U	8,61	kWh	Lognormal	1,24			(2,1,3,1,1,5); Questionnaire
Light fuel oil, burned in industrial furnace 1MW, non-modulating/CH U	20	MJ	Lognormal	1,24			(2,1,3,1,1,5); Questionnaire
Alkyd paint, white, 60% in solvent, at plant/RER U	0,07	kg	Lognormal	1,24			(2,1,3,1,1,5); Questionnaire
Corrugated board, mixed fibre, single wall, at plant/CH U	0,5	kg	Lognormal	1,24			(2,1,3,1,1,5); Questionnaire
Polypropylene, granulate, at plant/RER U	0,025	kg	Lognormal	1,24			(2,1,3,1,1,5); Questionnaire
Butyl acrylate, at plant/RER U	0,7	kg	Lognormal	1,24			(2,1,3,1,1,5); Questionnaire
Steel, low-alloyed, at plant/RER U	4,7	kg	Lognormal	1,24			(2,1,3,1,1,5); Questionnaire
Hot water tank factory/CH/I U	4,0E-7	p	Lognormal	2,34			(5,5,3,1,5,5); Rough estimation
Transport, lorry 20-28t, fleet average/CH U	0,3	tkm	Lognormal	2,1			(4,5,na,na,na,na); Standard distance 50km
Transport, freight, rail/RER U	3,6	tkm	Lognormal	2,1			(4,5,na,na,na,na); Standard distance 600km
Welding, gas, steel/RER U	0,5	m	Lognormal	1,24			(2,1,3,1,1,5); Questionnaire
(Insert line here)							

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

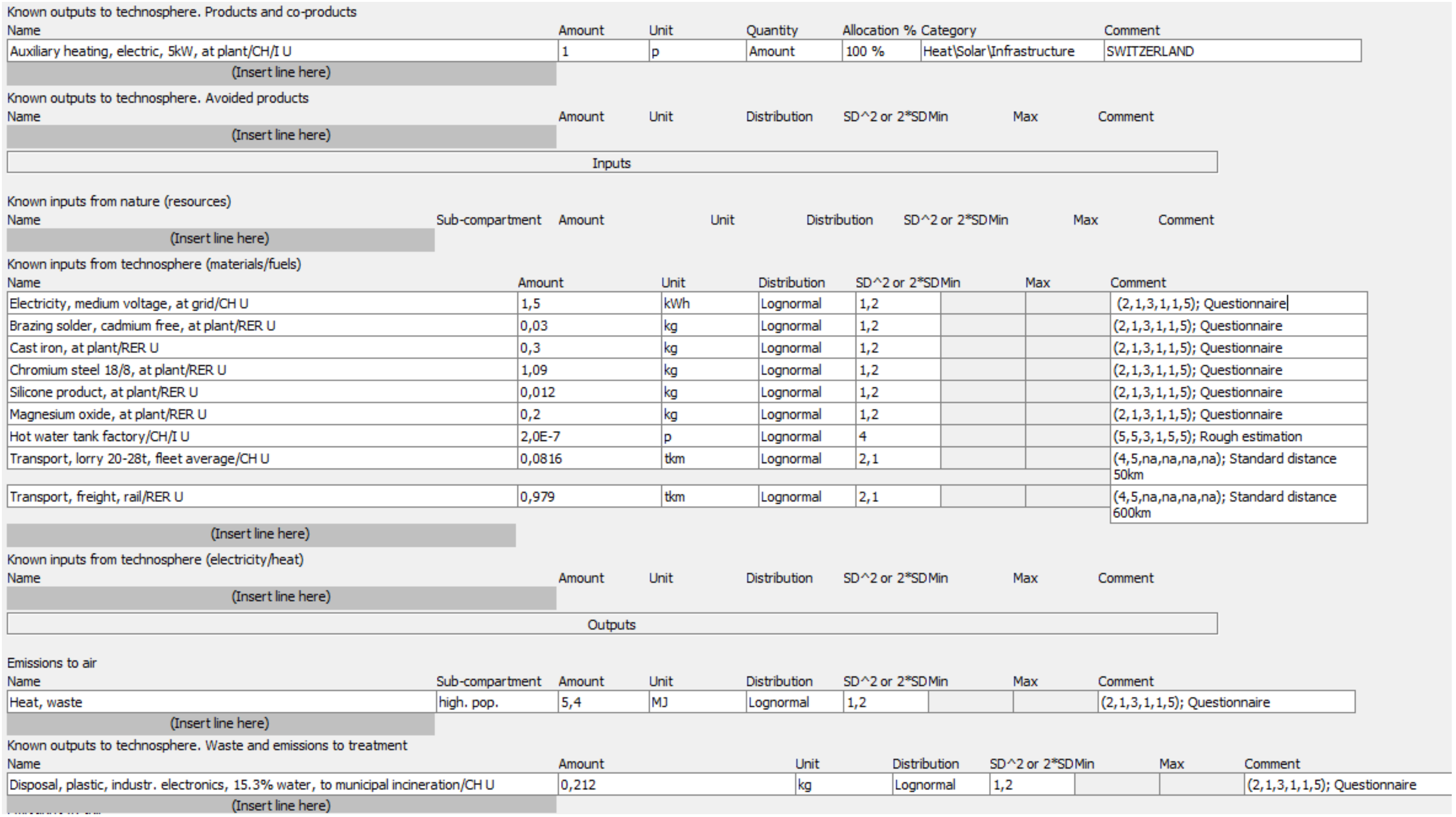
Outputs

Emissions to air

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Heat, waste	high. pop.	31	MJ	Lognormal	1,24			(2,1,3,1,1,5); Questionnaire
(Insert line here)								

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Disposal, packaging cardboard, 19.6% water, to municipal incineration/CH U	0,5	kg	Lognormal	1,24			(2,1,3,1,1,5); Questionnaire
Disposal, plastics, mixture, 15.3% water, to municipal incineration/CH U	0,77	kg	Lognormal	1,24			(2,1,3,1,1,5); Questionnaire
Disposal, polypropylene, 15.9% water, to municipal incineration/CH U	0,025	kg	Lognormal	1,24			(2,1,3,1,1,5); Questionnaire
(Insert line here)							

7.4.2.5 Auxiliary heating, electric



Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Category	Comment
Auxiliary heating, electric, 5kW, at plant/CH/I U	1	p	Amount	100 %	Heat\Solar\Infrastructure	SWITZERLAND
(Insert line here)						

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD Min	Max	Comment
(Insert line here)						

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD Min	Max	Comment
(Insert line here)							

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Electricity, medium voltage, at grid/CH U	1,5	kWh	Lognormal	1,2			(2,1,3,1,1,5); Questionnaire
Brazing solder, cadmium free, at plant/RER U	0,03	kg	Lognormal	1,2			(2,1,3,1,1,5); Questionnaire
Cast iron, at plant/RER U	0,3	kg	Lognormal	1,2			(2,1,3,1,1,5); Questionnaire
Chromium steel 18/8, at plant/RER U	1,09	kg	Lognormal	1,2			(2,1,3,1,1,5); Questionnaire
Silicone product, at plant/RER U	0,012	kg	Lognormal	1,2			(2,1,3,1,1,5); Questionnaire
Magnesium oxide, at plant/RER U	0,2	kg	Lognormal	1,2			(2,1,3,1,1,5); Questionnaire
Hot water tank factory/CH/I U	2,0E-7	p	Lognormal	4			(5,5,3,1,5,5); Rough estimation
Transport, lorry 20-28t, fleet average/CH U	0,0816	tkm	Lognormal	2,1			(4,5,na,na,na,na); Standard distance 50km
Transport, freight, rail/RER U	0,979	tkm	Lognormal	2,1			(4,5,na,na,na,na); Standard distance 600km
(Insert line here)							

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD Min	Max	Comment
(Insert line here)						

Outputs

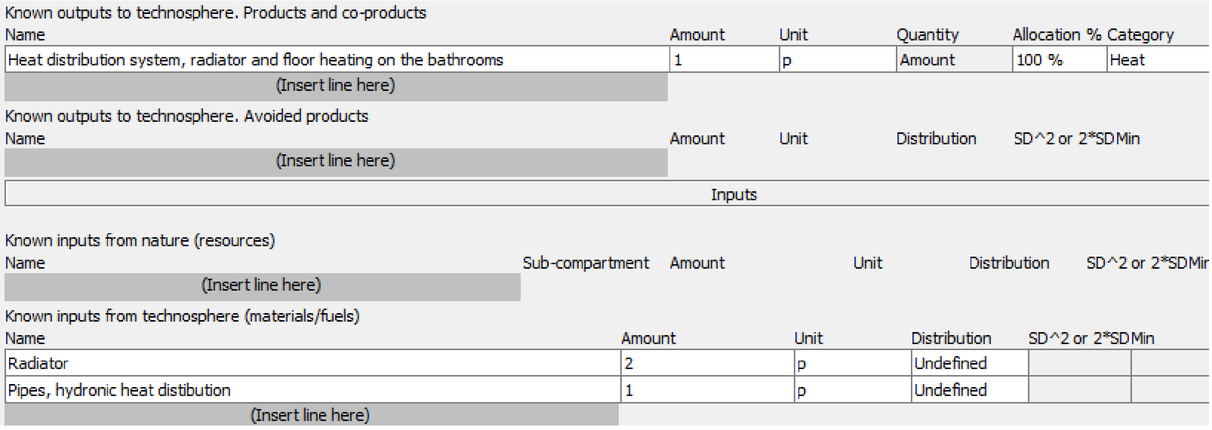
Emissions to air

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Heat, waste	high. pop.	5,4	MJ	Lognormal	1,2			(2,1,3,1,1,5); Questionnaire
(Insert line here)								

Known outputs to technosphere. Waste and emissions to treatment

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Disposal, plastic, industr. electronics, 15.3% water, to municipal incineration/CH U	0,212	kg	Lognormal	1,2			(2,1,3,1,1,5); Questionnaire
(Insert line here)							

7.4.2.6 Hydronic heat distribution system



Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Category
Heat distribution system, radiator and floor heating on the bathrooms	1	p	Amount	100 %	Heat
(Insert line here)					

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min
(Insert line here)					

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Mir
(Insert line here)						

Known inputs from technosphere (materials/fuels)

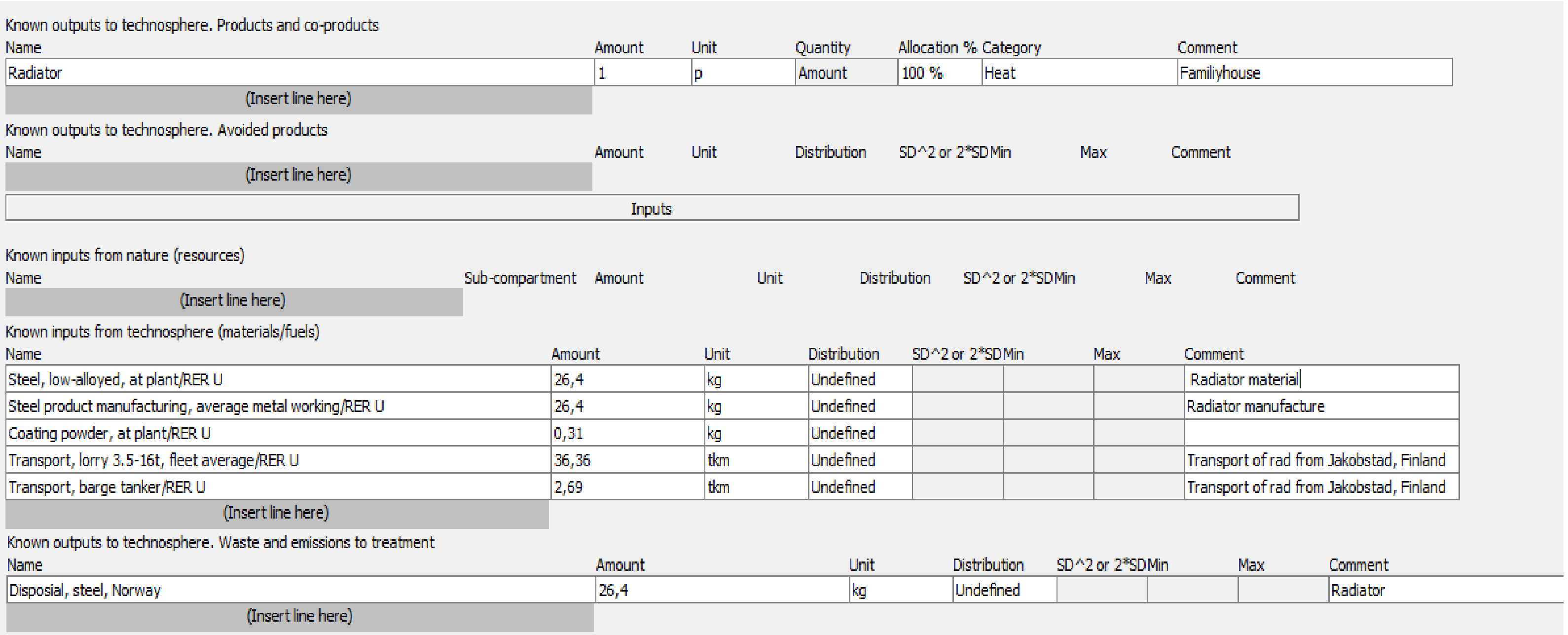
Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min
Radiator	2	p	Undefined		
Pipes, hydronic heat distibution	1	p	Undefined		
(Insert line here)					

Table 7.1: Material input in the distribution system [25]

The hydronic distribution system

Material	***Type***	***kg/m***
Steel pipes	3/8"	0,68
	1 1/4 "	2,25
Copper	DN12	0,35
	DN32	1,41
Silicone	-	0,052
Mineral wool	Thickness: 20 mm	0,06

Radiators



Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Category	Comment
Radiator	1	p	Amount	100 %	Heat	Familiyhouse
(Insert line here)						

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

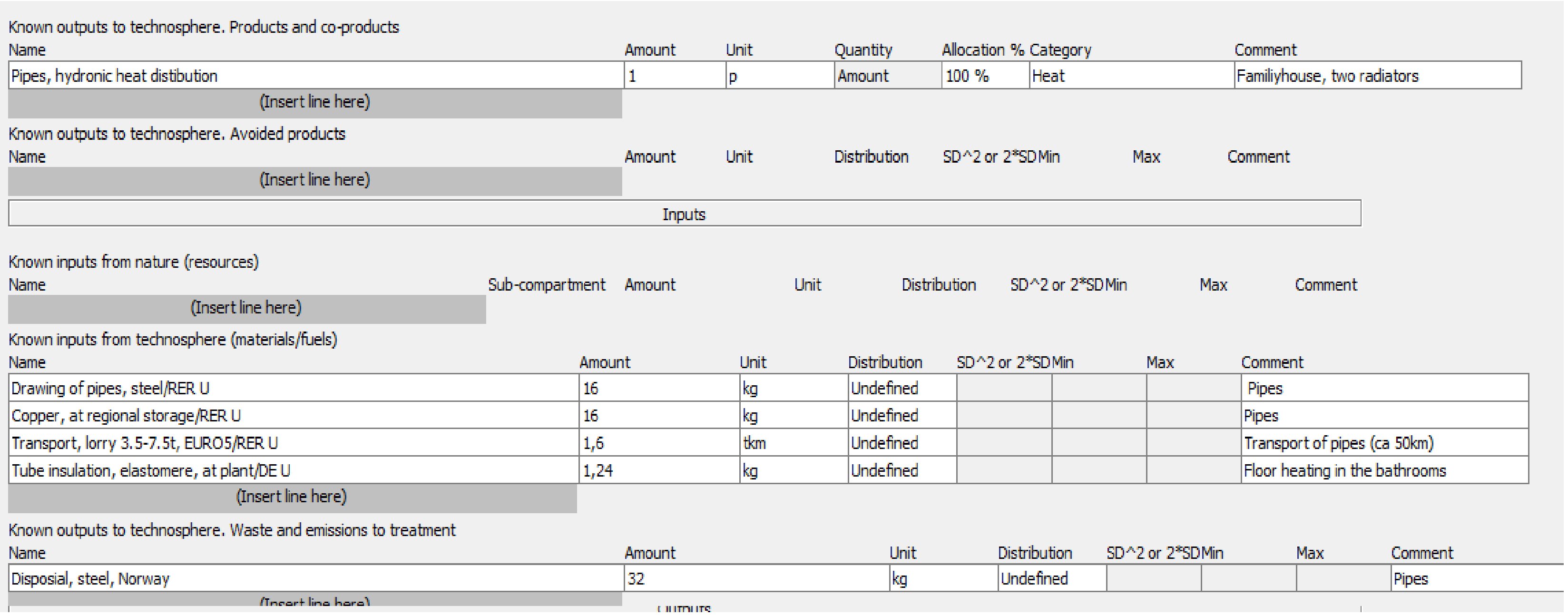
Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Steel, low-alloyed, at plant/RER U	26,4	kg	Undefined				Radiator material
Steel product manufacturing, average metal working/RER U	26,4	kg	Undefined				Radiator manufacture
Coating powder, at plant/RER U	0,31	kg	Undefined				
Transport, lorry 3.5-16t, fleet average/RER U	36,36	tkm	Undefined				Transport of rad from Jakobstad, Finland
Transport, barge tanker/RER U	2,69	tkm	Undefined				Transport of rad from Jakobstad, Finland
(Insert line here)							

Known outputs to technosphere. Waste and emissions to treatment

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Disposial, steel, Norway	26,4	kg	Undefined				Radiator
(Insert line here)							

Pipes



Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Category	Comment
Pipes, hydronic heat distibution	1	p	Amount	100 %	Heat	Familiyhouse, two radiators
(Insert line here)						

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

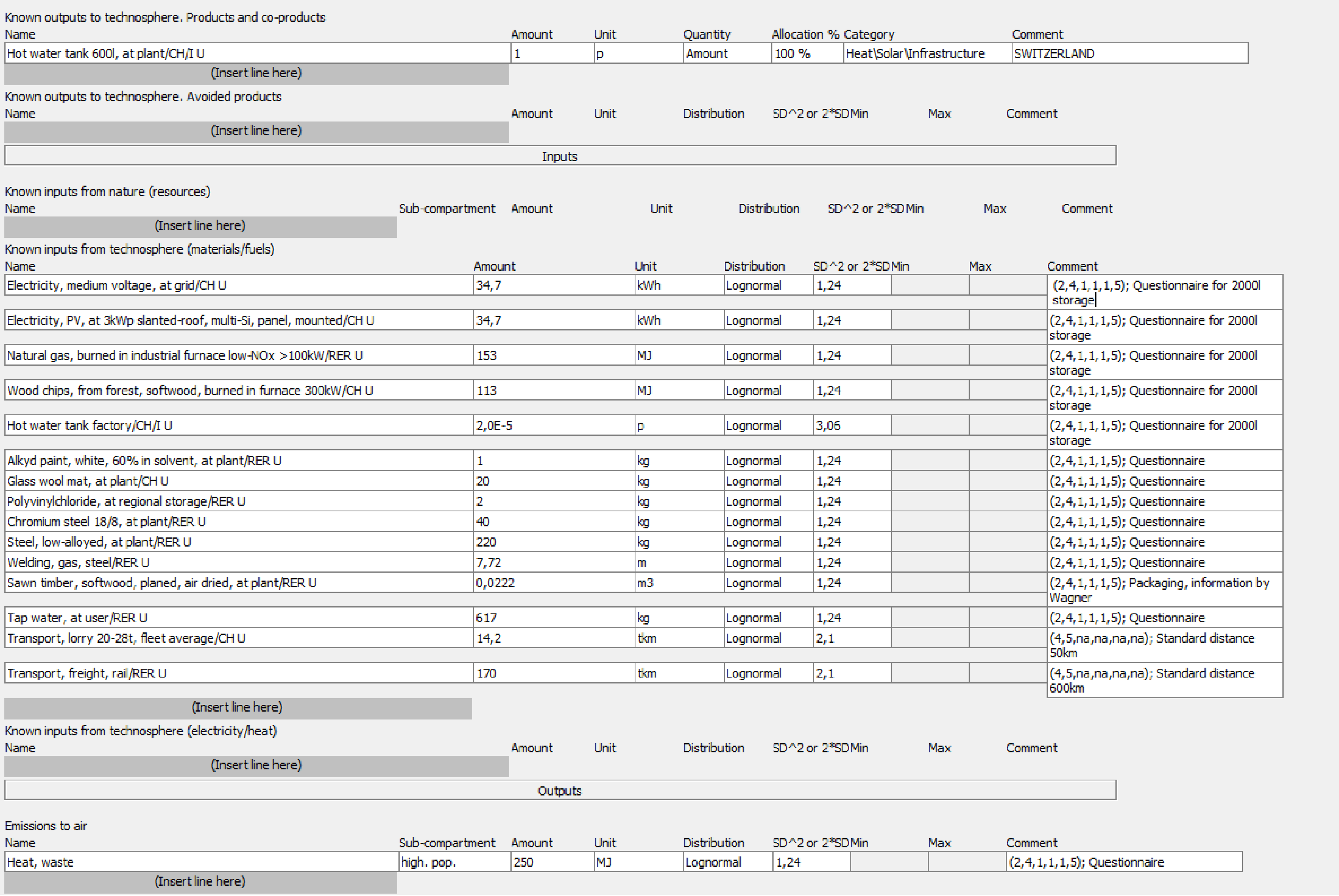
Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Drawing of pipes, steel/RER U	16	kg	Undefined				Pipes
Copper, at regional storage/RER U	16	kg	Undefined				Pipes
Transport, lorry 3.5-7.5t, EURO5/RER U	1,6	tkm	Undefined				Transport of pipes (ca 50km)
Tube insulation, elastomere, at plant/DE U	1,24	kg	Undefined				Floor heating in the bathrooms
(Insert line here)							

Known outputs to technosphere. Waste and emissions to treatment

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Disposial, steel, Norway	32	kg	Undefined				Pipes
(Insert line here)							

7.4.2.7 Hot water tank, hydronic



Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Category	Comment
Hot water tank 600l, at plant/CH/I U	1	p	Amount	100 %	Heat\Solar\Infrastructure	SWITZERLAND
(Insert line here)						

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Electricity, medium voltage, at grid/CH U	34,7	kWh	Lognormal	1,24			(2,4,1,1,1,5); Questionnaire for 2000l storage
Electricity, PV, at 3kWp slanted-roof, multi-Si, panel, mounted/CH U	34,7	kWh	Lognormal	1,24			(2,4,1,1,1,5); Questionnaire for 2000l storage
Natural gas, burned in industrial furnace low-NOx >100kW/RER U	153	MJ	Lognormal	1,24			(2,4,1,1,1,5); Questionnaire for 2000l storage
Wood chips, from forest, softwood, burned in furnace 300kW/CH U	113	MJ	Lognormal	1,24			(2,4,1,1,1,5); Questionnaire for 2000l storage
Hot water tank factory/CH/I U	2,0E-5	p	Lognormal	3,06			(2,4,1,1,1,5); Questionnaire for 2000l storage
Alkyd paint, white, 60% in solvent, at plant/RER U	1	kg	Lognormal	1,24			(2,4,1,1,1,5); Questionnaire
Glass wool mat, at plant/CH U	20	kg	Lognormal	1,24			(2,4,1,1,1,5); Questionnaire
Polyvinylchloride, at regional storage/RER U	2	kg	Lognormal	1,24			(2,4,1,1,1,5); Questionnaire
Chromium steel 18/8, at plant/RER U	40	kg	Lognormal	1,24			(2,4,1,1,1,5); Questionnaire
Steel, low-alloyed, at plant/RER U	220	kg	Lognormal	1,24			(2,4,1,1,1,5); Questionnaire
Welding, gas, steel/RER U	7,72	m	Lognormal	1,24			(2,4,1,1,1,5); Questionnaire
Sawn timber, softwood, planed, air dried, at plant/RER U	0,0222	m3	Lognormal	1,24			(2,4,1,1,1,5); Packaging, information by Wagner
Tap water, at user/RER U	617	kg	Lognormal	1,24			(2,4,1,1,1,5); Questionnaire
Transport, lorry 20-28t, fleet average/CH U	14,2	tkm	Lognormal	2,1			(4,5,na,na,na,na); Standard distance 50km
Transport, freight, rail/RER U	170	tkm	Lognormal	2,1			(4,5,na,na,na,na); Standard distance 600km
(Insert line here)							

Known inputs from technosphere (electricity/heat)

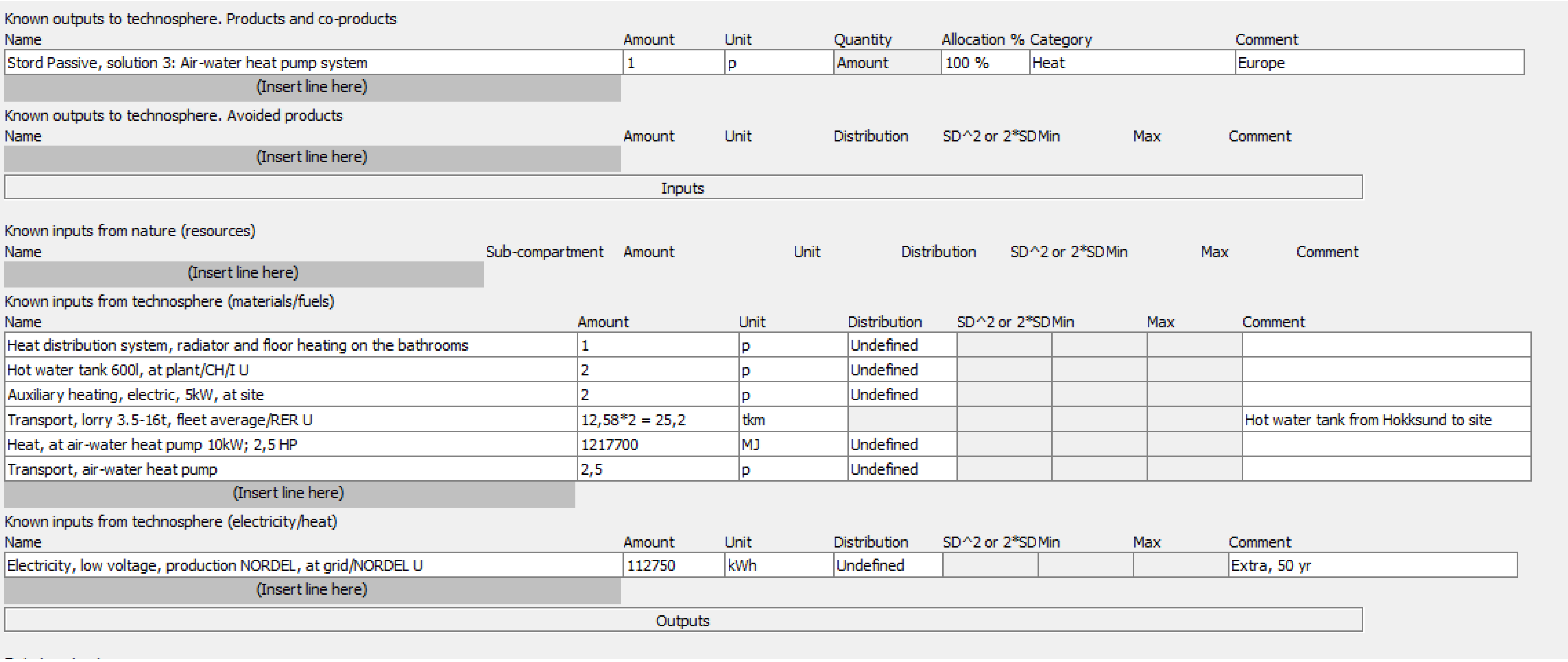
Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Outputs

Emissions to air

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Heat, waste	high. pop.	250	MJ	Lognormal	1,24			(2,4,1,1,1,5); Questionnaire
(Insert line here)								

7.4.3 Stord Passive S3: Air-water heat pump system



Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Category	Comment
Stord Passive, solution 3: Air-water heat pump system	1	p	Amount	100 %	Heat	Europe
(Insert line here)						

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Known inputs from technosphere (materials/fuels)

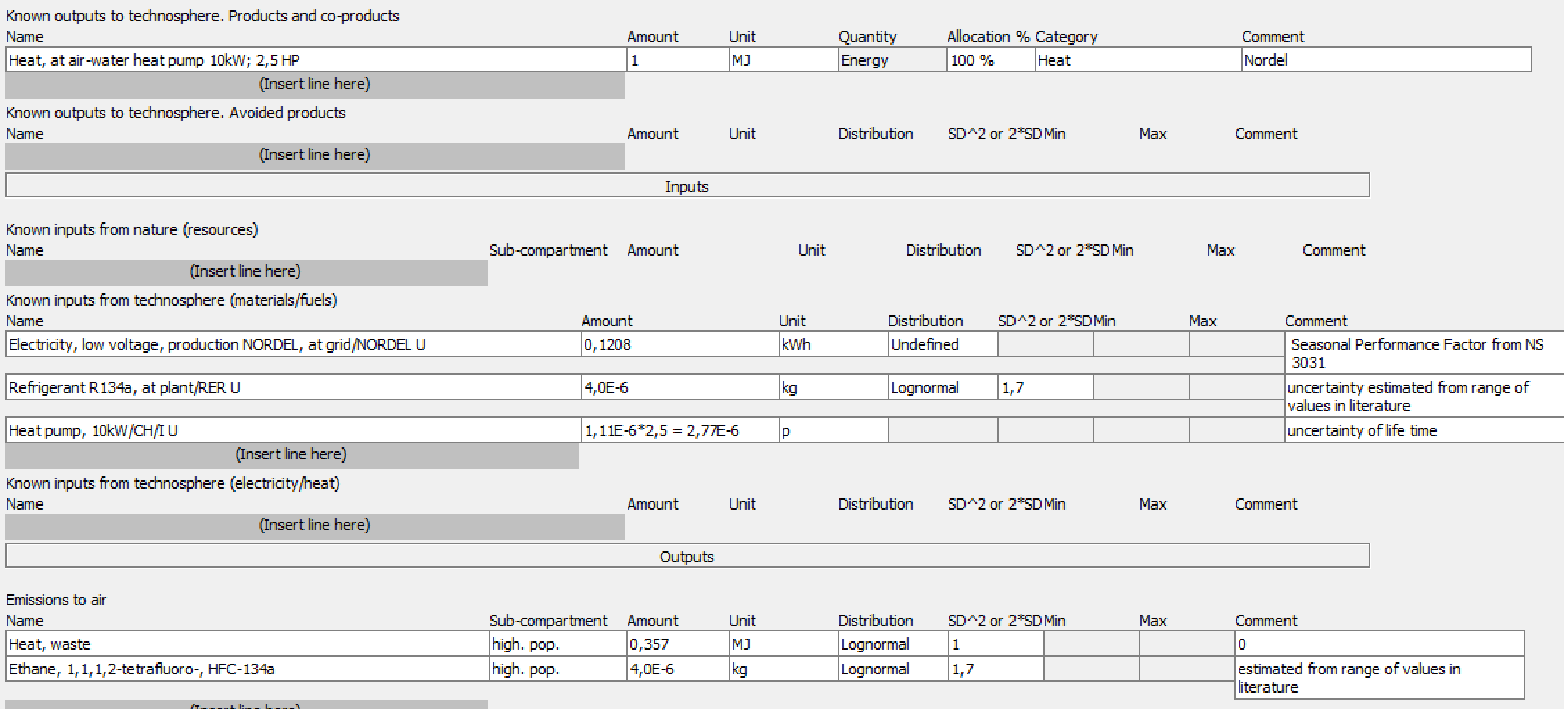
Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Heat distribution system, radiator and floor heating on the bathrooms	1	p	Undefined				
Hot water tank 600l, at plant/CH/I U	2	p	Undefined				
Auxiliary heating, electric, 5kW, at site	2	p	Undefined				
Transport, lorry 3.5-16t, fleet average/RER U	12,58*2 = 25,2	tkm					Hot water tank from Hokksund to site
Heat, at air-water heat pump 10kW; 2,5 HP	1217700	MJ	Undefined				
Transport, air-water heat pump	2,5	p	Undefined				
(Insert line here)							

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Electricity, low voltage, production NORDEL, at grid/NORDEL U	112750	kWh	Undefined				Extra, 50 yr
(Insert line here)							

Outputs

7.4.3.1 Heat, at air water heat pump



Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Category	Comment
Heat, at air-water heat pump 10kW; 2,5 HP	1	MJ	Energy	100 %	Heat	Nordel
(Insert line here)						

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SDMin	Max	Comment
(Insert line here)						

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SDMin	Max	Comment
(Insert line here)							

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SDMin	Max	Comment
Electricity, low voltage, production NORDEL, at grid/NORDEL U	0,1208	kWh	Undefined			Seasonal Performance Factor from NS 3031
Refrigerant R134a, at plant/RER U	4,0E-6	kg	Lognormal	1,7		uncertainty estimated from range of values in literature
Heat pump, 10kW/CH/I U	1,11E-6*2,5 = 2,77E-6	p				uncertainty of life time
(Insert line here)						

Known inputs from technosphere (electricity/heat)

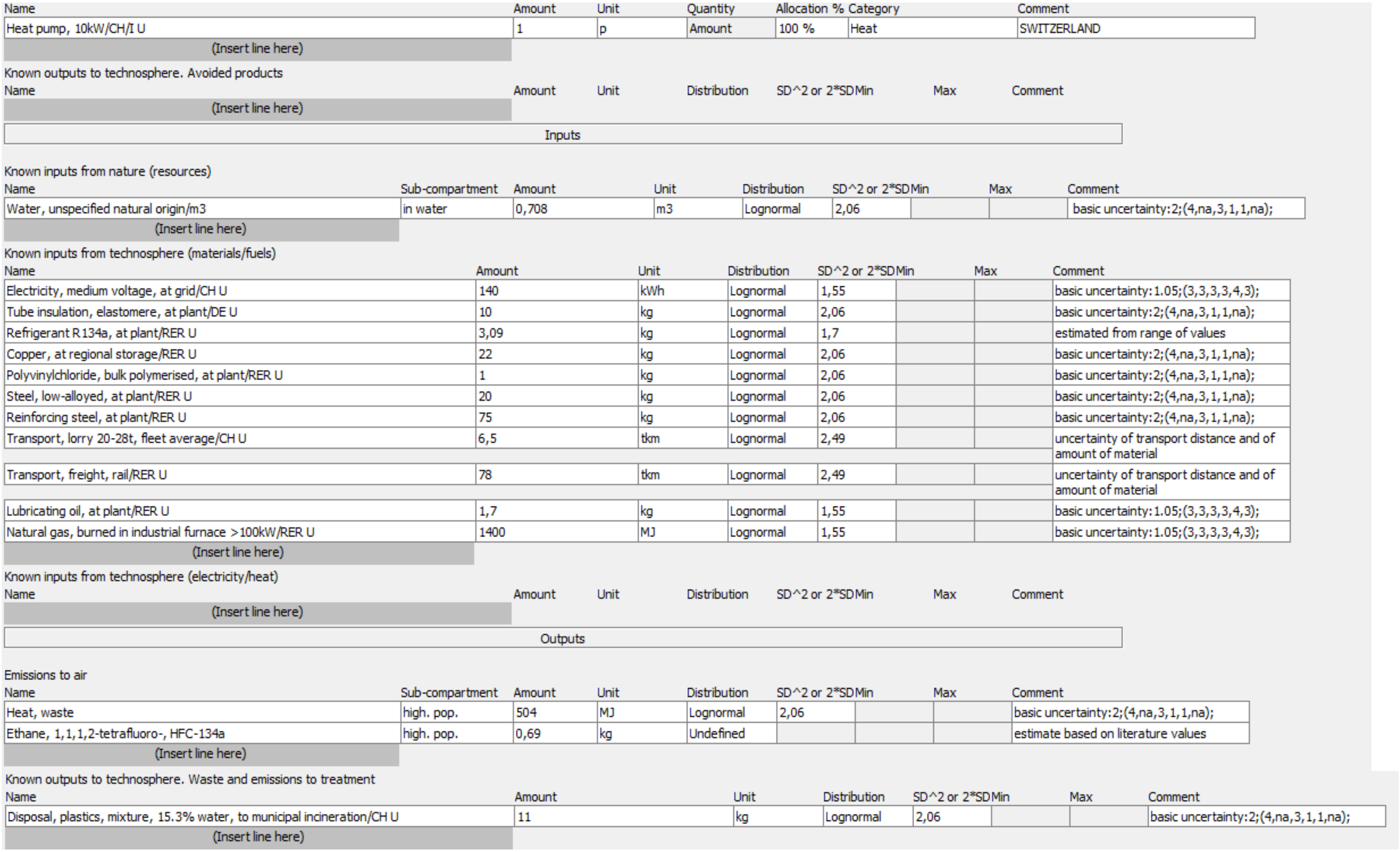
Name	Amount	Unit	Distribution	SD^2 or 2*SDMin	Max	Comment
(Insert line here)						

Outputs

Emissions to air

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SDMin	Max	Comment
Heat, waste	high. pop.	0,357	MJ	Lognormal	1		0
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	high. pop.	4,0E-6	kg	Lognormal	1,7		estimated from range of values in literature
(Insert line here)							

7.4.3.2 Heat pump 10 kW



Name	Amount	Unit	Quantity	Allocation %	Category	Comment
Heat pump, 10kW/CH/I U	1	p	Amount	100 %	Heat	SWITZERLAND
(Insert line here)						

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Water, unspecified natural origin/m3	in water	0,708	m3	Lognormal	2,06			basic uncertainty:2;(4,na,3,1,1,na);
(Insert line here)								

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Electricity, medium voltage, at grid/CH U	140	kWh	Lognormal	1,55			basic uncertainty:1.05;(3,3,3,3,4,3);
Tube insulation, elastomere, at plant/DE U	10	kg	Lognormal	2,06			basic uncertainty:2;(4,na,3,1,1,na);
Refrigerant R134a, at plant/RER U	3,09	kg	Lognormal	1,7			estimated from range of values
Copper, at regional storage/RER U	22	kg	Lognormal	2,06			basic uncertainty:2;(4,na,3,1,1,na);
Polyvinylchloride, bulk polymerised, at plant/RER U	1	kg	Lognormal	2,06			basic uncertainty:2;(4,na,3,1,1,na);
Steel, low-alloyed, at plant/RER U	20	kg	Lognormal	2,06			basic uncertainty:2;(4,na,3,1,1,na);
Reinforcing steel, at plant/RER U	75	kg	Lognormal	2,06			basic uncertainty:2;(4,na,3,1,1,na);
Transport, lorry 20-28t, fleet average/CH U	6,5	tkm	Lognormal	2,49			uncertainty of transport distance and of amount of material
Transport, freight, rail/RER U	78	tkm	Lognormal	2,49			uncertainty of transport distance and of amount of material
Lubricating oil, at plant/RER U	1,7	kg	Lognormal	1,55			basic uncertainty:1.05;(3,3,3,3,4,3);
Natural gas, burned in industrial furnace >100kW/RER U	1400	MJ	Lognormal	1,55			basic uncertainty:1.05;(3,3,3,3,4,3);
(Insert line here)							

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Outputs

Emissions to air

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Heat, waste	high. pop.	504	MJ	Lognormal	2,06			basic uncertainty:2;(4,na,3,1,1,na);
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	high. pop.	0,69	kg	Undefined				estimate based on literature values
(Insert line here)								

Known outputs to technosphere. Waste and emissions to treatment

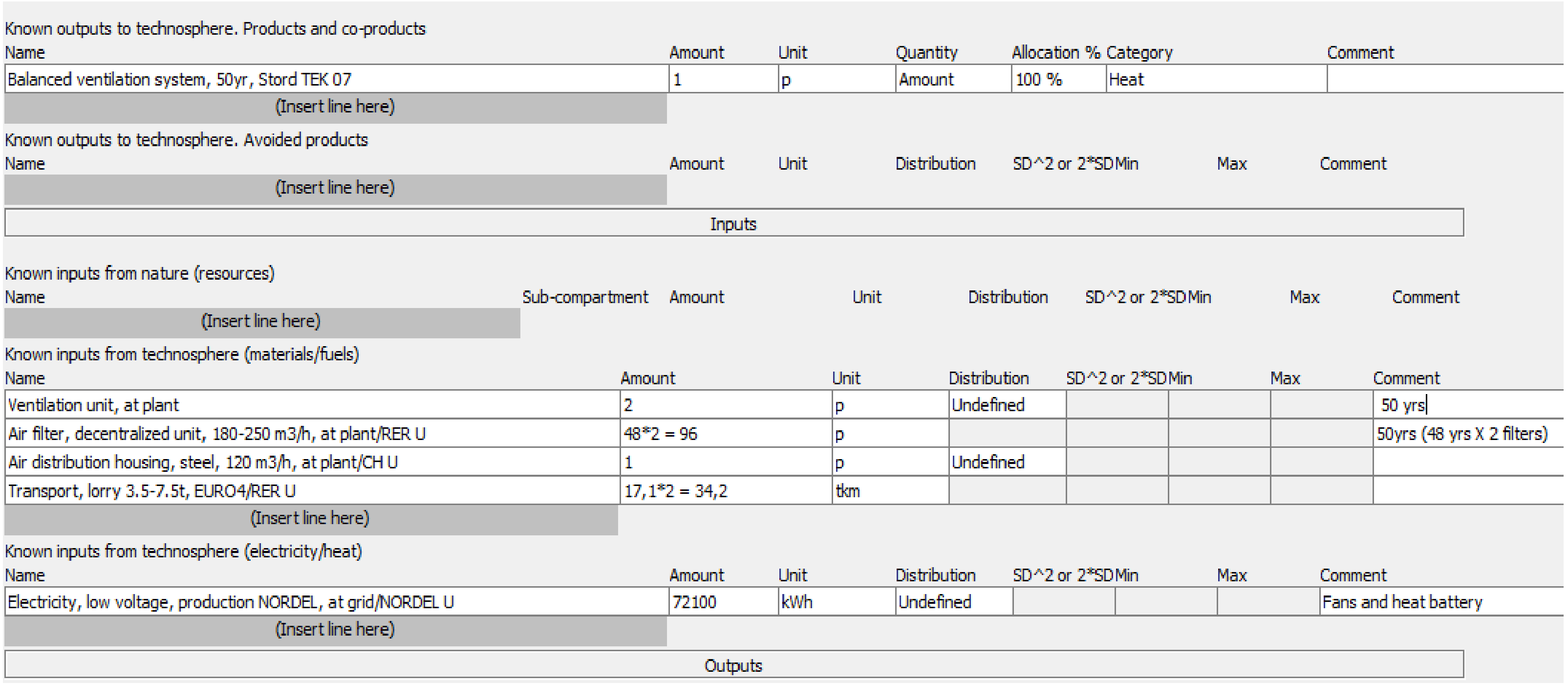
Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Disposal, plastics, mixture, 15.3% water, to municipal incineration/CH U	11	kg	Lognormal	2,06			basic uncertainty:2;(4,na,3,1,1,na);
(Insert line here)							

Table 7.2: Material input in the heat pump [33]

Heat pump 10 kW		
INPUT		
Basic materials:		
Steel unalloyed	75	kg
Steel low-alloyed	20	kg
Copper	22	kg
Armaflex (pipe insulation)	10	kg
PVC	1	kg
R134a	3,09	kg
Resources:		
Water	0,7	m3
Transport:		
Rail	78	tkm
Truck 28 t	6,5	tkm
Energy source:		
Lubricating oil	1,7	kg
Natural gas	1400	MJ
Electricity - European mix	140	kWh
OUTPUT		
Waste:		
Plastic in the incinerator	11	kg
Emissions to air:		
R134a	3,69	kg
Waste heat	504	MJ

7.4.4 Ventilation

7.4.4.1 The total balanced ventilation system over 50 years



Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Category	Comment
Balanced ventilation system, 50yr, Stord TEK 07	1	p	Amount	100 %	Heat	
(Insert line here)						

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Known inputs from technosphere (materials/fuels)

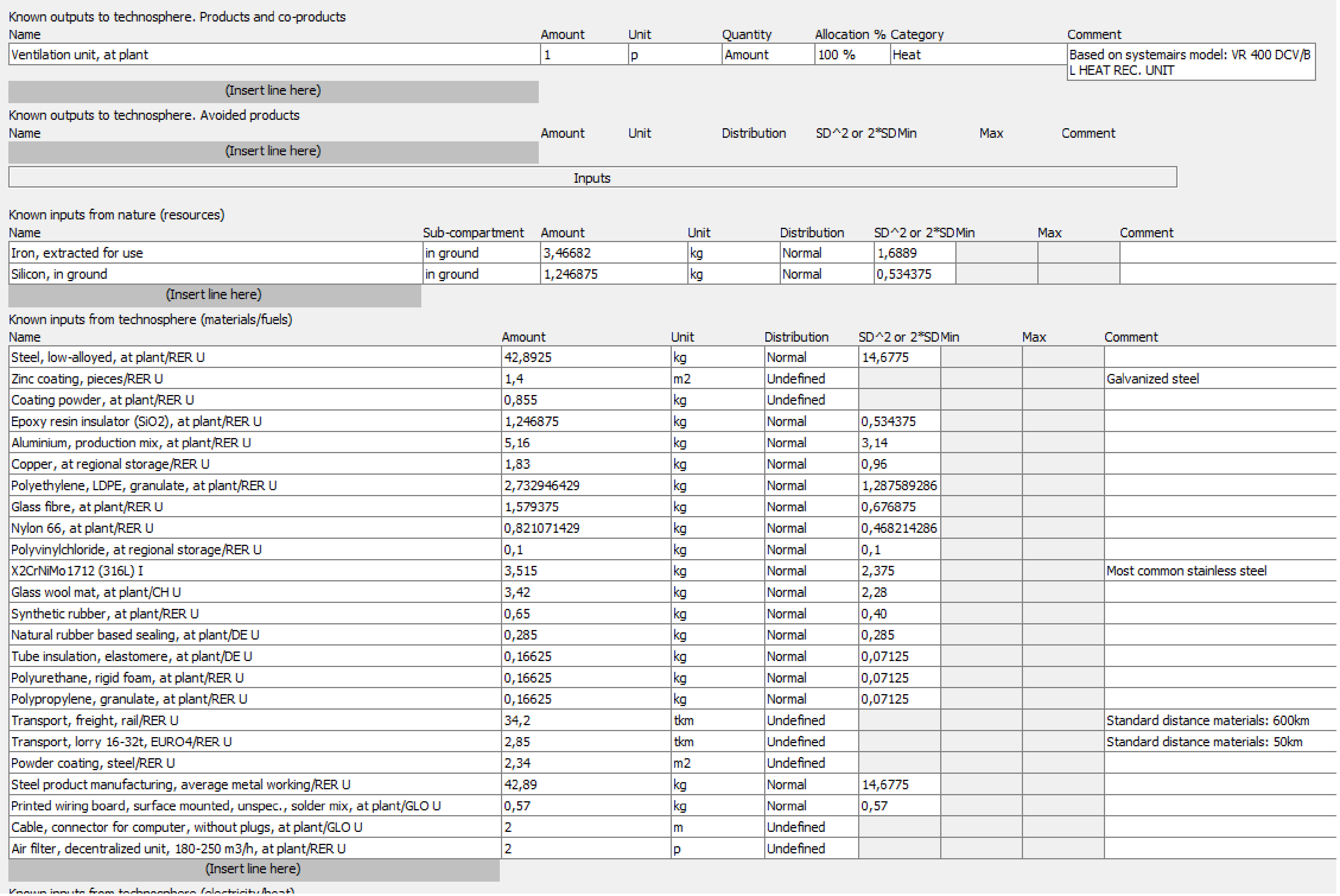
Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Ventilation unit, at plant	2	p	Undefined				50 yrs
Air filter, decentralized unit, 180-250 m3/h, at plant/RER U	48*2 = 96	p					50yrs (48 yrs X 2 filters)
Air distribution housing, steel, 120 m3/h, at plant/CH U	1	p	Undefined				
Transport, lorry 3.5-7.5t, EURO4/RER U	17,1*2 = 34,2	tkm					
(Insert line here)							

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Electricity, low voltage, production NORDEL, at grid/NORDEL U	72100	kWh	Undefined				Fans and heat battery
(Insert line here)							

Outputs

7.4.4.2 Ventilation unit



Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Category	Comment
Ventilation unit, at plant	1	p	Amount	100 %	Heat	Based on systemairs model: VR 400 DCV/BL HEAT REC. UNIT
(Insert line here)						

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Iron, extracted for use	in ground	3,46682	kg	Normal	1,6889			
Silicon, in ground	in ground	1,246875	kg	Normal	0,534375			
(Insert line here)								

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Steel, low-alloyed, at plant/RER U	42,8925	kg	Normal	14,6775			
Zinc coating, pieces/RER U	1,4	m2	Undefined				Galvanized steel
Coating powder, at plant/RER U	0,855	kg	Undefined				
Epoxy resin insulator (SiO2), at plant/RER U	1,246875	kg	Normal	0,534375			
Aluminium, production mix, at plant/RER U	5,16	kg	Normal	3,14			
Copper, at regional storage/RER U	1,83	kg	Normal	0,96			
Polyethylene, LDPE, granulate, at plant/RER U	2,732946429	kg	Normal	1,287589286			
Glass fibre, at plant/RER U	1,579375	kg	Normal	0,676875			
Nylon 66, at plant/RER U	0,821071429	kg	Normal	0,468214286			
Polyvinylchloride, at regional storage/RER U	0,1	kg	Normal	0,1			
X2CrNiMo1712 (316L) I	3,515	kg	Normal	2,375			Most common stainless steel
Glass wool mat, at plant/CH U	3,42	kg	Normal	2,28			
Synthetic rubber, at plant/RER U	0,65	kg	Normal	0,40			
Natural rubber based sealing, at plant/DE U	0,285	kg	Normal	0,285			
Tube insulation, elastomere, at plant/DE U	0,16625	kg	Normal	0,07125			
Polyurethane, rigid foam, at plant/RER U	0,16625	kg	Normal	0,07125			
Polypropylene, granulate, at plant/RER U	0,16625	kg	Normal	0,07125			
Transport, freight, rail/RER U	34,2	tkm	Undefined				Standard distance materials: 600km
Transport, lorry 16-32t, EURO4/RER U	2,85	tkm	Undefined				Standard distance materials: 50km
Powder coating, steel/RER U	2,34	m2	Undefined				
Steel product manufacturing, average metal working/RER U	42,89	kg	Normal	14,6775			
Printed wiring board, surface mounted, unspec., solder mix, at plant/GLO U	0,57	kg	Normal	0,57			
Cable, connector for computer, without plugs, at plant/GLO U	2	m	Undefined				
Air filter, decentralized unit, 180-250 m3/h, at plant/RER U	2	p	Undefined				
(Insert line here)							

Known inputs from technosphere (electricity/heat)

7.5 Net cumulated primary energy

Table 7.3: Net cumulated primary energy divided on energy sources, Stord TEK 07.

Net cumulated energy - Stord TEK 07

Unit: Giga Joule, GJ

	Ventilation system	*Effect of heat recovery*	*Net emissions*
Non renewable, fossil	195,5	-987,7	-792,3
Non-renewable, nuclear	216,4	-1156,5	-940,1
Renewable, biomass	58,7	0,0	58,7
Renewable, wind, solar, geothermal	4,8	-315,9	-311,2
Renewable, water	165,8	-25,5	140,2
Total	*641,1*	*-2485,7*	*-1844,6*

Table 7.4: Net cumulated primary energy divided on energy sources, Stord Passive.

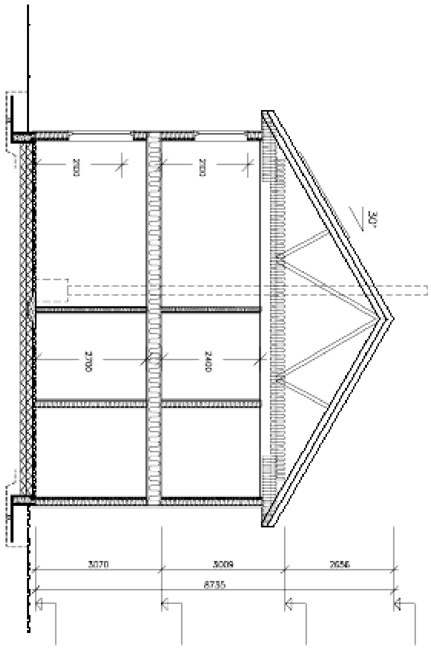
Net cumulated energy - Stord Passive

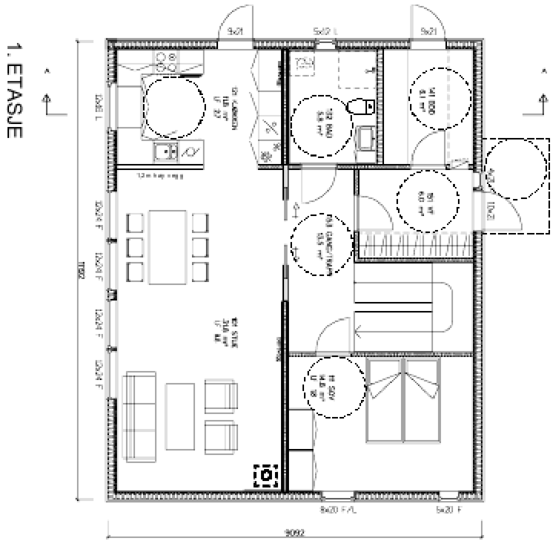
Unit: Giga Joule, GJ

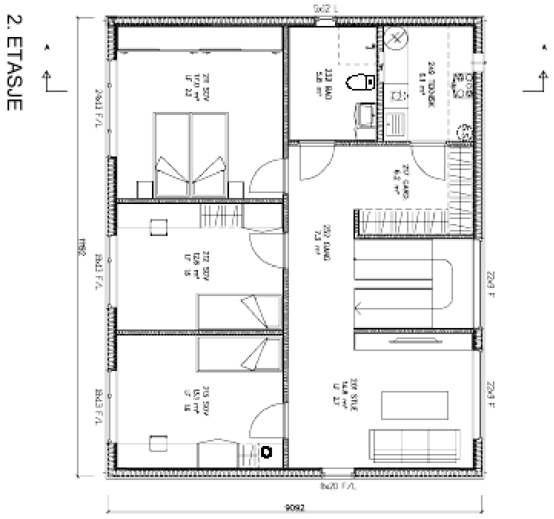
	Ventilation system	*Effect of heat recovery*	*Net emissions*
Non renewable, fossil	174,2	-318,1	-144,0
Non-renewable, nuclear	191,5	-372,4	-181,0
Renewable, biomass	51,9	0,0	51,9
Renewable, wind, solar, geothermal	4,2	-101,7	-97,5
Renewable, water	146,4	-8,2	138,2
Total	*568,2*	*-800,5*	*-232,3*

7.6 Stord TEK 07, illustrations of the construction

AREAL	BRA	P-Rom
Boleilighet		
Underetasje/Kjeller		
Hovedplan/1.etg	93.5	87.4
Loftplan/2.etg	93.5	87.4
Garasje/Utv. bod		
SUM Hovedleilighet	187.0	174.8
Loft-areale ved 1,9m høyde		
Bebygd areal, BYA = 104.0		
Diverse :		







7.7 Stord Passive, illustrations of the construction

AREAL	BRA	P-Rom
Boligenhet		
Underetasje/Kjeller		
Hovedplan/1.etg	93.5	87.4
Loftplan/2.etg	93.5	87.4
Garasje/Utv. bod		
SUM Hovedboligenhet	187.0	174.8
Loft-bredde ved 1,9m høyde		
Bebygd areal, BYA : 112.4		
Diverse :