NTNU – Trondheim
Norwegian University of
Science and Technology

Cost Optimality of Energy Systems in Zero Emission Buildings in Early Design Phase

Sjur Vullum Løtveit

Master of Science in Physics and Mathematics
Submission date: June 2013
Supervisor: Arne Mikkelsen, IFY
Co-supervisor: Vojislav Novakovic, EPT
Igor Sartori, SINTEF

Norwegian University of Science and Technology
Department of Physics

NTNU

Norwegian University
of Science and Technology

Department of Energy
and Process Engineering

EPT-M-2013-??

MASTER THESIS

for

Stud.techn. Sjur Løtveit

Spring 2013

Cost optimality of energy systems in Zero Emission Buildings in early design phase

Kostnadsoptimalisering av energisystemer for null utslippsbygg i en tidligfase av design

Background and objective

A survey among relevant consultants and contractors shows the need for better knowledge and more systematic information in order to make decisions regarding the selection of system for energy supply of ZEBs (Zero Emission Buildings). The ZEB centre aims to develop a computer-based tool for this purpose that will include both a calculation tool and an information database. This assignment will be part of this development.

The main objective of this work is to evaluate the cost optimality of different energy systems for a ZEB using the European cost optimal methodology introduced in the context of the EPBD (Energy Performance of Buildings). Both modelling and evaluation of energy performance of the building and its energy systems and calculation of costs are part of this assignment.

Modelling of a typical new residential building will be performed using the dynamic simulation tool IDA-ICE; while the calculation of costs will be based on the data previously collected by the student during his project assignment and summer job. The choice of the type of building to model will be made in connection with the pilot projects of the ZEB centre.

This assignment is closely related to The Research Centre on Zero Emission Building at NTNU and SINTEF (FME ZEB) that has the vision to eliminate the greenhouse gas emissions caused by buildings. The main objective of FME ZEB is to develop competitive products and solutions for existing and new buildings that will lead to market penetration of buildings that have zero emissions of greenhouse gases related to their production, operation and demolition.

The following tasks are to be considered:

1. Describe the European cost optimal methodology, incl. both financial and macroeconomic analysis, and define suitable energy prices and CO2 prices to be applied. Economic analysis of the electricity exchanged with the grid will also be included in the operating costs (ref - Plusskunder ordningen).
2. Choose a number of energy system combinations, e.g. heat pump plus photovoltaic, and describe their main technical and economic characteristics. The energy systems will include combinations of: Heat Pumps (HP), Biomass Boiler (BB), District Heating (DH), Photovoltaic (PV) and Solar Thermal (ST).
3. Model a new residential ZEB with the different energy systems and simulate the energy performance at hourly level, using IDA-ICE. The model will use user profiles in input, available from the Master Thesis work of Eline Rangøy.
4. Use the energy flows from simulation and cost from previously developed database in order to calculate cost optimality for the various systems.
5. Perform a sensitivity analysis for uncertainties in investment costs as well as energy prices. Discuss the results.

-- ” --

Within 14 days of receiving the written text on the master thesis, the candidate shall submit a research plan for his project to the department.

When the thesis is evaluated, emphasis is put on processing of the results, and that they are presented in tabular and/or graphic form in a clear manner, and that they are analyzed carefully.

The thesis should be formulated as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents etc. During the preparation of the text, the candidate should make an effort to produce a well-structured and easily readable report. In order to ease the evaluation of the thesis, it is important that the cross-references are correct. In the making of the report, strong emphasis should be placed on both a thorough discussion of the results and an orderly presentation.

The candidate is requested to initiate and keep close contact with his/her academic supervisor(s) throughout the working period. The candidate must follow the rules and regulations of NTNU as well as passive directions given by the Department of Energy and Process Engineering.

Risk assessment of the candidate's work shall be carried out according to the department's procedures. The risk assessment must be documented and included as part of the final report. Events related to the candidate's work adversely affecting the health, safety or security, must be documented and included as part of the final report. If the documentation on risk assessment represents a large number of pages, the full version is to be submitted electronically to the supervisor and an excerpt is included in the report.

Pursuant to “Regulations concerning the supplementary provisions to the technology study program/Master of Science” at NTNU §20, the Department reserves the permission to utilize all the results and data for teaching and research purposes as well as in future publications.

The final report is to be submitted digitally in DAIM. An executive summary of the thesis including title, student’s name, supervisor's name, year, department name, and NTNU's logo and name, shall be submitted to the department as a separate pdf file. Based on an agreement with the supervisor, the final report and other material and documents may be given to the supervisor in digital format.

☐ Work to be done in lab (Water power lab, Fluids engineering lab, Thermal engineering lab)
☐ Field work

Department of Energy and Process Engineering, 16. January 2013

Olav Bolland	Vojislav Novakovic
Department Head	Academic Supervisor

Research Advisors:
Igor Sartori, Postdoc

Note: As described above the model should originally use user profiles as input, obtained from the master thesis work of Eline Ragnøy. But after an agreement with co-supervisor Igor Sartori it was decided that this task should not be considered after all. Instead, user profiles were created manually in IDA-ICE.

Abstract

The building sector accounts for a significant proportion of industrial countries total energy use, thus a cut in this sector has been regarded necessary to reach future climate goals. An important measure in this context is the introduction of zero emission buildings, buildings which can be defined as having a net zero annual energy demand. This master thesis is centered around finding cost optimal energy supply systems for zero emission buildings at an early stage of the building process.

This thesis is closely linked to the Ådland project, currently the largest pilot project for the Research Center on Zero Emission Buildings. The testing was performed on a four floor building block located in Bergen. The ZEB-definition used was net zero primary energy consumption, where primary energy factors were used as weighting factors for the various energy carriers. Two types of primary energy factors were tested; total primary energy factors and non-renewable primary energy factors. Five different energy supply packages were investigated: Bio+PV, CHP+PV, DH+PV, HP+ST+PV and CHP+ST+PV. The base heating systems were dimensioned to cover the heating demand (space heating and domestic hot water), while PV was dimensioned so that the building reached the ZEB balance. Excess electricity was exported to the grid and sold to the local power company. The simulation tool IDA-ICE was used both for modeling the building and performing the energy simulations. The cost calculations followed the European Cost Optimal Methodology, calculating the net present value of all costs attributed to the implementation of the different packages (investments, annual costs and residual values) over a calculation period of 30 years. Both a pure financial and a macroeconomic calculation were performed for all packages. Sensitivity analyses were performed on the energy price escalation as well as investment costs.

When total primary energy factors were used, the package HP+ST+PV proved to be the optimal package in all the different scenarios considered. The macroeconomic and the financial results were almost identical, mainly because of the low CO_2-prices. The sensitivity analyses showed that the result is very stable with respect to uncertainties in both investment costs and future energy costs.

For non-renewable primary energy factors the results showed that the package HP+ST+PV is best for both normal and high future energy price development, while the package Bio+PV was the best alternative for low energy price developments. The sensitivity analysis on investment cost showed the result for low energy price development was very sensitive for changes in investment costs, while for medium and high energy price development the result were more stable. Overall, for the energy supply packages considered and the primary energy factors used in this thesis, the conclusion is that HP+ST+PV is the cost optimal energy supply solution for the evaluated building.

Sammendrag

Energibruk i bygg utgjør en betydelig del av industrialiserte samfunns totale energibehov. En reduksjon i denne sektoren har derfor blitt ansett som nødvendig for å nå fremtidige klimamål. Et viktig tiltak i denne sammenhengen er introduksjonen av nullutslippshus, bygninger som kan defineres å ha netto null årlig energibehov. Denne masteroppgaven er sentrert rundt å finne kostnadsoptimale energiforsyningsløsninger til nullutslippshus, hovedsakelig i en tidlig fase av bygningsplanleggingen.

Denne masteroppgaven er nært knyttet til Ådland-prosjektet som for øyeblikket er det største pilotprosjektet til ”the Research Center on Zero Emission Buildings”. Testingen ble utført på en fire etasjers stor blokk plassert i Bergen. ZEB-definisjonen som er brukt er null primærenergiforbruk, der primærenergifaktorer ble brukt som vektfaktorer for de forskjellige energibærerne. To forskjellige type primærenergifaktorer ble testet; totale primærenergifaktorer og ikke-fornybare primærenergifaktorer. Fem energiforsyningsløsninger ble undersøkt: Bio+PV, CHP+PV, DH+PV, HP+ST+PV and CHP+ST+PV. Oppvarmingssystemene ble dimensjonert til å dekke hele varmebehovet (romoppvarming og varmtvann), mens PV ble dimensjonert slik at bygget oppnådde ZEB-balansen. Generert overskuddselektrisitet ble eksportert til strømnettet og solgt til det lokale kraftselskapet. Simuleringsverktøyet IDA-ICE ble brukt både for modellering av bygningen og for å utføre energisimuleringene. Kostnadskalkuleringene ble utført i henhold til den Europeiske Kostnadsoptimale Metoden, der nåverdien til alle kostnadene knyttet til de forskjellige energiforsyningspakkene over en kalkuleringsperiode på 30 år ble beregnet og sammenlignet. Både en finansiell og en makroøkonomisk beregning ble utført. Sensitivitetsanalyser for både energipriseskalering og investeringskostnader ble gjennomført til slutt.

For totale primærenergifaktorer viste det seg at energiforsyningspakken HP+ST+PV var den optimale pakken i alle de vurderte scenarioene. De makroøkonomiske og de finansielle resultatene var nærmest identiske, noe som skyldes de lave CO_2-kostnadene. Sensitivitetsanalysene viste at resultatet er veldig stabilt med tanke på usikkerheter i både investeringskostnader og fremtidige energikostnader.

For ikke-fornybare primærenergifaktorer viste resultatene at pakken HP+ST+PV er best for middels og høy energiprisutvikling, mens pakken Bio+PV var det beste alternativet for lav energiprisutvikling. Sensitivitetsanalysen gjennomført på investeringskostnadene viste at resultatet for lav energiprisutvikling var veldig følsomt ovenfor forandringer i kostnadene, mens for medium og høy energiprisutvikling var resultatet mer stabilt. Alt i alt, gitt de valgte vektfaktorene (primærenergifaktorene), kan det konkluderes at pakken HP+ST+PV er den mest kostnadsoptimale løsningen av de fem vurderte energiforsyningspakkene.

Preface

“Cost optimality of energy systems in Zero Emission Buildings in early design phase” is a master thesis completed at the Department of Physics at the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway. The thesis is a continuation of my specialized project from autumn 2012 which primarily consisted of gathering the cost database used in this master thesis.

This thesis marks the end of my Master of Science Degree in Applied Physics at The Faculty of Natural Sciences and Technology.

I would like to show my gratitude to all the people who have helped me with this thesis, and all who have contributed to six fantastic years here in Trondheim. Vojislav Novakovic and Arne Mikkelsen, NTNU, thank you for being my supervisors and giving me important guidance when I needed it. Igor Sartori, co-supervisor, SINTEF, thank you for essential cooperation and useful advices throughout the whole semester. My sister Solveig Vullum Løtveit, thank you for carefully reading through the thesis and pointing out essential errors. My mother Sigrun Vullum, thank you for both financial and general support through these years. My friends, thank you for all the fun times we had here in Trondheim. My girlfriend Stine Emilie Stokkli, thank you for all the encouraging words and support☺.

Sjur Vullum Løtveit
Trondheim, June 17, 2013

Contents

List of figures

List of tables

Symbols/abbreviations

Symbol	Description	Unit
A_{fl}	Heated floor space	m^2
C_G	Global cost	NOK
E_{prim}	Primary energy	kWh
H	Heat loss number	$W/(m^2K)$
kWe	Kilowatt of electricity	kW
$PEF(f_{prim})$	Primary energy factor	[kWh/kWh]
R_D	Discount rate	-
R_R	Real interest rate	%
Wp	Watt peak	W
Θ_{ym}	Annual average temperature	K
%/a	% per year	-
Bio	Bio energy	-
BoS	Balance of system	-
CHP	Combined heat and power	-
COP	Coefficient of performance	-
DH	District heating	-
DHW	Domestic hot water	-
El	Electricity	-
GHG	Greenhouse gasses	-
HP	Heat pump	-
LEH	Low energy house	-
n-ZEB	Nearly Zero Emission Building	-
PE	Primary energy	-
PEF	Primary energy factor	-
PH	Passive house	-
PV	Photovoltaic (Solar cell)	-
ST	Solar thermal collector	-
ZEB	Zero emission building	-

Definitions

Coefficient of performance (COP): A metric of performance for heat pumps which gives the ratio between the provided heat energy over the consumed electric energy.

Energy carrier: A mechanism or a substance which can be converted into mechanical work or heat, or to operate chemical or physical processes (e. g. electricity, fuel).

Energy grid: A network connecting multiple houses and buildings where energy can be distributed or exported. E. g. the electrical grid or the district heating grid.

Energy metric: A number that typically describes the consumption or emission of a substance in relation to a given energy carrier (for example CO_2-emission [g CO_2/kWh] or primary energy consumption [kWh/kWh]).

Global cost: The global cost is the sum of the present value of the initial investment cost, the annual cost of every year as well as the residual value. For the calculation at a macroeconomic level, the cost of greenhouse gas emissions should also be introduced.

Net ZEB balance: A condition that is satisfied when weighted energy supply meets or exceeds weighted energy demand over a period of time, normally a year. This is usually determined either from the balance between delivered and exported energy or between load and generation. A third option is using monthly values of load and generation.

On-site energy production: Energy produced within the physical boundary of the building(s). The physical boundary can encompass a single building or a cluster of buildings. Examples are: PV, ST, and CHP.

Off-site energy production: Energy produced outside the physical boundary of the building(s). Examples are: DH, electricity from a windmill farm, electricity from a hydro plant.

Price escalation rate: Some times the price development of some cost is higher than the inflation rate. Usually this applies to energy prices. The real energy price escalation rate is the development of energy prices when inflation is removed. This is an important rate when estimating future energy prices.

Primary energy: For a building primary energy is the total energy extracted from nature to produce the energy delivered to the building. It is calculated by multiplying the delivered energy for a given energy source with a primary energy factor. The primary energy factor takes into account extraction, processing, storage, transport, transformation, distribution and other necessary steps for delivering the energy to the building. Low primary energy factors indicate an efficient utilization of the primary energy.

1 Introduction

1.1 Background

The world is facing great challenges related to energy and climate. The Kyoto-protocol, accepted in 1997, set binding obligations on industrialized countries to reduce their emissions of greenhouse gases. In 2011 Norway, as a member of the European Free Trade Association (EFTA), implemented EU's renewable directive [1], setting requirements for the amount of energy coming from renewable sources in gross final consumption of energy. Overall the future energy targets for Norway are [2]:

- Norway's share of renewables in gross final consumption of energy should reach 67.5% within 2020.
- Norway will cut GHG-emissions by 30% from the levels in 1990 within 2020.
- Norway will become carbon neutralized within 2050.

In February 2009 the Minister of Petroleum and Energy appointed eight new research centers for environmentally friendly energy (FME). The goal was to create time limited research centers to cope with the challenges related to climate and energy. One of these research centers was The Research Center on Zero Emission Buildings (ZEB). The ZEB center's main objective is to develop products and solutions for existing and new buildings that will lead to a market penetration of buildings that have zero emissions of greenhouse gases related to their production, operation and demolition [3]. This goal shall gradually be realized through pilot projects, test buildings and publication of research papers. The ZEB center's leadership is divided between SINTEF and NTNU, and through its project period of eight years the center has a budget of around 320 million NOK [4].

In the autumn 2011 there were arranged meetings with YiT and Multiconsult among others [5]. The meetings identified that there were some challenges with choosing energy supply systems for buildings other than the ones most commonly used. As a result of this, 12 advisors, consultants and entrepreneurs were interviewed in the time period August to December 2011. The interviews confirmed that there's a need for better knowledge and more systematic information in order to make good decisions regarding the selection of energy supply systems. Often standard energy choices like heat pumps and district heating are chosen even though there are better alternatives, leading to a lot of inefficient systems. The ZEB center is now developing a computer based tool, later referred to as "the tool", which will provide information and assistance for choosing early stage energy supply solutions for zero emission buildings (ZEBs). This assignment is a part of this development.

1.2 Idea behind “the tool”

The main idea with the tool is to propose cost optimal energy supply systems for ZEBs, based on the *European cost optimal methodology* defined later, primarily at an early stage of the building process. The energy supply systems will consist of a combination of different technologies (solar cells, solar thermal collectors, heat pumps, bio energy, district heat, etc.). The reason for this is that an energy supply system consisting of only one technology would lead to an oversized system, since it has to be dimensioned to cover even the peak load. This is neither cost efficient because of high investment, nor energy efficient since the system would mostly run on low load which usually is inefficient. This is illustrated in Figure 1-1 which shows the demand for efficiency throughout one year. The peak load will typically be during the coldest winter days.

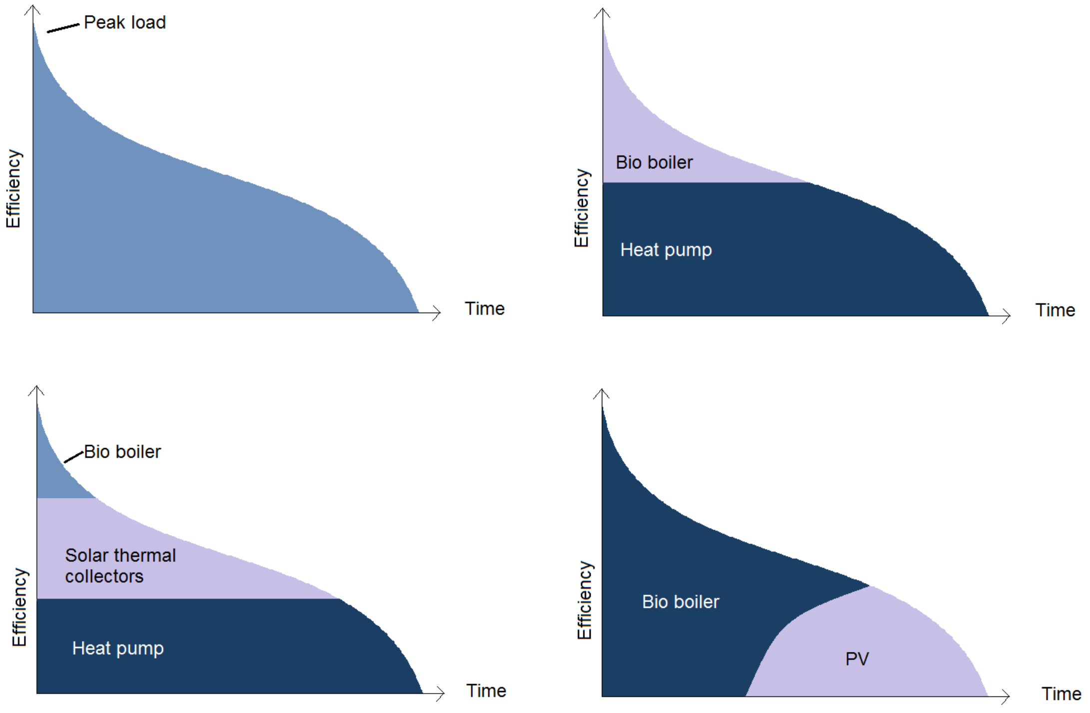


Figure 1-1: Duration curves, adapted from [6]

The tool will include both a calculation tool and an information database. The calculation tool must be able to simulate a building’s annual energy demand for heating, domestic hot water and equipment, taking into account the building geometry, climatic data, occupants, etc. Due to the ZEB center’s limited project period, it has been decided that the calculation tool shall be based on an already existing tool. There are many energy simulation tools available today: BSim, ESP-r, TRNSYS, SIMIEN, IDA-ICE and others. The tool shouldn’t be too complicated for normal consultants to learn, but at the same time accurate enough to generate realistic results. As for now, the simulation program IDA-ICE by EQUA AB stands out as the most suitable alternative for these purposes.

The information database will consist of both cost data and technical data for the relevant technologies, and will thus provide necessary information for making a cost optimal decision. The database has to be updated regularly.

1.3 Objectives and outline of the thesis

The objective of this thesis is to perform cost optimal analysis on possible energy supply solutions for a Zero Emission Building (ZEB). The test building is a building block located in Ådland in Bergen. The building is part of a large building park which currently is the largest pilot project for the ZEB center. The energy supply solutions will be chosen as suitable combinations between PV, solar thermal collectors, heat pumps, district heating, combined heat and power, and biomass boilers. The method that will be used for the analysis is the European Cost Optimal Methodology (net present value method). A cost optimal result will be calculated both at a financial and a macroeconomic level. The modeling of the building and the energy simulations will be done in IDA-ICE. At the end, sensitivity analyses for uncertainties in investment costs as well as energy prices will be performed and the result will be discussed.

The theory section (chapter 1) starts by giving the definition of Zero Emission Buildings used in this study. This is placed first because it’s useful to have the appropriate definition in mind when viewing the rest of the thesis. Then the energy performance of buildings directive is mentioned which contains background information about the European Cost Optimal Methodology which is defined afterwards. The European cost optimal methodology describes how to calculate the global cost of an energy system and how to decide a cost optimal alternative both in a pure financial and in a macroeconomic perspective. After this there’s an introduction to the relevant energy supply systems for this master thesis, their main strengths and weaknesses. Relevant energy prices will be defined as well as plus customers. The theory chapter ends with a short introduction to the simulation tool IDA-ICE.

In the approach section (chapter 1) the test building in Ådland is introduced closer including relevant parameters for the modeling in IDA-ICE. Then five relevant energy supply packages for the building are presented, followed by the chosen appropriate rates for the calculations: the discount rate, inflation and future energy price developments. In the end of this section an overview over the most relevant information and input factors for the cost optimal calculation are shown, both for the financial and the macroeconomic analysis.

In the result section (chapter 1) the models in IDA-ICE are discussed, and the results from the energy simulations and the cost optimal calculations are presented. In the discussion section (chapter 5) the model, the cost data and the results are discussed in detail, including possible future improvements.

2 Theory

2.1 Zero Emission Buildings

There's still no clear ZEB definition. However, it is conceptually understood that a ZEB is a building with greatly reduced energy demand and which is able to generate electricity from renewable energy sources [7]. The common denominator for all ZEB definitions is the annual balance between weighted demand and weighted supply. A building will typically have highest energy demand in winter, while for instance photovoltaic (PV) will generate most during summer. But as long as the building is able to export excess energy to the grid and a net annual balance is obtained the building can still be regarded a ZEB. This is illustrated in Figure 2-1. If A equals B the building has an annual net zero energy need.

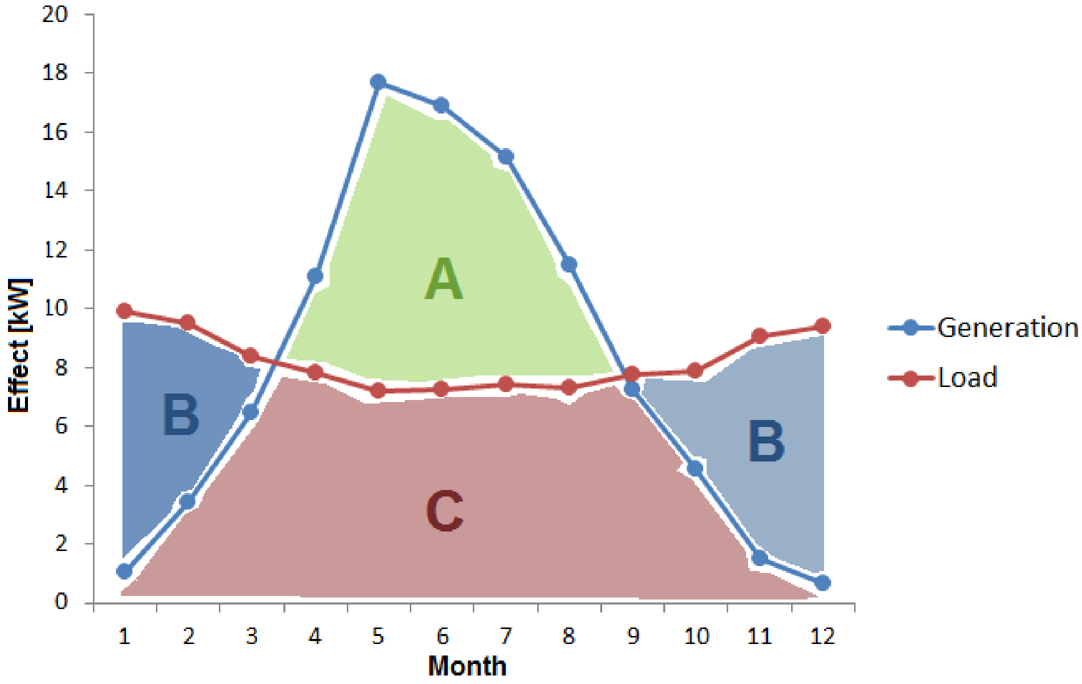


Figure 2-1: Monthly average generation and load of electricity

The weighted demand and weighted supply balance may be calculated in different ways. The *export/import* balance takes into account the self-consumption of generated energy, and afterwards creates a balance between the need for exported and imported energy (see Figure 2-2); this balance applies well in monitoring. The *load/generation* balance is a simpler approach where the interactions between the grids are overlooked. This is equivalent to assume that, per each carrier, the load is completely satisfied by delivered energy while generated energy is entirely fed into the grid [8]. This balance is applicable in early stage design for compliance with building codes. On the other hand it's inaccurate for cost analysis because self-consumption of generated energy is more cost efficient than exporting it. There’s also a third type of balance which is the *monthly net balance*, which can be seen as a combination of the other two.

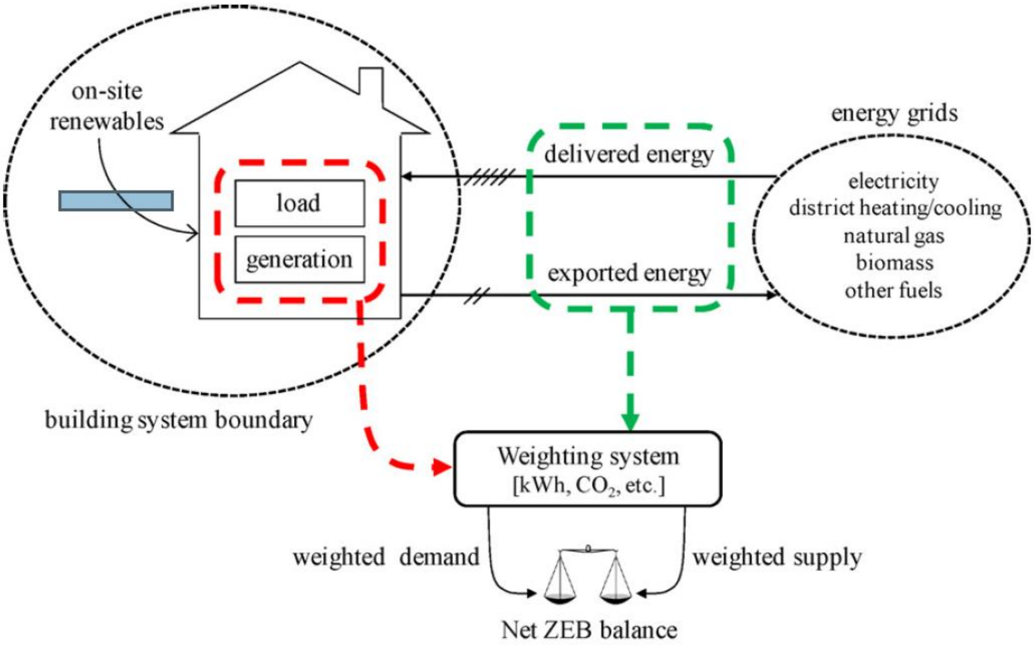


Figure 2-2: Illustration of different weighting systems for a ZEB [8]

ZEB definition 1, import/export balance:

This is the definition that will be used in this study. The balance can be written as ([8]):

$$ZEB\ definition\ 1: |export| - |import| \geq 0 \qquad \text{Equation 2-1}$$

This balance includes all energy carriers (e. g. electricity, district heat, biomass, etc). To compare and weigh the different energy carriers against each other in terms of greenhouse gas emissions or primary energy consumption, *energy metrics* are used. The terms in the ZEB balance inequality can then be expressed as follows [8]:

$$import = \sum_i delivered\ energy(i) \times weighting\ factor(i) \qquad \text{Equation 2-2}$$

$$export = \sum_i feed\ in\ energy(i) \times weighting\ factor(i) \qquad \text{Equation 2-3}$$

The weighting factors/metrics used in this master thesis are *primary energy factors (PEFs)* which will be defined further in the European cost optimal methodology (chapter 0). *i* represents the different energy carriers.

ZEB definition 2, load/generation balance:

The *load/generation* balance is defined in a similar way ([8]):

$$ZEB\ definition\ 2{:}\ |generation| - |load| \geq 0 \qquad \text{Equation 2-4}$$

Where the terms in the inequality can be written as ([8]):

$$generation = \sum_i generated\ energy(i) \times weighting\ factor(i) \qquad \text{Equation 2-5}$$

$$load = \sum_i consumed\ energy(i) \times weighting\ factor(i) \qquad \text{Equation 2-6}$$

The ZEB balances described above can be visualized as in Figure 2-3. The figure illustrates the net zero balance line in relation to the weighted supply and the weighted demand of primary energy, CO_2-emission or whatever metric used in the ZEB balance. This type of illustration is useful to compare different ZEBs. When for example considering the energy supply system for a ZEB, some systems will consume much energy but at the same time export the corresponding amount while others will consume less but hence also export less. This can be useful information when deciding the optimal alternative. Often as little energy demand as possible is desirable.

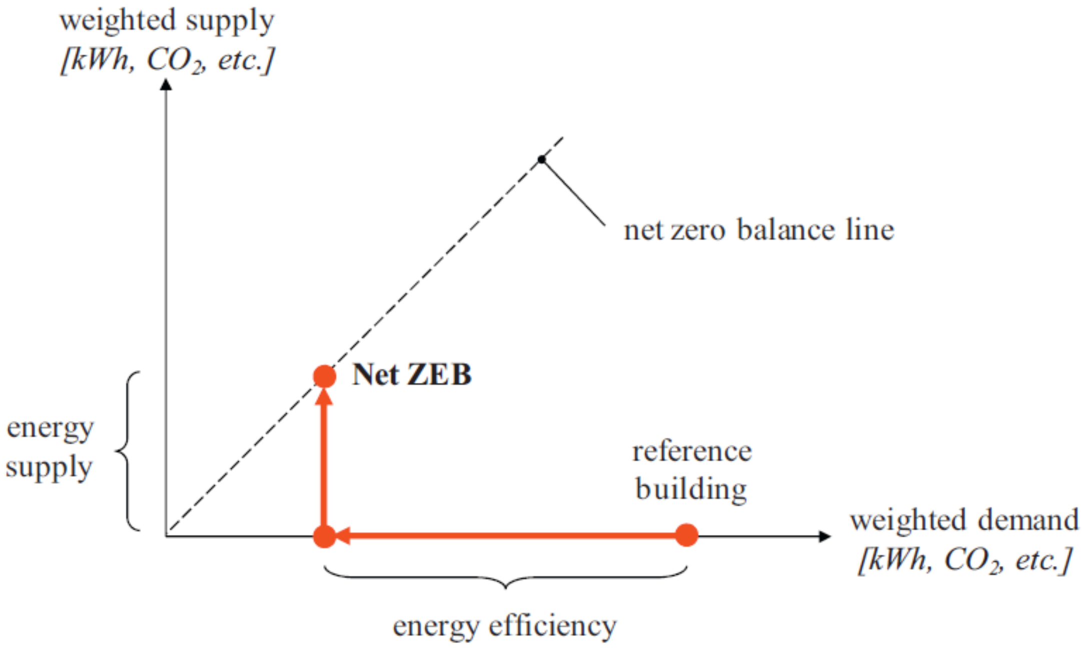


Figure 2-3: Graph representing the net ZEB balance [8]

The definitions above describes how to calculate the energy balance for a ZEB, i. e. where to set the balance and which metrics to use. But there are also different ambition levels for ZEBs. For the most ambitious ZEBs the energy production must be large enough to compensate for both production and demolition of building materials, as well as the operation of the building. Some of the different ambition levels are described in Appendix M.

2.2 The energy performance of buildings directive

In industrial countries energy use in buildings (residential and non-residential) accounts for 30-40 % of the total energy consumption [9]. A reduction of the energy consumption and a more extensive use of energy from renewable sources in the building sector constitute important measures needed to reduce the countries energy dependence and greenhouse gas emissions. In May 2010 EU adopted a revised energy performance of buildings directive (EPBD) to be implemented in national law by 9 July 2012 [10]. The directive is now under processing regarding implementation into the EEA-agreement and thus also Norwegian laws and regulations. The main objective of this directive is to enhance the energy performance of buildings taken into account outdoor climatic conditions, as well as indoor climate requirements and cost-effectiveness. To achieve this objective the directive lay down 31 articles giving requirements regarding:

- a methodology for calculating the energy performance of buildings
- minimum requirements for the energy performance of new buildings and building elements
- minimum requirements for the energy performance of existing buildings and building elements that are subject to major renovation
- national plans for increasing the number of nearly zero energy buildings

In November 2010 a consultation paper was sent out to different companies and authorities regarding potential needs for change in Norwegian law as a result of this directive. Here are summaries of the most relevant articles for this thesis and theirs relations to the current Norwegian laws and regulations based on the consultation response from Tore Strandskog (Norsk Teknologi) [11]:

Member States shall apply a methodology for calculating the energy performance of buildings in accordance with the common general framework set out in Annex 1 [12].

In Norway the standard NS 3031 [13] was developed for this purpose, and covers all the requirements given in this article.

Member states shall establish minimum standards for the energy performance for new and renovated buildings that are cost-optimal over the lifetime of the building. Furthermore, member states shall adopt measures which ensures that energy performance when replacing new building element is cost-optimal [12].

The TEK10 regulation is in accordance with the directive’s provisions.

The Commission shall establish a comparative methodology framework for calculating cost-optimal levels of minimum energy performance for buildings and building elements [12].

This is where the European cost optimal methodology first is introduced, which is the methodology used for the cost calculations in this study. As given in the article this methodology was established by the European Commission to compare and select different energy measures on a building. The methodology will be further explained in the next section.

Member States shall take the necessary measures to ensure that new buildings meet the minimum energy performance requirements set in accordance with Article 4. For new buildings, Member States shall ensure that, before construction starts, the technical, environmental and economic feasibility of high-efficiency alternatives (heat pumps, cogeneration, district heating etc) is considered and taken into account [12].

This article demonstrates the need to consider high-efficiency energy supply systems for new buildings, and take the necessary steps to reach the relevant energy target (TEK10, PH, ZEB). This master thesis is a part of finding solutions to these types of problems.

Member States shall ensure that by 31 December 2020 all new buildings are nearly zero-energy buildings. New buildings occupied and owned by public authorities shall be nearly zero-energy buildings by 31 December 2018 [12].

This article shows how relevant zero emission buildings are, and how important it is to conduct research on this. The Commission puts the responsibility on the member states to ensure that all new buildings will be n-ZEB by 2020. In Norway the most important measure for this task was the creation of the Research Center on Zero Emission Buildings.

2.3 The European cost optimal methodology

2.3.1 Introduction

"The European cost optimal methodology specifies how to compare energy efficiency measures, measures incorporating renewable energy resources and packages of such measures in relation to their energy performance and the cost attributed to their implementation and how to apply these to selected energy reference buildings with the aim of identifying cost-optimal levels of minimum energy performance requirements" [14]

The European cost optimal methodology makes it possible to compare and choose between different energy supply solutions, for example a bio stove or a heat pump, or other energy measures, even though they may have different annual costs, different lifetimes, consume different fuels, etc. This is possible by converting all costs attributed to their implementation into global costs, and their energy consumption into primary energy consumption. This is described in detail further down. It should be pointed out that the tool aims to calculate cost optimal energy supply solutions and other energy measures, given some minimum energy performance requirements, for any buildings at an early construction phase instead of being limited to one or few reference buildings.

2.3.2 Calculation of global costs

Global cost calculation makes it possible to compare different energy supply solutions and other energy measures in an economic life cycle perspective. The global cost of an energy measure is the net present value of all costs associated with it during the defined calculation period. Long lasting equipment can be taken into account by subtracting its residual value at the end of the calculation period. An alternative to global cost calculation is the annuity method, which transforms any costs to an average annualized cost. The advantage of the global cost method is that it allows the use of a uniform calculation period. According to the European cost optimal methodology-regulation [15], member states shall use a calculation period of 30 years for residential buildings, and a calculation period of 20 years for non-residential buildings.

According to the European Commission the following separate cost categories shall be used [15]:

a) *Initial investment costs*

b) *Running costs.* This should include periodic replacement costs and maintenance. Energy produced by renewable energy sources on-site should be regarded as earnings in the financial calculation

c) *Energy costs*. Shall reflect overall energy cost including energy price, capacity tariffs and grid tariffs

d) *Disposal costs*. If appropriate

For the calculation at a macroeconomic level, the following cost category should also be included:

e) Cost of greenhouse gas emissions

Real discount rate:

The discount rate is used in discounted cash flow analysis to determine the present value of future cash flows (see discount factor). The discount rate takes into account the time value of money, i. e. 1000 NOK today is worth more than 1000 NOK next year since interest can be earned, for example by putting the money in the bank. The real discount rate also takes into account the inflation rate and is given as ([16]):

$$R_R = \frac{R - R_i}{1 + R_i/100} \qquad [\%] \qquad \text{Equation 2-7}$$

where

R is the market interest rate;

R_i is the inflation rate.

The linear approximation of Equation 2-7 given as follows

$$R_R = R - R_i \qquad [\%] \qquad \text{Equation 2-8}$$

is widely used.

Discount factor:

The discount factor is used to determine the net present value of a future cost, and is given as [16]:

$$R_D(p) = \left(\frac{1}{1 + R_R/100}\right)^p \qquad [\text{-}] \qquad \text{Equation 2-9}$$

where

p is the number of years after the starting period.

Global cost calculation can be done at a financial or a macroeconomic level. At a financial level the relevant prices to be taken into account are the prices paid by the customer, including both taxes and ideally also subsidies. This method only considers the immediate costs and benefits of the investment decision. The macroeconomic perspective on the other hand looks at other indirect costs and benefits that are relevant to the society as a whole, including the cost of greenhouse gas emissions. Taxes and subsidies are excluded in the calculations. The macroeconomic perspective makes it easier to compare investment in energy efficient buildings against other measures that reduce energy use, energy dependency and CO_2-emissions. According to The European Commission [14] it is up to the Member States to decide which of the calculations is to be used as the national cost optimal benchmark.

Global costs in a financial perspective:

Global costs shall be calculated by summing the different types of costs and apply to these the discount factor so to express them in terms of value in the starting year plus the discounted residual value, given as follows [15]:

$$C_G(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} \left(C_{a,i}(j) \times R_D(i) \right) - V_{f,\tau}(j) \right] \quad \text{[NOK]} \qquad \text{Equation 2-10}$$

where:

τ	means the calculation period;
$C_G(\tau)$	means global cost (referred to starting year τ_0) over the calculation period;
C_I	means initial investment costs;
$C_{a,i}(j)$	means annual cost at year i for component j;
$R_D(i)$	means discount factor for year i;
$V_{f,\tau}(j)$	means final value of component j at the end of the calculation period.

If the annual costs ($C_{a,i}(j)$) and the real discount rate are assumed constant, the last sum in this equation can be regarded as a difference between two converging geometric series, where *i* is ranging from 1 to ∞ and from $\tau+1$ to ∞. By using the fact that the sum of such series can be written as [17]:

$$\sum_{i=1}^{\infty} ar^{i-1} = \frac{a}{1-r} \qquad \text{where } |r|<1 \qquad \text{Equation 2-11}$$

Equation 2-10 can be rewritten as:

$$C_G(\tau) = C_I + \sum_j \left[C_{a,i}(j) \times \left(\frac{1 - R_D(\tau+1)}{1 - R_D(1)} - 1 \right) - V_{f,\tau}(j) \right] \qquad \text{Equation 2-12}$$

Global costs in a macroeconomic perspective:

The global cost in a macroeconomic perspective can be written as [15]:

$$C_G(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} \left(C_{a,i}(j) \times R_D(i) + C_{c,i}(j) \right) - V_{f,\tau}(j) \right] \quad \text{[NOK]} \quad \text{Equation 2-13}$$

where:

$C_{c,i}(j)$ means carbon cost for at year I for component j.

Final value:

The estimated lifecycle of equipment and buildings elements in the global cost calculation can either be longer or shorter than the calculation period. If the lifecycle is shorter than the calculation period the building elements or equipment will be replaced with an additional investment cost. At the end of the calculation period the final value of all building elements and equipment will be determined and referred back to the starting year as a negative investment cost. The final value of a component is determined by straight-line depreciation of the initial investment cost or the last replacement cost until the end of the calculation period [13]. This is illustrated in Figure 2-4. The final value can be calculated as follows [16]:

$$V_{f,\tau}(j) = V_o(j) \times (1 + R_p/100)^{n_\tau(j) \times \tau_n(j)} \times \left[\frac{(n_\tau(j) + 1) \times \tau_n(j) - \tau}{\tau_n(j)} \right] \times R_D(\tau) \quad \text{[NOK]}$$

$$\text{Equation 2-14}$$

where

$n_\tau(j)$ represents the total number of replacements of component j throughout the calculation period;

$R_D(\tau)$ is the discount factor at the end of the calculation period;

$V_o(j) \times (1 + R_p/100)^{n_\tau(j) \times \tau_n(j)}$ represents the last replacement cost, when taking into account the price development for the product, R_p (inflation rate is used in this study);

$\left[\frac{(n_\tau(j)+1) \times \tau_n(j) - \tau}{\tau_n(j)} \right]$ is the straight-line depreciation of the last replacement cost.

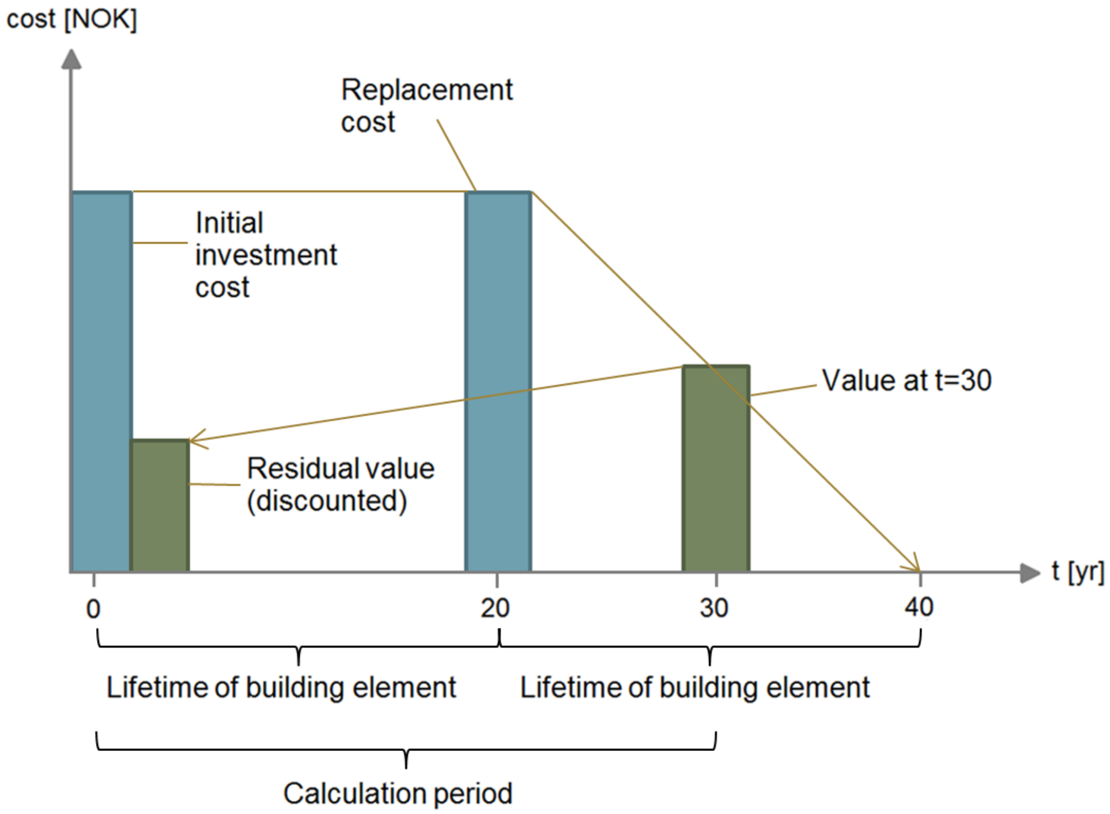


Figure 2-4: Illustration of the final value of a building element

2.3.3 Primary energy- and CO_2-factors

As described in chapter 2.1 some sort of weighting factors are needed for comparing different energy supply systems in an environmentally friendly manner, depending on the appropriate ZEB-definition. This is because different energy carriers are bound to different energy losses and greenhouse gas emissions when considering each step in the energy value chain (extraction, transformation, distribution, etc). As described in the regulation [15], primary energy calculation makes the basis in the European cost optimal calculation, but as mentioned earlier the cost of carbon emission are needed for the macroeconomic evaluation. Since both a financial and a macroeconomic analysis will be performed in this master thesis, a definition for both primary energy factors and CO_2-factors are needed:

Primary energy factors:

Primary energy is usually defined as energy in its original form [2]. Examples of primary energy sources are coal, crude, natural gas, uranium, bio energy, potential energy in sun, wind and water. The primary energy sources usually have little utility in their original form. They have to be extracted, distributed, transformed and transported before delivered as useful energy to the retail.

During these processes there will be energy losses, preventing a complete utilization of the primary energy. This is illustrated in Figure 2-5

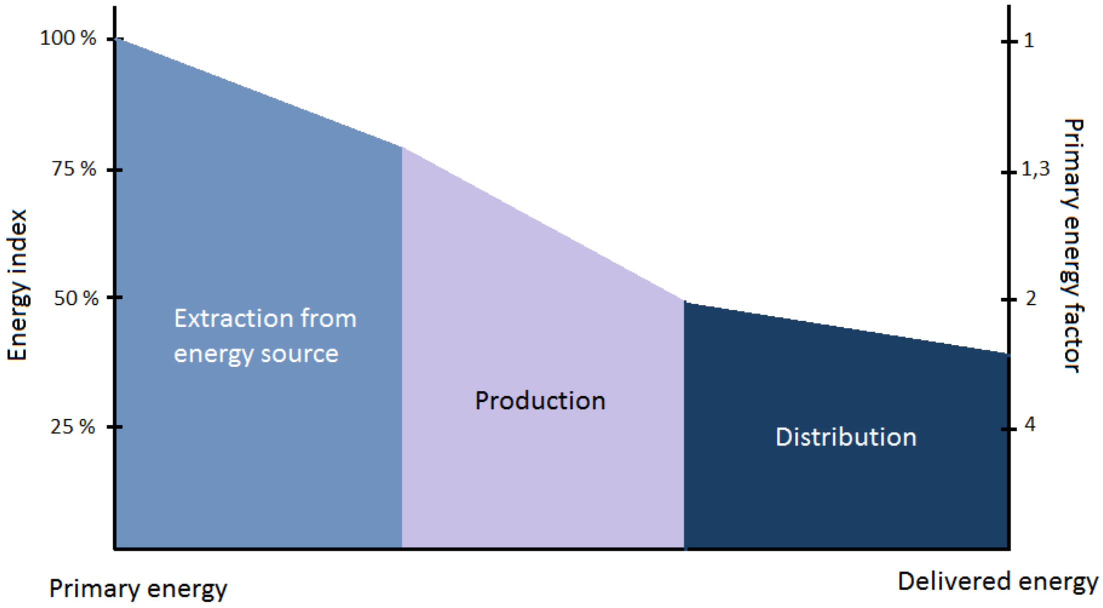


Figure 2-5: Illustration of energy losses from primary energy to delivered energy, adapted from [2]

The relationship between primary energy and delivered energy can be defined as the primary energy factor (PEF). The PEF indicates how efficient the primary energy is being utilized. The system efficiency is the inverse of the PEF.

$$primary\ energy \times system\ efficiency = delivered\ energy \qquad \text{Equation 2-15}$$

$$delivered\ energy \times PEF = primary\ energy \qquad \text{Equation 2-16}$$

There are usually some challenges with defining PEFs. For example how to define the geographical scope for the PEFs, how energy is processed and distributed in this area, efficiencies in the energy production, etc. In international statistics there are essentially two methods for calculating primary energy factors: the partial substitution method and the physical energy content method [18]. The main difference between these methods is based on how they calculate PEFs for nuclear power and renewable power (hydro, sun, geothermal, etc). In both methods the form of the primary energy to be considered must be defined. In for example hydro power, the choice is between the kinetic energy in the water and the electricity generated. For photovoltaic electricity, the choice is between the received solar radiation and the electricity generated. A rule of thumb is that the primary energy form should be the first energy form downstream in the production process where multiple energy uses are practical, leading to the following primary energy forms [18]:

- **Heat:** Geothermal and solar thermal
- **Electricity:** hydro, wind, tide/wave/ocean, photovoltaic

In the partial substitution method the primary energy equivalent of the above sources of electricity generation is the amount of energy that would be necessary to generate a given amount of electricity in a conventional thermal power plant (coal, oil, gas). This method is not relevant for countries with a high share of hydro generation though, such as Norway, since efficiency in a hydro plant isn’t the same as the efficiency in for example a coal plant. This is why the physical energy content method has been developed. This method considers heat as the primary energy from nuclear power and geothermal power and uses 33% and 10% as efficiencies respectively. For hydro, sun and wind the primary energy is set equal as the electricity production, i. e. 100% efficiency. The physical energy content method gives in many cases a more exact picture of the primary energy consumption than the partial substitution method [2].

In addition to these two methods the European Committee for Standardization (CEN) has developed a model described in the standard NS:EN 15603:2008 [19]. The main purpose with this model is to focus attention on the primary energy consumed by buildings. The model distinguishes between two PEFs: the total primary energy factor and the non-renewable primary energy factor. The total primary energy factor considers all losses in the energy value chain, and will for this reason always exceed unity (see Figure 2-5). The non-renewable primary energy factor represents the same energy overheads as the total primary energy factor, except that it excludes renewable energy components. This is why non-renewable primary energy factors may be less than unity for renewable energy sources.

CO_2-factors:

A CO_2-factor gives the relationship between carbon emission and the consumption of different energy carriers (delivered energy). The factor may include other greenhouse gases than CO_2, but they are usually calculated as CO_2-equivalents according to how much they contribute to global warming [2]. How to calculate indirect greenhouse gas emission caused by energy use in buildings is described in the standard NS:EN 15603:2008 [19]. According to the standard the CO_2-factor for a given energy carrier shall include all CO_2-emissions in the energy value chain (transformation, transportation, distribution, etc.) back to when the primary energy were extracted. In addition the standard suggests that an annex with CO_2-factors shall be developed at a national level. This has not been done in Norway [13], but guiding values exist in NS:EN 15603:2008 (see Appendix H)

In Table 2-1 PEFs and CO_2 factors for electricity, pellets and district heating are defined. The values are obtained from [8], and can also be found in Appendix I and Appendix J. Since no PEFs have been developed for the Norwegian marked yet, the PEFs in Table 2-1 are based on German values. The table includes both the total primary energy factors and the non-renewable primary energy factors.

Table 2-1: Primary energy factors and CO_2 factors, obtained from [8]

Energy carrier	Total primary energy factors [kWh/kWh]	El equivalent total	Non-renewable primary energy factor [kWh/kWh]	El equivalent n.r.	CO_2 factor [g CO_2/kWh]
Electricity	3.0	1	2.6	1	395
Pellets	1.2	0.4	0.2	0.08	14
District heating	0.7	0.23	0.7	0.27	231

2.3.4 Calculation of primary energy consumption and CO_2-emission

To calculate a buildings primary energy consumption and CO_2-emission, the delivered energy to the building is needed as given in Equation 2-16. According to the methodology [15], it’s convenient to calculate according to Figure 2-6, from left to right. I. e. energy need -> energy use -> delivered energy. First the energy need for heating and cooling shall be decided. Subsequently the energy use for space heating, ventilation, domestic hot water, lightning and equipment is calculated taken into account efficiencies in energy supply systems. The need for delivered energy to the building is decided after energy produced and consumed on-site is accounted for. Delivered primary energy is calculated using appropriate PEFs as given in Equation 2-6. Primary energy consumed by the building is the difference between primary energy delivered and primary energy exported. The calculation described above can be a complicated process considering that both the energy need and the performance of energy supply systems are highly dependent on weather and climate. Therefore carefully validated simulation tools like SIMIEN [20] or IDA-ICE [21] have to be used.

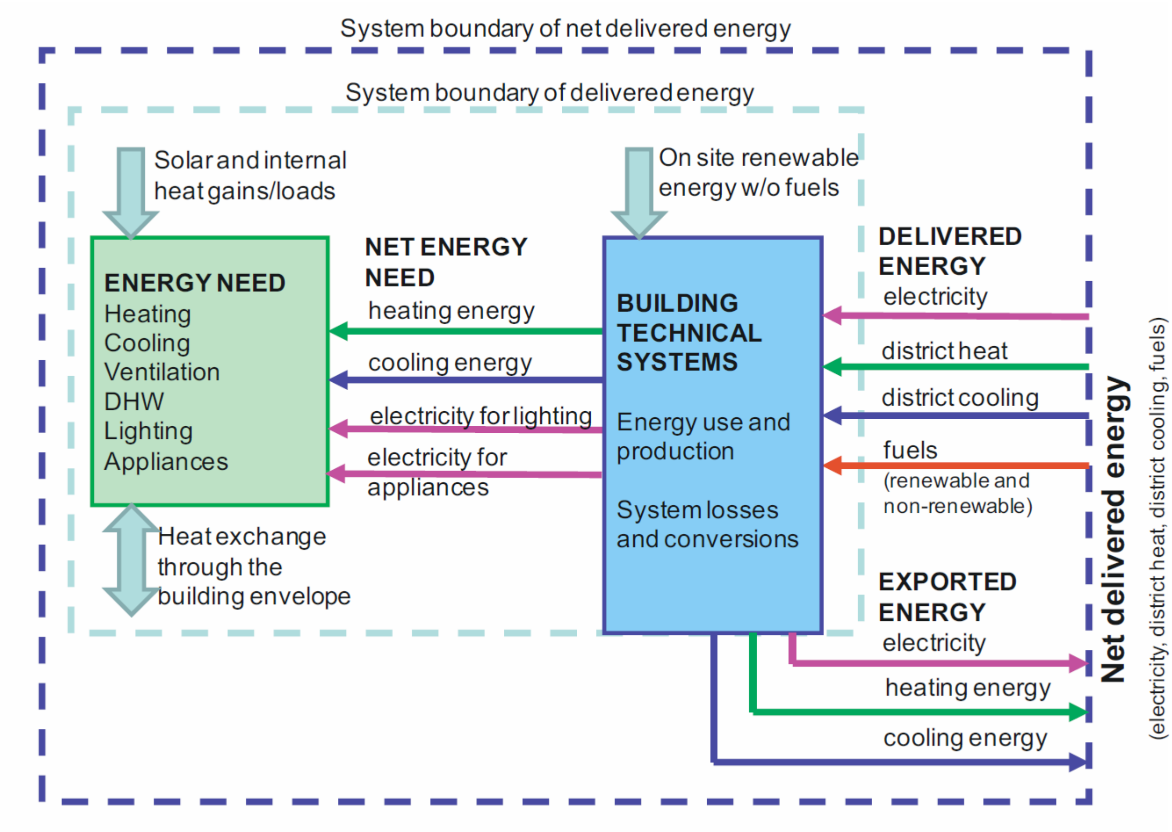


Figure 2-6: Schematic representation of the connection between energy need, energy use, delivered energy and exported energy [22]

Based on the simulated demand for different energy carriers the need for primary energy and CO_2-emission can be calculated.

The annual primary energy consumption:

$$E_{prim} = \sum_i (E_{del,i}\, f_{prim,del,i}) - \sum_i (E_{exp,i}\, f_{prim,exp,i}) \qquad [\text{kWh}] \qquad \text{Equation 2-17}$$

where

E_{prim} is annual primary energy consumption given in kWh;

$E_{del,i}$ is annual delivered energy from energy carrier *i,* in kWh;

$E_{exp,i}$ is annual exported energy from energy carrier *i,* in kWh;

$f_{prim,del,i}$ is the PEF for the delivered energy carrier *i*, in kWh/kWh;

$f_{prim,exp,i}$ is the PEF for the exported energy carrier *i*, in kWh/kWh.

The annual CO_2 emission is given by:

$$m_{CO2} = \sum_i (E_{del,i}\, K_{del,i}) - \sum_i (E_{exp,i}\, K_{exp,i}) \qquad \text{[kg]} \qquad \text{Equation 2-18}$$

where

m_{CO2}	is annual CO_2-emission, in kilogram;
$E_{del,i}$	is annual delivered energy from energy carrier *i,* in kWh;
$E_{exp,i}$	is annual exported energy from energy carrier *i,* in kWh;
$K_{del,i}$	is the CO_2-factor for the delivered energy carrier *i*, in kWh/kWh;
$K_{exp,i}$	is the CO_2-factor for the exported energy carrier *i*, in kWh/kWh.

2.3.5 Deciding the cost optimal alternative

Based on the calculations of primary energy use and global cost associated with different energy supply solutions or other energy measures, the cost optimal alternative can be decided. Generally there are some minimum energy requirements that have to be fulfilled, like TEK10, PH, ZEB, etc. When these requirements are met the optimal alternative will be the one associated with the lowest global cost. This is illustrated in Figure 2-7. If two or more packages have similar global costs, the one associated with the least primary energy consumption should be the preferred alternative [14].

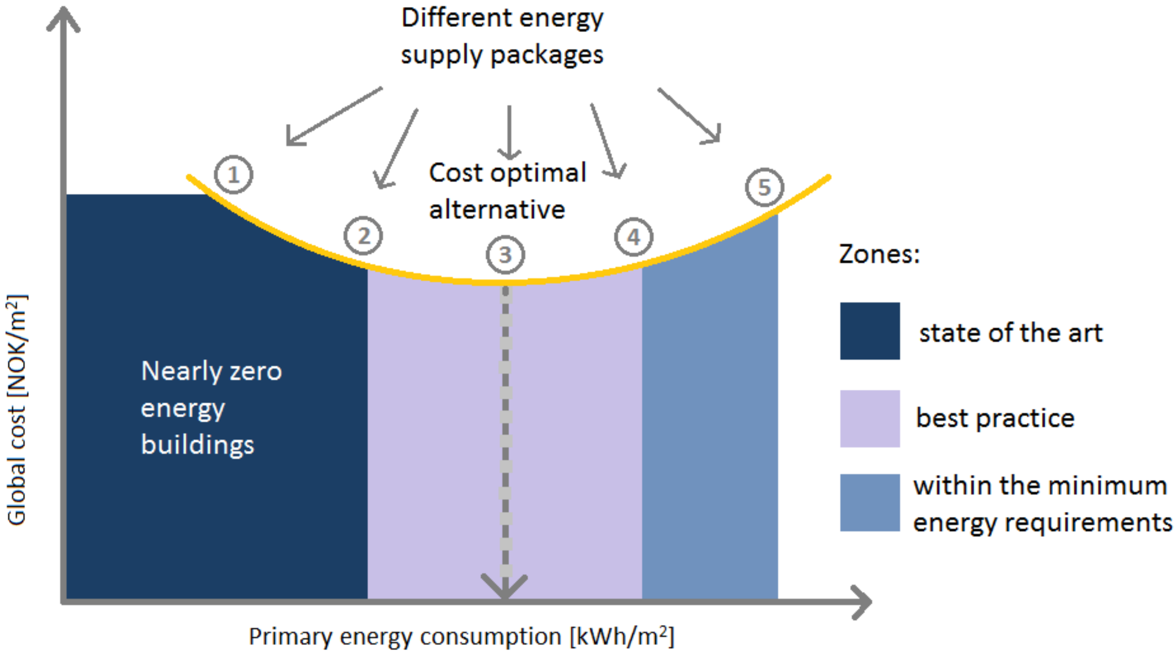


Figure 2-7: Deciding the cost optimal system, adapted from [23]

For a ZEB the net primary energy consumption should by definition be zero, and therefore all packages will be placed on the y-axis in Figure 2-7. In those cases, given that the ZEB target is reached for all packages, the one with the lowest global cost should be the chosen alternative.

2.4 Energy supply systems

For a ZEB to fulfill the definition described in the chapter 2.1, it has to produce energy from renewable energy sources. In addition the ZEB must be able to feed surplus energy back to the grid. On-site electricity production is therefore a minimum requirement when designing a ZEB's energy supply system. In addition to electricity, some sort of heat supply is needed. Heat supply systems can be either standalone systems or central systems [24]. The difference is that standalone systems only provide one type of heat (space heating, hot water, etc.) while the central systems cover all needs. The latter requires waterborne heat distribution in the building. Since waterborne heat distribution is assumed necessary for ZEBs, only central systems will be considered in this study.

There are also some practical challenges that have to be considered when deciding the most applicable technologies, like space requirements and noise from the systems. In addition the maturity of the different technologies should be considered. Although it's worth mentioning that even if some technologies are immature today, they might be a vital alternative for future ZEBs.

Based on the criteria mentioned the following technologies will be considered in this study: Heat Pump (HP), Biomass Boiler (BB), District Heating (DH), Photovoltaic (PV), Solar Thermal (ST) and Combined Heat and Power (CHP). Their main pros and cons are evaluated in Table 2-2.

Table 2-2: Main advantages and drawbacks with the applicable technologies, adapted from [25]

Technology	Pros	Cons
Heat pumps	• Mature technology • Can cover both heating and cooling demands • Can use waist heat as a heat source (ventilation air)	• High investment cost (brine-to-brine HP) • Needs electricity
Biomass boilers	• Low GHG emissions from a life-cycle perspective • Mature technology • It's economically competitive	• Possible local pollution • Requires a chimney/flue
District heating	• Utilize heat which else has limited value • Well known and well developed technology	• High infrastructure investment • Only available in areas with high consumer density
Photovoltaic	• Produces electricity directly from the sun (free fuel) • Long lifetime/robust (no moving parts)	• High investment cost • Variable performance throughout the year (season dependent)
Solar thermal	• Mature technology • Free fuel	• Needs additional heating system • Lack of experience in Norway • Small production when demands are high
Combined heat and power	• High combined efficiency • Higher thermodynamic efficiency (exergy) than heat pumps and bio stoves • Can use many different types of fuel, both gaseous and liquid fuels	• Usually doesn't use renewables directly. Need additional systems to make biogas or hydrogen gas. • Few systems in Norway, and little experience • An additional heating system is usually needed, especially for ZEBs

In the following there will be a brief introduction to the technologies mentioned above with their main technical and economical characteristics relevant for the calculations.

2.4.1 Heat pumps

Heat pumps are devices that are designed to move thermal energy opposite the direction of spontaneous heat flow, i. e. from a colder heat source to a warmer heat sink. This is obtained by using a relatively small amount of high quality energy such as electricity. Theoretically, the total heat quantity delivered by the heat pump is equal to the heat quantity extracted from the heat source plus the amount of drive energy supplied [25]. The performance of the heat pump is usually described by the *coefficient of performance* (COP) which is the ratio between the heat quantity delivered and the amount of electricity supplied. The COP is highly dependent on the source and sink temperatures as illustrated in Figure 2-8 and Figure 2-9.

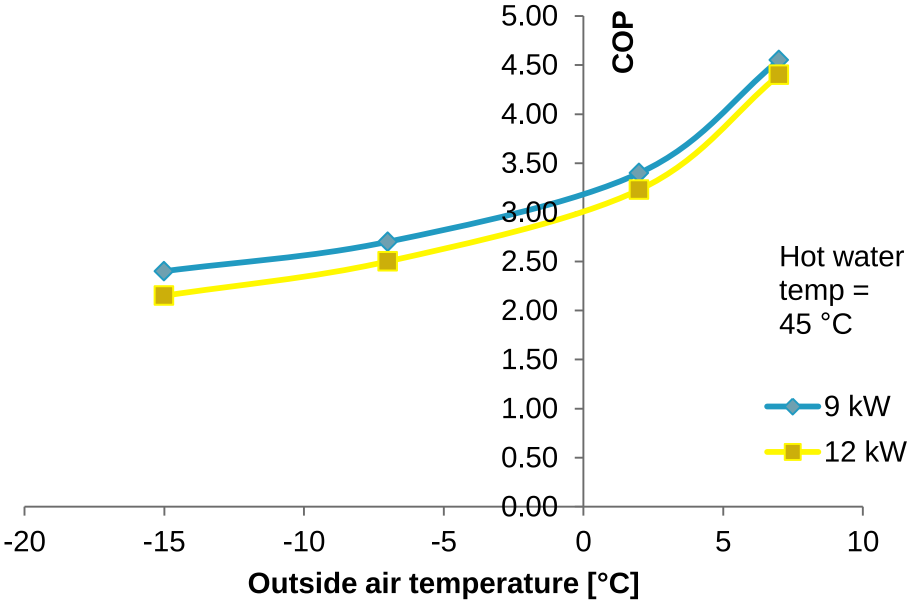


Figure 2-8: COP variations with outside air temperature, obtained from the earlier project work [26]. Heat sink temp = 45 °C

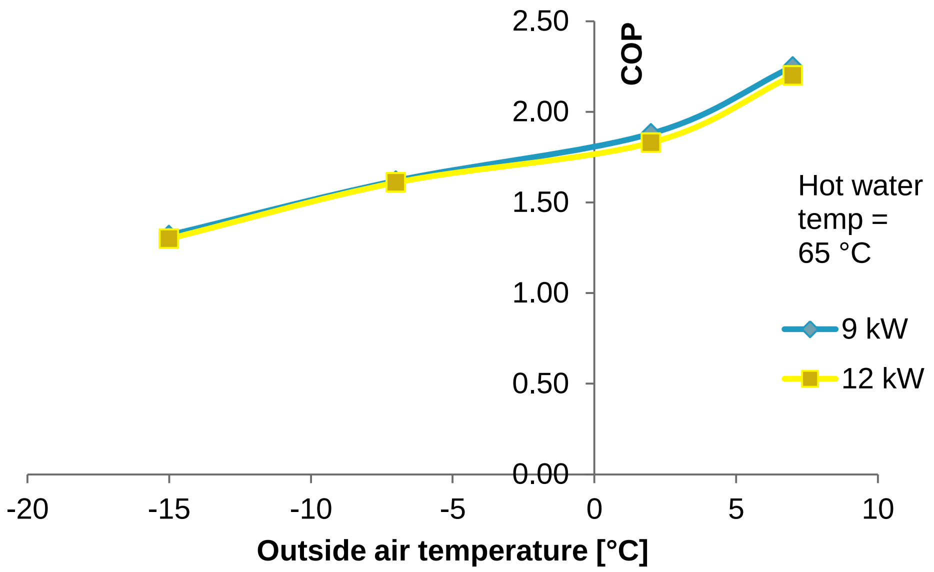


Figure 2-9: COP variations with outside air temperature, obtained from the earlier project work [26]. Heat sink temp = 65 °C

Heat pumps can use different types of heat sources, such as ambient air, exhaust air, sea water, rivers, or ground sources [25]. Some advantages and disadvantages with the different heat sources are listed below:

- Ambient air is the most available and most common source. This is mainly because heat pumps utilizing ambient air have the lowest investment cost. However, the seasonal performance is lower than for other sources due to low temperatures in the winter. In many cases a better alternative is to utilize the exhaust (ventilation) air. The advantage with this is a higher and more stable source temperature, and the positive effect of utilizing heat which else would be lost.

- Water based sources has the advantage of a more stable source temperatures. Rivers, lakes and sea water are in principle good heat sources, but great care has to be taken in system design to avoid freezing of the evaporator in winter time. Ground water systems have higher and even more stable source temperatures between 4 and 10 °C [25]. The drawback is the high investment cost for such systems.

- Ground source systems have, as ground water systems, a stable and high source temperature providing a high COP. In addition the bedrock can be used to store heat as an underground thermal storage. It’s also worth mentioning that ground source systems can be installed almost anywhere. The downside is the high cost of installing such systems due to the necessary borehole which in most cases must be over 100 m deep.

2.4.2 Biomass boilers

The material of plants and animals, including their wastes and residues, is called biomass [27]. Biomass is an organic, carbon-based material that reacts with oxygen in combustion to release heat. It's considered renewable if growth keeps pace with use, and will in that case not contribute to greenhouse gas emissions either.

Woody biomass is the most commonly used fuel and comes in different forms, mainly wood logs, wood chips and wood pellets. Wood chips are the least expensive, but are mostly only available in larger systems (> 100 kW) [25]. Wood pellets are more applicable for households, but have a higher production cost than logs and chips. Wood logs lie in between pellets and chips when it comes to price, but requires more labor as you have to feed the boiler manually.

The performance of bio boilers roughly vary between 10-80 kW [24]. The boilers have to be placed in an own boiler room and connected to a chimney. Since the boilers are connected to a waterborne heat distribution system, they usually cover the buildings entire demand for space heating and hot water. They can also be combined with other heat supply systems such as solar thermal collectors. The space required for storage of pellets is relatively large. For a house with an annual heating demand of 10000 kWh, approximately 2.9 m^3 pellets are needed. The pellets can be stored inside and refilled during the heating season, or can be stored outside in a silo containing one year's supply [24].

Heating is a very efficient use of biomass, with modern boilers achieving >90% efficiency. On the other hand, if considering thermodynamic efficiency (exergy), combustion of biomass scores very low (6.1%) compared to for example *combined heat and power* (34%) [25]

2.4.3 District heating

A DH system produces, delivers and distributes hot water or other heat carriers to external users. The use of DH requires that the building has installed a waterborne heat distribution system. A DH system consists of a heat central and a distribution network. The heat input usually comes from combustion of waste, biomass, bio fuel, coal oil or natural gas. But heat can also be delivered from heat pumps, geothermal, or waste heat from industry [25]. The heat distribution network is a closed pipe system where water (or other heat carriers) circulates with temperatures around 45-120 °C. The water releases heat to the users and is then returned back to the heat central for heating. The heat distribution network consists of isolated steel pipes (16 or 25 bar) or plastic pipes (5 bar) buried in sand. The heat loss in the distribution network constitutes about 5-15 % of the heat central's annual production [24]. The overall system efficiency for DH, including production and distribution losses, is given in the standard NS 3031 as 0.84.

2.4.4 Photovoltaic

PV is a semiconductor device that produces electricity directly when exposed to light. There are many types of PV in modern technology depending on application (performance, efficiency, flexibility, lifetime, etc.), but for electricity production in buildings silicon based PVs are most used. Silicon based PVs consist of mono-crystalline (m-Si), poly-crystalline (p-Si) and amorphous silicon (a-Si).

PV systems can generally be divided into two different systems, stand-alone-systems and grid-connected systems. Since stand-alone-systems are not connected to the grid and therefore some sort of storage is needed to ensure electricity production during cloudy days. Today, the most practical option for this purpose is lead-acid or nickel/cadmium batteries. Stand-alone-systems can be found in buildings where grid-connection is not possible, such as cabins in Norway. They are typically about 1 kW in size and can provide electricity for low load applications such as refrigeration, lightning, etc. [25]. A grid-connected system is installed to give the option of exporting excess energy to the grid, which is necessary for all ZEBs. It comprises of PV modules and Balance of System (BoS) components [28]. The BoS components usually include the inverter, mounting system, cabling, protection, disconnection switches and system monitoring.

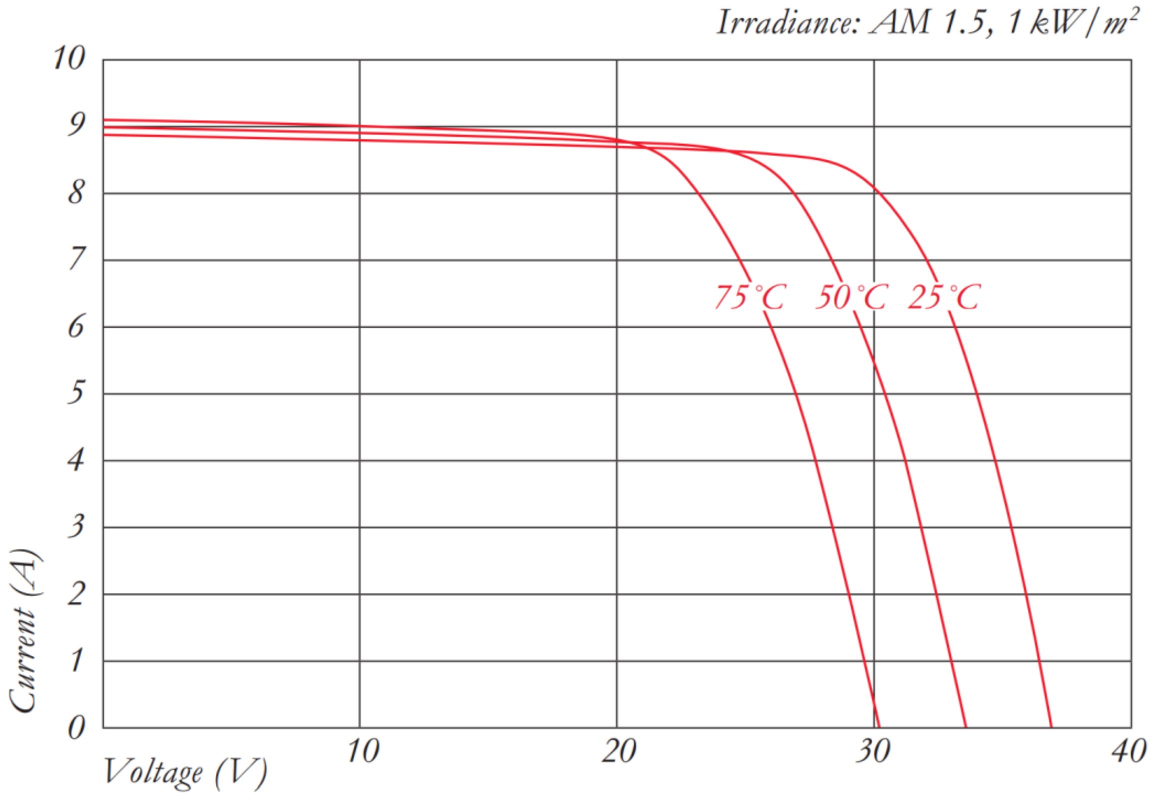


Figure 2-10: Current-voltage characteristics for different cell temperatures [29]

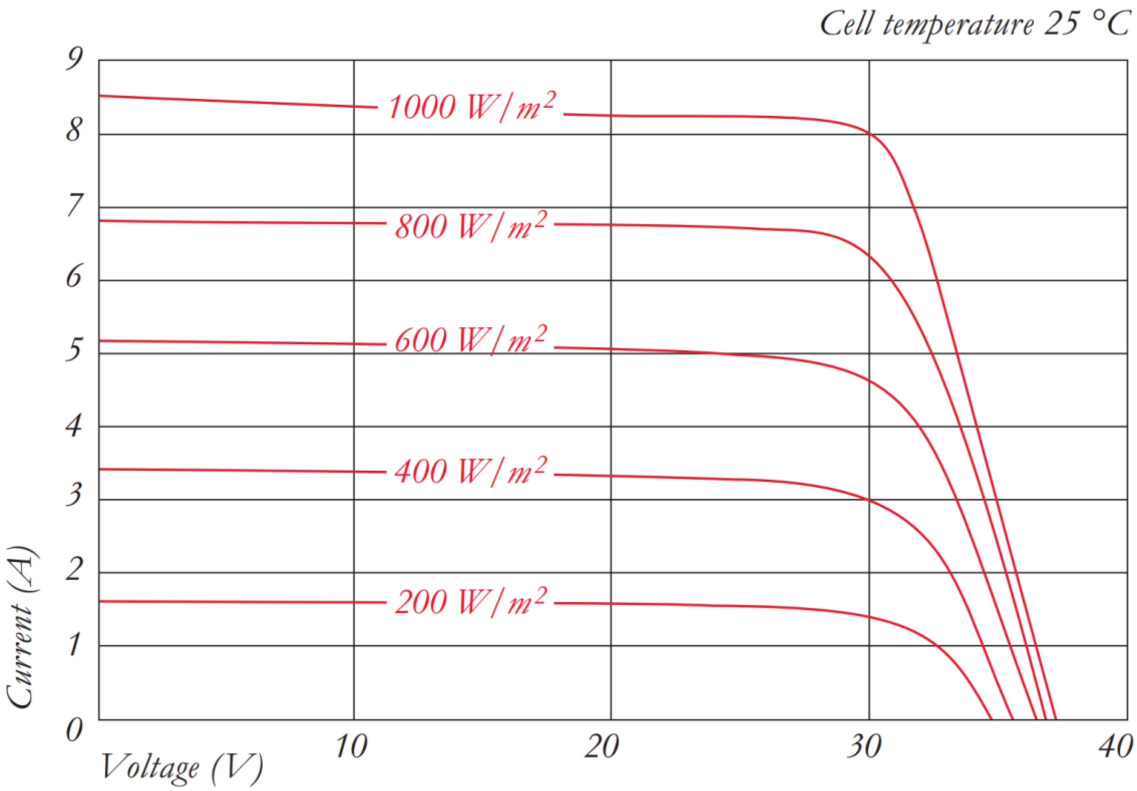


Figure 2-11: Current-voltage characteristics for various irradiance levels [29]

The performance of the solar cell is highly dependent on working conditions like solar irradiance and temperature, as illustrated in Figure 2-10 Figure 2-11. The current generated in a solar cell is directly proportional to the photon flux. The voltage variation is small (depend logarithmically on the irradiance), and therefore usually neglected in practical applications. The effect of temperature is not so obvious, but has an important influence on the efficiency of the cell. The temperature of the solar cell is namely not the same as the ambient temperature. Nevertheless the temperature of the solar cell can be estimated by using the fact that the difference between the cell temperature and the ambient temperature is linearly dependent on irradiance. By measuring the cell temperature under some reference conditions, usually called the *normal operating cell temperature* (NOCT), this linear dependence can easily be obtained. Typically the voltage will decrease with increasing temperature with about 2.3 mV per °C. The temperature variation of the current or the fill factor are less pronounced, and are usually neglected [30].

2.4.5 Solar thermal collectors

According to the report *Solar Heat Worldwide [31]* Norway has 13 MW of ST installed which is about 18500 m^2. If the growth rate of ST in Norway is similar to the growth in EU in the 2000s, there will be installed about 220000 m^2 ST in Norway within 2020 [32]. At the same time, as stated in The energy performance of buildings directive, all new buildings shall be nearly-ZEB by 2020. This indicates that ST will be an important energy supply system for ZEBs in the future.

The main components in a ST system are the collectors, heating storage and heat distribution system, as illustrated in Figure 2-12. The distribution system consists of pipes, pumps and valves, delivering the heat from the collector to the building. In most cases also an automatic control unit is needed to ensure efficient system control. The control unit can for example switch pumps on and off depending on temperature and irradiation [33].

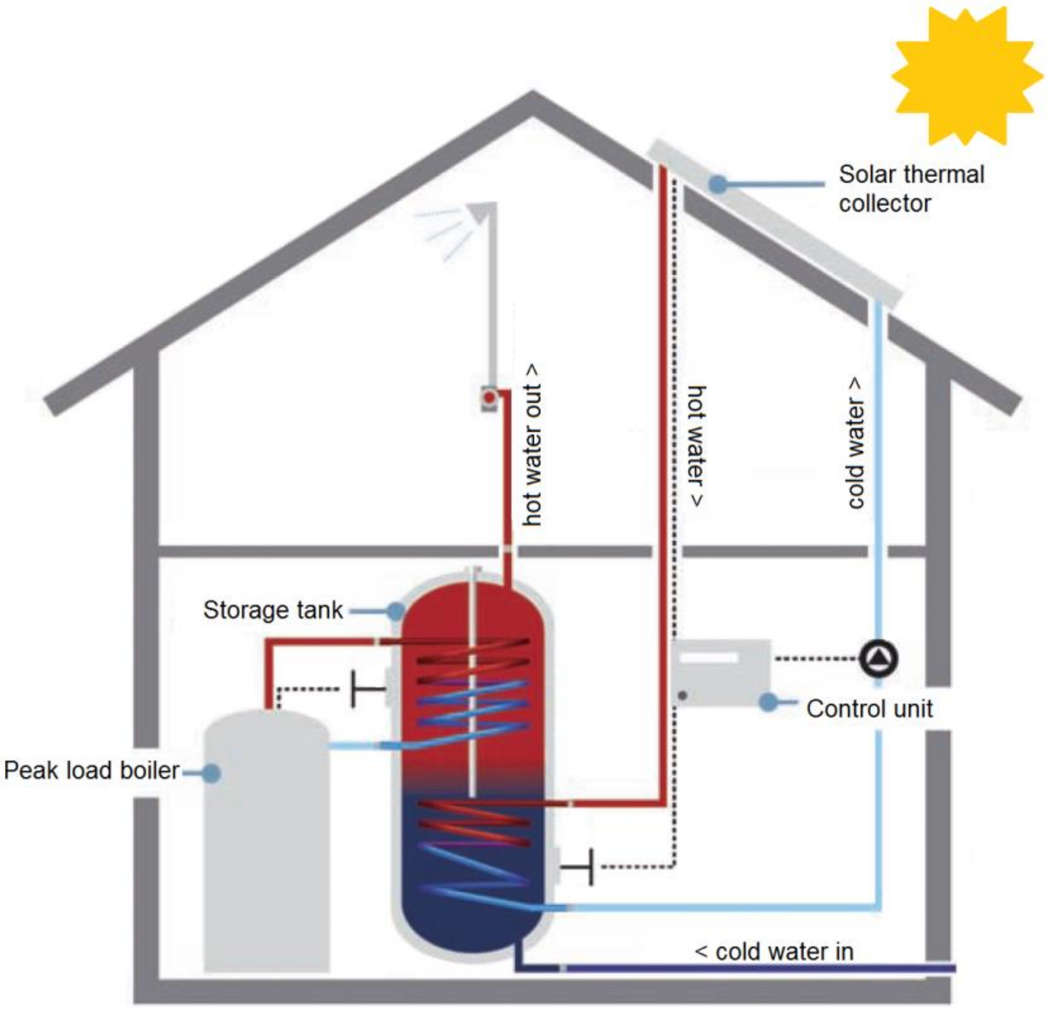


Figure 2-12: Solar thermal system, adopted from [33]

There are two main types of STs applicable for energy supply in buildings: flat plate collectors and vacuum tube collectors. Both collectors consist of three main parts: absorber, cover and isolation [33].

Flat plate STs:

The absorber is the central part of every ST system and is for flat plates usually made up by a thin black metal plate with a selective surface to prevent infrared emission. A transparent cover is usually applied on top of the ST to improve the efficiency. The cover works as a heat trap as it lets short wavelength through while it prevents long wavelength radiation from letting out. It also prevents convection losses from the absorber, especially in cold and windy weather conditions.

The efficiency is highly dependent on the temperature difference between the outside air and the heat carrier, but also on irradiance. To achieve a high efficiency the STs should therefore be used for low temperature heat distribution systems, such as floor or roof systems [24]

Vacuum tube STs:

Vacuum tube STs are made up by one- or two-layer glass tubes, where the inner layer is coated with an absorbing material. Inside the inner tube, metal plates or metal tubes (usually copper) are placed which is connected to the pipe system for the heat carrier. Since the air pressure is very low in and between the pipes, the heat loss is less than for flat plate STs. Vacuum tubes are therefore more applicable in colder climate and for hot water production. Because of low production costs in China the price for vacuum tube STs are comparable with the best flat plate STs [24].

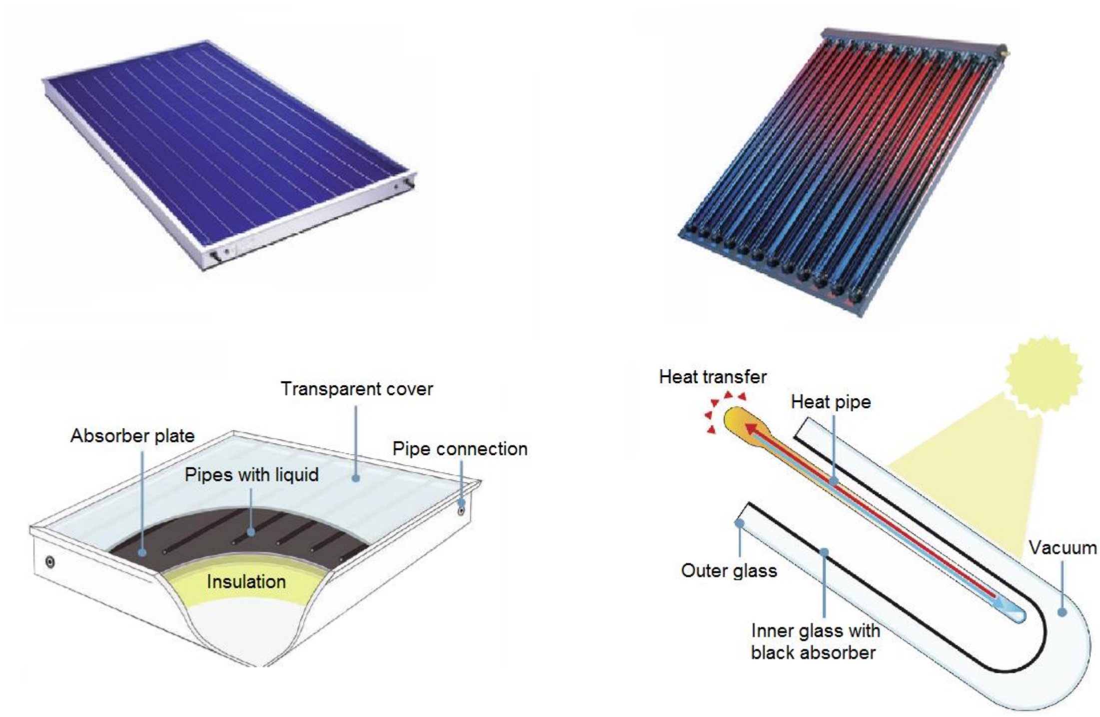


Figure 2-13: The two most used STs in building application, flat plate collectors and vacuum tube collectors [25]

2.4.6 Combined heat and power

CHP, also known as cogeneration, provides very high efficiency by combining heat and electricity production, but unfortunately doesn't exist in small scale (micro-CHP) on the Norwegian marked yet. The cost data used in this study are mainly from UK, Germany and the Netherlands.

There are many types of CHPs. Some uses external combustion engines like Stirling engines or Rankine engines. These are best suited for stationary, constant running application. Then there are the internal combustion engines which are better suited for applications where there is a need for rapid variations in power output, which can be achieved by changing the supply fuel rate. The last main type of CHP is the fuel cell-type, which can be either Solid oxide fuel cells (SOFC) or proton exchange membrane fuel cells (PEMFC).

In CHP systems specific cost are usually given in €/kWe where smaller units have lower electrical efficiency with similar overall efficiency [25]

2.4.7 Alternative energy supply systems

To fulfill the ZEB-definition a building must produce and export electricity. An alternative to PV is micro wind turbines. Although this is a highly relevant technology for future ZEBs, it is not investigated in this project. Here is a short introduction to the technology:

Micro wind turbines:

Just as for PV micro wind turbines are available in both stand-alone and grid-connected systems. They vary in performance with a range of models available from less than 0.1 kW to 50 kW. The size of the turbines vary but are usually mounted 3-4m above the rigid line of the attached building or up to 16m for free-standing systems [25].

It's hard to give exact cost numbers for micro wind turbines, but a survey of micro wind turbines in Sweden suggest that the price lies in the order of 3000-5000 €/kW [34].

Pros:

- Well know and well developed technology
- Suitable for locations with high wind speeds and open landscapes
- Free fuel
- Produces electricity

Cons:

- Visual impact and noise
- Unsuitable for urban areas because of turbulent wind conditions caused by buildings
- Unsuitable in areas with low wind speed (<5m/s), excluding many locations in Norway

2.5 Energy prices and CO_2 prices

In this section energy prices for the relevant energy carriers will be presented. Since the test building used in this study is located in Bergen, the energy prices will as good as possible be based on local prices. For example will BKK (the largest power company in the west coast of Norway) be the provider of both electricity and district heating. Other relevant cost data for this study, like investment costs for the different energy supply systems presented above, are given in the Appendix.

2.5.1 CO_2 prices

Information on estimated long-term carbon price developments are given in annex II in [15]. The projections assume a price per tonne of €20 until 2025, €35 until 2030 and €50 beyond 2050. By using the rate per March 13th, 2013 of 7.443 NOK/€, this numbers are approximately 150 NOK until 2025, 260 NOK until 2030 and 370 NOK beyond 2030. These numbers will be used for the macroeconomic analysis in this thesis.

2.5.2 Pellets

Wood pellets is a product made up by compressed wood chips, shaped as small cylinders 6-8 mm in diameter. Pellets are usually bought in small bags weighing 12-16 kg, larger bags weighing up to 1000 kg, or delivered as bulk pellets. Bulk pellets requires an advanced silo-system, which usually is the best alternative for larger systems.

Bag pellets:
There are several suppliers of bag pellets in Norway. Table 2-3 shows two price examples.

Table 2-3: Prices for pellets delivered in larger bags

Supplier	Amount [kg]	Price [NOK]	1)Shipping [NOK]	Total cost [NOK]	Specific price [NOK/kg]	2)Energy price [NOK/kWh]
Energihuset	832	2650	450	3100	3.73	0.78
Felleskjøpet	1000	3198	450	3648	3.65	0.76

1) Within zone 1 (Oslo-region) obtained from [35]

2) Assumed energy density of 4.8 kWh/kg

Bulk pellets:
The price for bulk pellets is lower. According to "Energirapporten" nr. 38 for 2012 [36], the price for bulk pellets is 0.359 NOK/kWh excl. VAT. The price assumes deliverance within a radius of 250 km, and a fully loaded truck. The energy density is assumed 4.8 kWh/kg. By adding VAT of 25 % the price for bulk pellets becomes 0.45 NOK/kWh.

2.5.3 El-price

Nord Pool runs the leading power market in Europe, and is owned by the Nordic transmission system operators: Statnett SF, Svenska Kraftnät, Fingrid Oyj, Energinet.dk and the Baltic transmission system operators Elering and Litgrid. The market price for electricity changes hourly on Nord Pool. Most power companies in Norway offer deals where you pay the spot price for electricity with an additional monthly fee, which is the basis for the calculations in this study. To determine the initial electricity price an average spot price in Bergen over the last three years is used, giving an initial electricity price of 0.33 NOK/kWh [37]. By including VAT (25%) and electricity certificate (0.017 NOK/kWh) the price becomes 0.43 NOK/kWh. In addition to the spot price there's an energy dependent grid tariff which must be accounted for. This is described in chapter 2.5.5 about plus customers.

2.5.4 District heat

The price model for DH in this study is based on the prices given by BKK. The energy price for DH is determined by two parts. One part follows the spot price from Nord Pool. The price will be a weighted average of the spot price over a given consumption period. In this study the spot price mentioned under El-price will be used (minus the el-certificate) as the current price, namely 0.42 NOK/kWh. The second part is regulated according to the current grid tariff for private customers, and additional fees. From 1st of January 2013 this is 0.35 NOK/kWh (incl VAT) [38]. This gives a total energy price for DH of 0.77 NOK/kWh incl. VAT. BKK also charge an annual fee of 3750 NOK/yr which has to be taken into account in the cost optimal calculation since this amount is not applied to all energy supply packages [38].

2.5.5 Plus customers

A plus customer is defined as a producer of electricity, where the annual production normally does not exceed the annual consumption, but in periods has excess electricity which can be fed into the grid [39]. Normally production and sale of electricity is strictly regulated by the law. Generally all electricity producing units, independent of size, have to make a balance-agreement with Statnett to gain access to trade in the wholesale electricity marked [40]. In addition, as given in § 4-2 in the Norwegian energy regulation [41], electricity selling units need a trading license. An application for a trading license can be a long and complicated process, and has therefore been an obstacle for end-users who want to be plus customers.

For these reasons it has generally been difficult and complicated for the end-users to sell and export their excess electricity. Therefore NVE released a document in 2010 giving a general dispensation for plus customers [40]. The dispensation means that grid companies can buy the excess electricity and rate customer's grid tariff more easily. First of all, the document states that future plus customers will not need to make a balance-agreement with Statnett, neither directly or through a balance-responsible [40]. Secondly NVE gave dispensation from the trading license described above, making it a lot easier to become a plus customer. The dispensation only applies to customers which have an annual production which does not exceed the annual consumption. The plus customer scheme implies that the customer cannot sell the excess electricity to other end-users or participate in the wholesale electricity marked [40], but are obliged to sell the excess electricity to the local power company.

In the document, NVE suggest that the price for the excess electricity shall reflect the market price in the given area. Since Norway is divided into five price zones, the price for the excess electricity will consequently vary between customers living in different areas. The electricity spot price is relatively unpredictable and varies as a result of supply and demand. Therefore, the price for excess electricity is highly dependent on season and time of the day the electricity is fed to the grid. In addition to the spot price, the power company shall also pay the plus customer an additional fee for the fed in electricity. This additional fee is a compensation for reduced losses in the local grid.

Since the dispensation given by NVE in 2010 several power companies are now offering deal for plus customers. In Table 2-4 and Table 2-5 two price examples from Hafslund and BKK are shown. The current legislation (FOR-1999-03-11-302) § 14-2 tells that el-customers (normal households) shall pay a fixed annual amount and an energy dependent amount when extracting electricity from the grid [42], which is normally known as the grid tariff [43]. The fixed annual amount shall cover the customer costs, and will therefore vary between different power companies. The energy dependent part shall reflect the loss inflicted by the customer when extracting electricity from the grid. This is also included in the tables.

Hafslund:

Table 2-4: Tariffs for plus customers, Hafslund

Plus customer tariff		1) **Annual fee** [NOK/yr]	**Energy tariff** [NOK/kWh]		
			Summer Apr-oct	**Winter Day** Nov-mar	**Winter Night/weekend** Nov-mar
Low voltage 230 V and 400 V	1) Extraction (grid tariff)	750	0.376		
	2) Feed-in, compensation	-	-0.043	-0.064	-0.064
	3) Feed-in, el-price	-	- spot price from Nord Pool Spot		

BKK:

Table 2-5: Tariffs for plus customers, BKK

Plus customer tariff		1) **Annual fee** [NOK/yr]	**Energy tariff**		
			Summer Apr-oct	**Winter Day** Nov-mar	**Winter Night/weekend** Nov-mar
Low voltage 230 V and 400 V	1) Extraction (grid tariff)	1650	0.345 [NOK/kWh]		
	2) Feed-in, compensation	-	-4%	-7%	-6%
	3) Feed-in, el-price	-	- spot price from Nord Pool Spot		

1) The grid tariff will vary according to the amount of extracted energy. These numbers applies for normal households. For corporates and larger households other numbers apply. The numbers are included VAT (25 %), the mandatory fee to the energy fund (Enova) of 0.01 NOK/kWh, and a consumption fee of 0.116 NOK/kWh.

2) Compensation for reduced losses in the local grid

3) The power companies buy the excess electricity for the current price at Nord Pool Spot.

2.6 IDA-ICE

IDA Indoor Climate and Energy (IDA ICE), developed by EQUA AB, is a whole-year detailed and dynamic multi-zone simulation tool for study of thermal indoor climate as well as the energy consumption of an entire building. IDA-ICE 4 is validated against NS-EN 15265 [44], which is required for all simulation programs used for documenting the energy performance of a building in Norway.

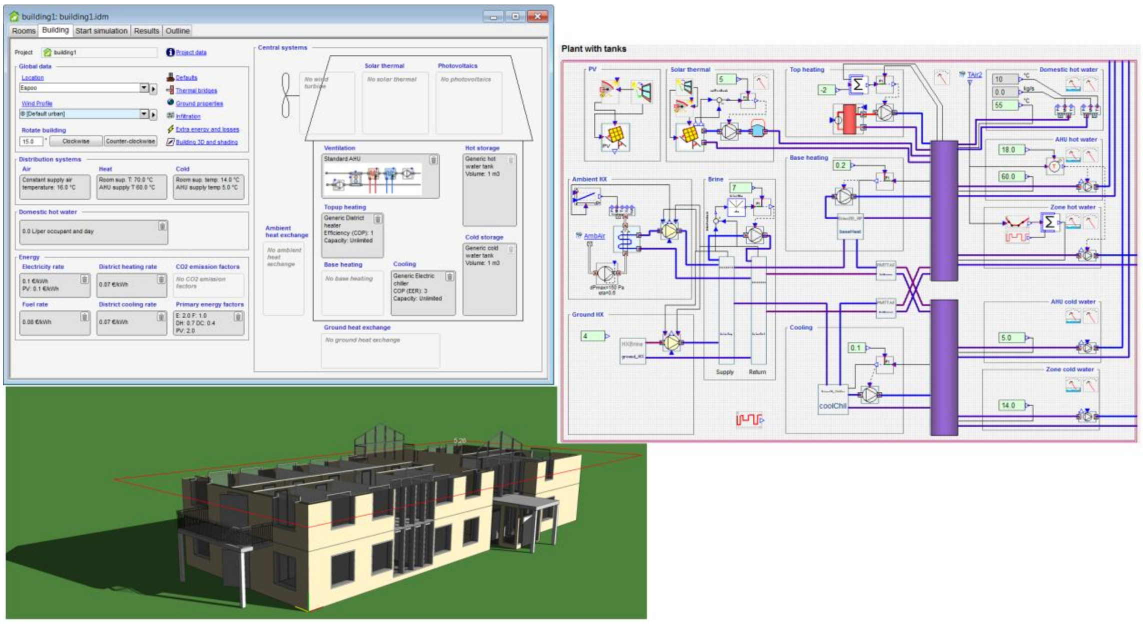


Figure 2-14: Screenshots from IDA-ICE 4.5

IDA-ICE 4.5 includes many new features and improvements compared to the earlier versions, which is highly useful for this study [45]:

- **Early Stage Building Optimization (ESBO):** ESBO is a new IDA-ICE wizard that simplifies early stage building optimization. Different variations in both building and systems can be performed with a minimum user input.
- **Renewable energy systems:** The version 4.5 includes new models for heat pumps, solar collectors, storage tanks, boreholes, CHP, wind turbines, PV, and other free energy sources.
- **New 3D look:** A new 3D look including shadows falling on the ground makes it easier to visualize the building.
- **Improved zone form:** A new improved zone form with 3D view and summary tables, making it easy to view and edit zone level input data.
- **Thermal bridges:** New thermal bridges have been added supporting inner corner meeting external slabs.

When working in IDA-ICE 4.5 it possible to operate in three different levels of detail: the wizard level, the physical level and the mathematical level.

The wizard level (ESBO) allows users to experiment with both the building and different systems with a minimum user input. The user has no direct control over the physical or mathematical model of the simulated system.

In the physical level the user builds up a physical model of the simulated system, but has no direct control over the mathematical model. The model is changed by inserting components and editing parameters. Components can be added by drag-and-drop directly in the 3D model.

In the mathematical level a model is build up by inserting objects into an open document and then connecting some of them. Objects mostly appear as boxes with explanatory pictures and connections as lines between pictures. A typical object is created with NMF (Neutral Model Format) or Modelica which are languages for describing mathematical models. Other objects work as boundary conditions. At this level it’s possible to view and edit the code, giving the user a direct control over the mathematics behind.

In other words it’s possible to use IDA-ICE in many different levels of detail, which give users freedom to develop models according to their needs and wishes. IDA-ICE also offers the opportunity to study various passive ventilation techniques, like window ventilation, which is highly relevant for Norwegian buildings.

3 Approach

3.1 The test building

The test building used in this study is linked to the pilot project in Ådland, which is the largest pilot project for the ZEB center. In 2010 Norconsult performed a consequence assessment for the construction plans and the chosen area [4]. The project was approved on most areas. The main drawback was the far distance to public transportation, which is inconsistent with the goal of reducing transportation needs. All in all though, the conclusion was that the project could be justified. In April 2013 the Minister of Environment, Bård Vegar Solhjell, confirmed that the project would be approved by the government.

The entrepreneur company ByBo AS, which is of the 20 partners in the ZEB center, has the main responsibility for the construction. ByBo was also the developer of Løvåshagen in Fyllingsdalen, which is the largest passive house project in Norway to date. Ådland is located in Bergen and will consist of 500-800 family homes. This includes dwellings, kindergarten and a business area. The building area is illustrated in Figure 3-1.

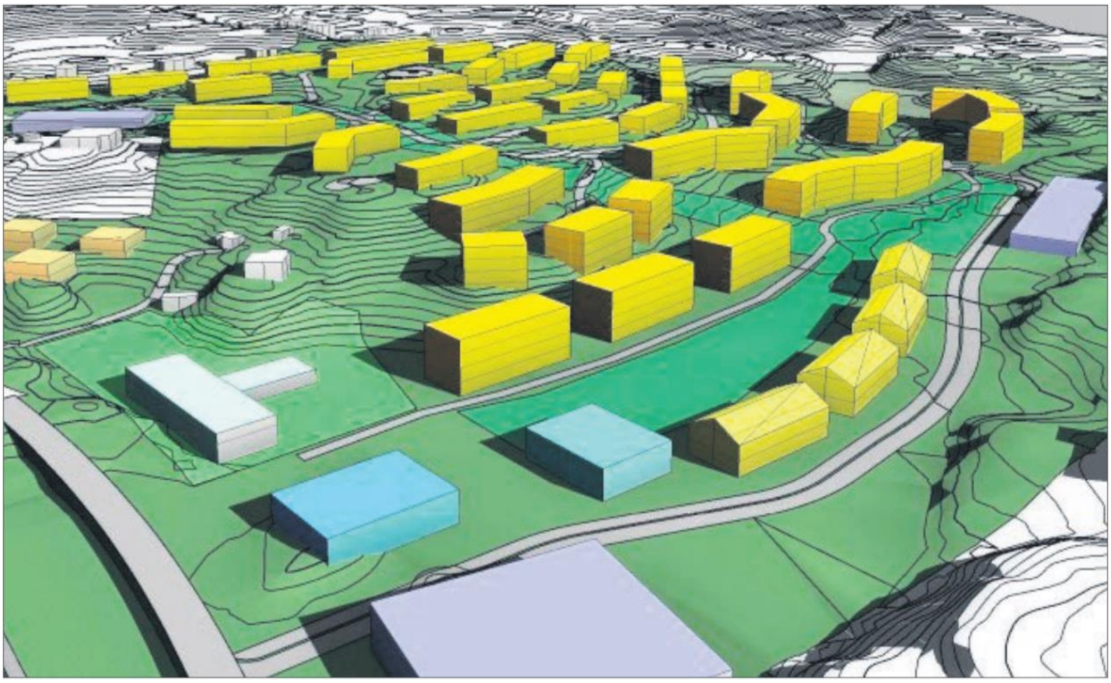


Figure 3-1: The pilot project in Ådland (Illustration made by Norconsult)

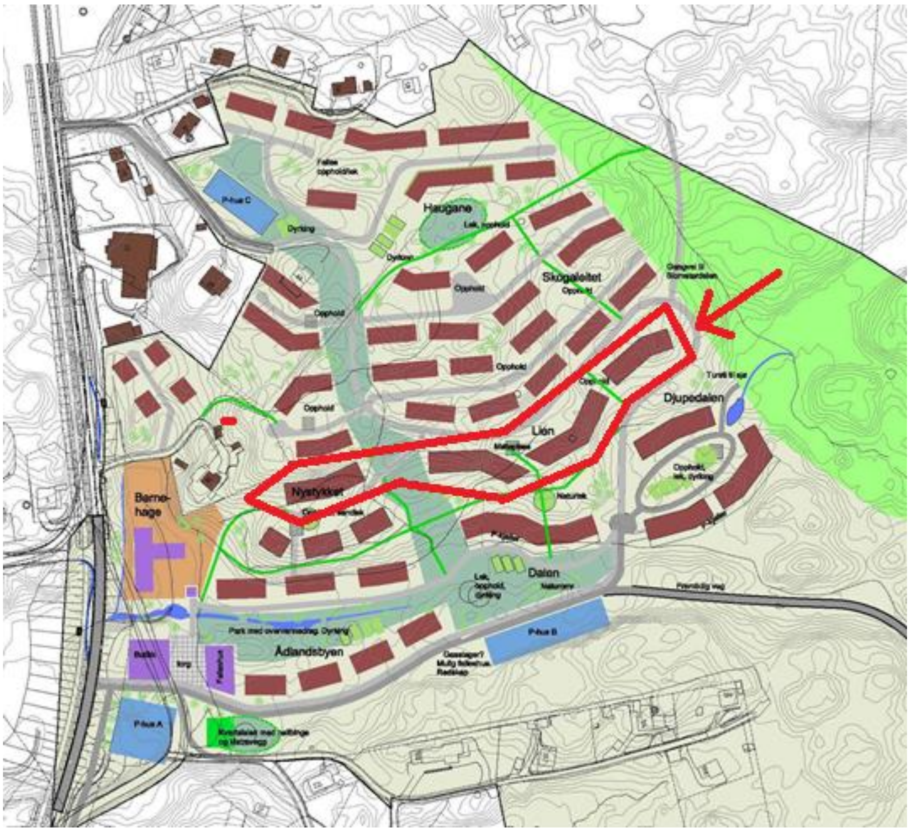


Figure 3-2: The building type used for the calculations in this study

Figure 3-2 shows the building type which will be evaluated in this study. Each of the encircled buildings consists of 28 apartments distributed over four floors. One of these buildings will be considered in this master thesis. The dimensions of the building is 10x56 m^2, giving a total heating floor area of 2240 m^2. Total air volume is 5443 m^3. The south face contains 280 m^2 windows, while the north face contains 168 m^2. The frame fraction is approximately 0.2 of the window area. Other relevant parameters are given in Table 3-1. As shown, the values are mostly way within the passive house requirements given in Appendix K.

Table 3-1: Main parameters for the reference house in Ådland

Parameter	Value
U-value external walls	0.13 W/m^{2}K
U-value ground floor	0.10 W/m^{2}K
U-value roof	0.10 W/m^{2}K
U-value windows	0.70 W/m^{2}K
Heat recovery ventilation, annual	85 %
Leakage number	0.5 h^{-1}
Energy use, lightning	9 kWh/m^{2}yr
Energy use, equipment	15 kWh/m^{2}yr
Thermal bridges	0.03 W/m^{2}K

The ZEB ambition level for the Ådland building park is ZEB-O-EQ or ZEB-O&M (more information given in Appendix M). ZEB-O&M includes emission related to both operation and materials. At this stage of the construction plans, information about materials is not available. For the calculation in this study the focus will therefore only be on the export-import balance.

3.2 The energy supply combinations

Based on the different technologies presented in chapter 2.4, possible energy supply combinations for ZEBs can be defined. It's assumed that the heating systems (HP, ST, DH, Bio and CHP) will cover the entire demand for space heating and domestic hot water, while PV (alternatively in combination with CHP) will generate the required electricity to reach the ZEB balance. Some of the electricity generated will be self-consumed while the rest will be exported to the grid. The following energy combinations will be considered:

- *Combined heat and power (CHP) + PV*
- *Bio energy (Bio) + PV*
- *District heating (DH) + PV*
- *Combined heat and power (CHP) + Solar thermal collectors (ST) + PV*
- *Heat pump (HP) + Solar thermal collectors (ST) + PV*

To reach the ZEB target, PV is required in all energy supply packages. This is because PV uses free fuel (the sun) and produces electricity directly which easily can be exported to the grid. For these reasons PV is arguably the most important energy supply system for ZEBs. ST also utilizes the sun, and like PV does not require any additional fuel. But since heat is more difficult to export to the grid ST alone cannot ensure that the ZEB target is reached. ST contributes to reducing a buildings fuel demand, and is therefore especially relevant when energy prices are high. ST is included in two energy supply packages is this study.

3.3 Discount rate, inflation and energy price development

The discount rate used in this study is based on the handbook of socio-economic analysis of energy projects by NVE [46]. The discount rate for energy projects should reflect the utility loss related to deferred consumption of capital, and the risk in the project. In the handbook it's proposed to use a discount rate of 6%/a for energy efficiency measures with a clear environmentally friendly advantage, and 8%/a if this is not the case. Based on this, the nominal discount rate used in this study will be 6%/a. The Norwegian Government has determined that the increase in consumer price over time (inflation) will be 2.5%/a [47]. By using Equation 2-7, the real discount rate becomes 3.4%/a.

Often the development of energy prices is higher than the inflation rate. When using the cost optimal methodology future energy prices for many years ahead are needed. It's therefore necessary to define a *price escalation rate* which applies on top of the inflation rate.

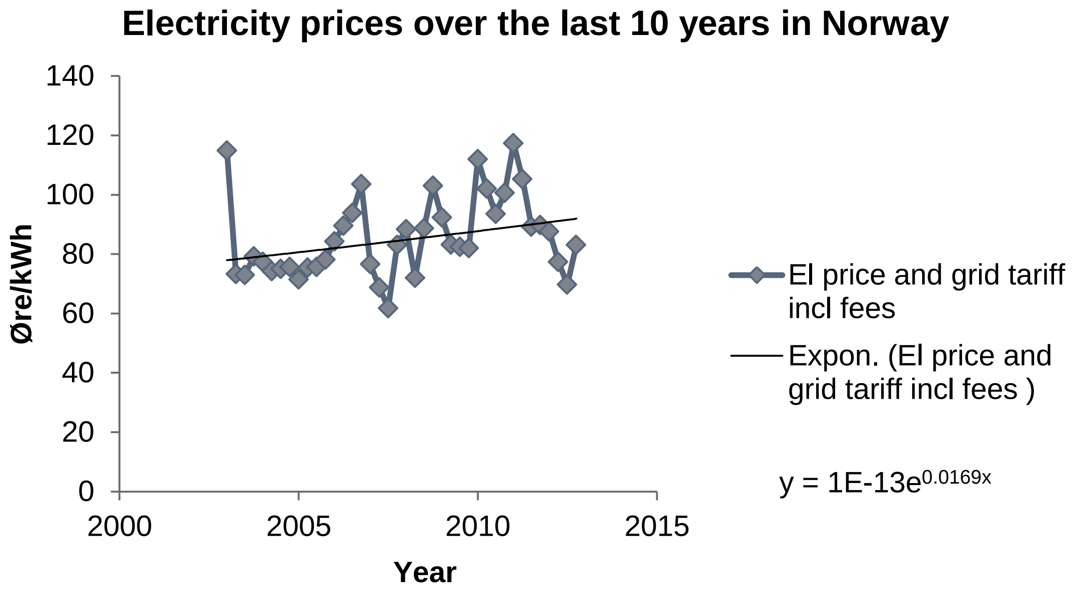


Figure 3-3: Electricity price development over the last 10 years in Norway [48]

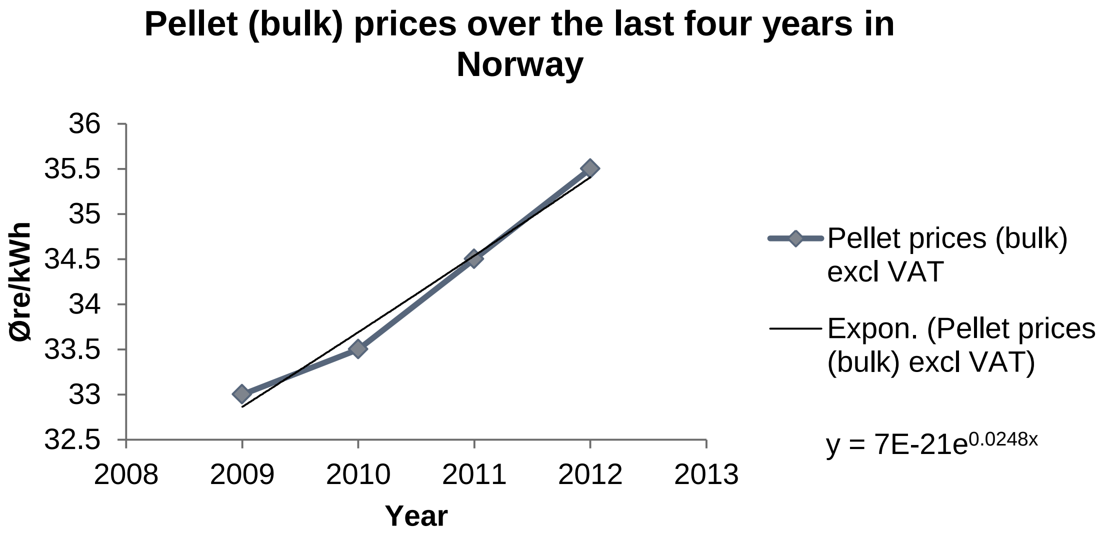


Figure 3-4: Pellet price development over the last four years in Norway [36]

Figure 3-3 illustrates the increase in electricity price over the last 10 years in real terms, hence excluding inflation. The exponential regression indicates a price escalation on electricity of 1.7%/a. Figure 3-4 illustrates the energy price development for pellets over the last four years, which indicates a price escalation of 2.5%/a.

The energy price escalation rate is an important factor which may influence the final results from the cost optimal calculations, but it is hard to predict an exact number. In this study three different scenarios will be analyzed; a low (1 %/a real), a medium (2.8 %/a real) and a high scenario (4 %/a real). The medium scenario reflects the EU energy price projections towards 2030 [49]. The high and the low scenarios are used for sensitivity analysis, i. e. to see if the result will differ with different rates.

3.4 Overview

As mentioned in the introduction, IDA-ICE stands out as the most suitable energy simulation program for “the tool” and will thus also be used in this master thesis. IDA-ICE 4.51 is the newest version available at this point and will therefore be used.

In the chapter 2.5.2 about prices for pellets, there are price examples for both bulk pellets and bag pellets. Bulk pellets requires a silo to store pellets and an automatic feeding system which will lead to a larger investment than buying bag pellets and feed the boiler manually. But as stated earlier bulk pellets have a much lower energy cost than bag pellets and is therefore the best option in the long run, especially for larger buildings. Bulk pellets will therefore be considered in the calculations.

When considering the two price examples for plus customers (see chapter 2.5.5) the deal from BKK (Table 2-5) will be used. This is because BKK is located in Bergen, the same as the Ådland building park. The energy dependent grid tariff of 0.345 NOK/kWh increases the total price for electricity to 0.78 NOK/kWh. This tariff does not apply to electricity exported to the grid. Electricity exported to the grid will be bought by BKK for the spot price plus compensation due to the reduced losses in the grid. In this study an average of the winter fee and the summer fee will be used. This means that BKK will buy exported electricity for 0.33+0.33*(0.07+0.04)/2 NOK/kWh = 0.35 NOK/kWh. Because of the price difference between exported and imported electricity it’s clear that self-consumption of generated electricity is more cost efficient than exporting it. The monthly fee, as all other fixed amounts that applies to all energy packages/combinations is not relevant for the cost optimal calculations and is therefore not included in the calculations. Future electricity prices are determined by inflation and the energy price escalation rate.

Table 3-2: Input factors for the cost optimal calculation

<table>
<tr><td>Building</td><td colspan="4">28 apartment building block, Ådland</td></tr>
<tr><td>Energy simulation and modeling tool</td><td colspan="4">IDA-ICE 4.51</td></tr>
<tr><td>Calculation method</td><td colspan="4">The European cost optimal methodology
(net present value method)</td></tr>
<tr><td>Energy supply packages</td><td colspan="2">• Bio + PV
• CHP + PV
• DH + PV</td><td colspan="2">• CHP+ST+PV
• HP+ST+PV</td></tr>
<tr><td>Cost categories</td><td colspan="2">• Initial investment cost
• Maintenance cost
• Replacement cost</td><td colspan="2">• Energy cost
• Residual value</td></tr>
<tr><td>Calculation period</td><td colspan="4">30 years</td></tr>
<tr><td rowspan="4">Primary energy factors $[kWh_{prim}/kWh_{del}]$</td><td></td><td colspan="2"><u>Total PEFs:</u></td><td><u>N.r. PEFs:</u></td></tr>
<tr><td>Wood pellets:</td><td colspan="2">1.2</td><td>0.2</td></tr>
<tr><td>District heating:</td><td colspan="2">0.7</td><td>0.7</td></tr>
<tr><td>Electricity:</td><td colspan="2">3.0</td><td>2.6</td></tr>
<tr><td rowspan="3">CO_2-factors</td><td colspan="4">Wood pellets: 14 g CO_2/kWh</td></tr>
<tr><td colspan="4">District heating: 291 g CO_2/kWh</td></tr>
<tr><td colspan="4">Electricity: 395 g CO_2/kWh</td></tr>
<tr><td>Inflation</td><td colspan="4">2.5%/a</td></tr>
<tr><td>Discount rate (real)</td><td colspan="4">3.4%/a</td></tr>
<tr><td>Current energy prices [NOK/kWh]</td><td colspan="4">Wood pellets (bulk): 0.45
District heating: 0.77
Electricity imported (incl. grid tariff): 0.78
Electricity exported: -0.35</td></tr>
<tr><td>CO_2-prices
(for macroeconomic analysis)</td><td colspan="4">150 NOK/tonne until 2025
260 NOK/tonne until 2030
370 NOK/tonne beyond 2030</td></tr>
<tr><td>Energy price development (real)</td><td colspan="4">• 1 %/a (low scenario)
• 2.8 %/a (medium scenario)
• 4 %/a (high scenario)</td></tr>
</table>

Table 3-2 gives an overview of the different input parameters for the cost optimal calculation. Investment cost and other relevant costs for the different technologies are given in the Appendix. In the table, both total primary energy factors and non-renewable primary energy factors are given. Cost optimal analyses will be performed with both types of primary energy factors.

As stated in the European cost optimal methodology, global cost calculation can be done both at a macroeconomic and a financial level. Both levels will be regarded in this study. The financial perspective regards all costs relevant for the investment decision including taxes and subsidies. The macroeconomic perspective looks at costs which are relevant for the society as a whole, thus excluding taxes and subsidies but including the cost of greenhouse gas emissions.

This study will consider the three scenarios for the energy price development defined above. This, in combination with the two different PEF-cases and both the financial and macroeconomic view gives, a total of 12 different evaluations/perspectives for the five different energy packages when evaluating all possibilities. In addition a sensitivity analysis will be performed on investment costs by increasing and decreasing the costs for the various technologies to see how dependent the results are on uncertainties in these numbers.

For each energy package the heating technologies (ST, CHP, DH, HP, Bio) are dimensioned to cover the entire demand for space heating and DHW. The PV (alternatively in combination with CHP) will then be dimensioned to generate the required electricity for the building to reach the ZEB balance. The amount of self-consumed electricity will be determined by comparing the generated electricity with the consumed electricity for every time step in the simulation (every 15 minutes). Since self-consumption of generated electricity is taken into consideration, the ZEB-balance used in this study is the *import/export* balance.

It's important to mention that the only energy measures considered in this study are measures based on the energy supply of the building. Other energy measures like better and more expensive insulation has not been taken into account. The U-values given in Table 3-1 are the basis parameters for the model, and will be held constant during the calculations.

4 Results

4.1 The model

The model of the building block is shown in Figure 4-1. The odd shape of the building is for reducing the simulation time, while the results still remains realistic. Firstly, the building contains four floors while the model only contains three. This is because the intermediate floors are assumed identical, i. e. identical surfaces (adiabatic ceiling and floor) and contents. Therefore, the intermediate floors are modeled as one zone, and the simulation result for that zone is multiplied by the number of floors. The space between each floor is created because IDA-ICE then considers the surfaces as adiabatic, as desired. This is because net heat transmission is ignored if surfaces have no adjacent zone or face (can be changes in the program). The surfaces are automatically considered having no adjacent zone or face in IDA-ICE if the space between the floors is larger than 60 cm. The windows are also a bit odd shaped. The real building will have 280 x 1m^2 windows on the south face, and 168 x 1m^2 on the north face. In the model the amount of windows are reduced to two large windows per floor, giving the same total window-area. This simplification does not influence the test results significantly, but has a huge impact on the simulation time (models including both large and normal windows were tested).

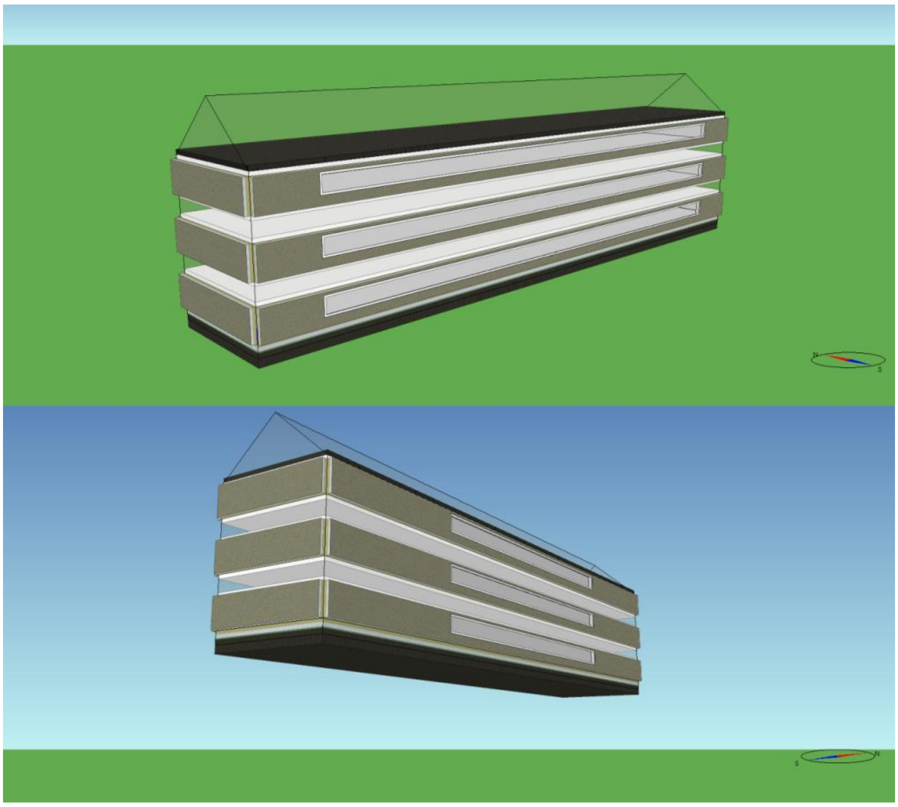


Figure 4-1: A 3D representation of the building model made in IDA-ICE

The roof of the building is not symmetrical as indicated in Figure 4-1. The south face of the roof is 405 m^2 with a tilt angle of approximately 30° while the north face is 282 m^2 with a tilt angle if 43.5°. The different roof in the model does not have any major effects on the result. The south face of the roof will be used for PV installation. In IDA-ICE the PV can be placed anywhere by giving it three specific coordinates, which is normally also shown in the 3D view (not in Figure 4-1). The shape of the roof is therefore not an obstacle for the possible ways to install the PV.

Every floor has 15 occupants. The average hot water use is set to 50 liters/occupant and day. Each floor has installed a total of 840 W of lightning and 1400 W of equipment. The lightning and equipment are assumed switched on from 06-22 every day, and off otherwise. Occupants are assumed always present. Every floor has installed a water radiator for space heating.

It’s worth mentioning that the inside of the building has not been modeled. Every floor is regarded as one zone with a total amount of occupants, equipment and lightning as described above. As proven in the energy budget below (Table 4-1), which shows fairly expected results, this is an acceptable approximation when only the buildings energy consumption is evaluated. Modeling the surroundings has also been neglected in this study. Modeling the surroundings is usually important for simulating solar shading, which also can have an impact the performance of PV and ST especially if placed in the façade. This simplification is mainly because the Ådland building park is in an early construction phase, and data about the surroundings is not available at this point.

The external walls, the external floor, the roof and the windows have been modeled according to the U-values in Table 3-1. The materials used are mostly light insulation, and rendered light weight concrete. In addition to satisfy the U-values, it’s important to have realistic values for specific heat capacity, which says something about the amount of heat that can be stored in the wall. If this value is too large or too small, it may affect the heat balance of the building. A wall with a large specific heat capacity will often radiate much heat during night, and slow the solar heating of the building in the morning.

Models for the energy supply systems are mostly integrated in IDA-ICE. By changing different parameters the models can be adjusted to reflect an actual product. Some of the adjustments that have been made are presented in the following, including relevant choices and changes that were made to obtain a realistic result. The physical dimensioning of the different energy supply systems are given in Appendix F.

4.1.1 Heat pump

As shown in chapter 2.4.1, the COP for HPs is highly dependent on working conditions, like temperatures and type of energy source. IDA-ICE uses an algorithm for generating COP-values, given in Appendix L. This algorithm is the same for all HPs, both water based and air based HPs, even though water based HPs usually have higher COP values. In IDA-ICE the user can vary four different calibration parameters to adjust the output of the algorithm. This is useful for making the COP values in IDA-ICE fit with COP-data given by the manufacturer. For this study an optimization code was developed in C++ to adjust these parameters in a best possible way. The code is given in Appendix L. Figure 4-2 illustrates the important effect this has on the COP-generation, and thus also the result of the simulations.

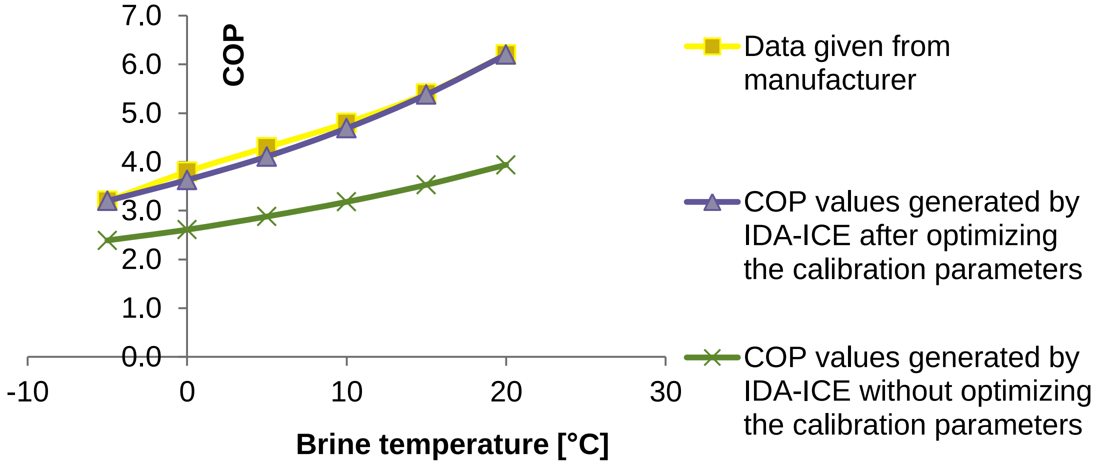


Figure 4-2: The effect of optimizing the calibration parameters for generating realistic COP values

The HP used in this study is of type Dimplex SI 14TU brine/water HP. In combination with ST the HP provides the necessary heat to cover the entire demand for space heating and DHW. The HP requires a ground source borehole loop, approximately 260 m deep. In IDA-ICE this is implemented as two 130 m deep boreholes. The cost data for the boreholes are based on data given by Båsum Boring AS, obtained from the earlier project work [26]. The cost data and the performance data for the HP are given in Appendix A.

4.1.2 Photovoltaic

The PV is primarily mounted on the south face of the roof, which is 405 m^2. In most energy supply packages this is not enough space for the PV, because the amount of electricity generated must outweigh the electricity used (lightning, equipment, HP etc.) but also compensate for the consumption of other energy carriers like pellets and district heat. The PV therefore has to be installed in alternative areas like the façade or on a possible garage roof. In the model all the

PV is assumed south faced with a tilting angle of 30°. An alternative way to install the PV in the façade is an east-west oriented system, where every other panel is oriented east and west with a small tilting angle. This type of installation will produce a little less electricity than the south faced system, but it will produce more in the morning and the evening which may fit better with the schedule of the occupants, hence contribute to a greater portion of self-consumed electricity. As mentioned earlier self-consumption of generated electricity is more cost efficient than exporting it.

The cost data and some technical data are given in Appendix D. The data are from SunPower and REC, obtained from the master thesis by Siv Helene Nordahl: Design of Roof PV Installation in Oslo [28]. The two price alternatives from REC use the same modules but different inverters. The alternative with the Eltek inverter will be used in this project.

4.1.3 Solar thermal collectors

Since the PV is install on the entire roof of the building, the ST has to be installed somewhere else. The outer wall was considered the best alternative, which is the case for all the ST in this study. The tilting angle then becomes 90° which is not optimal, but they should still provide a good amount of solar heat (approximately 77% of the heat produced by ST at a tilting angle of 30°).

The type of STs considered in this study is vacuum tubes. This is because vacuum tubes have less heat loss than flat plates, hence better suited for colder climates like Norway as described in chapter 2.4.5. The cost data are provided by SGP Varmeteknikk AS and are given in Appendix C.

4.1.4 Combined heat and power

Most CHP runs on natural gas, which is the main fuel alternative for many European countries. In Norway though, natural gas is usually not an option. As given described in chapter 2.4.6 about combined heat and power, some CHP are driven by external combustion engines like Stirling and Rankine engines. Stirling engines can usually run on biomass (pellets), and has therefore been the chosen alternative in this study. The lack of appropriate sized CHPs made it difficult to dimension the CHP to exactly cover the heating load for the building. In both packages CHP+PV and CHP+ST+PV the CHP is a bit oversized which might result in a slightly too high investment cost. The cost data for two types of Stirling engine driven CHP are given in Appendix E.

4.1.5 Bio boilers (pellets)

In IDA-ICE bio boilers are not in the selection of energy supply systems. The default options for base heating systems are brine-to-water HPs, ambient air-to-water HPs, and CHP. In this study the bio boilers were represented as CHP with zero electricity production efficiency but high heat production efficiency.

Pellets boilers usually have a higher efficiency for high load than for low load. It's therefore desirable to model the boiler so that it mostly runs on max capacity.

4.1.6 District heat

District heating is modeled as a heating system with unlimited capacity, and an efficiency of 0.84 which is according to the standard NS 3031. As shown in Appendix G, the Ådland building site in only partly within the concession area for DH in Bergen. This should be investigated closer if district heating is considered a valuable option. It's possible to install a new pipe system, but this might lead to high investment compared to other energy supply systems.

In this study there were made an attempt to get an estimate on investment cost for DH for the buildings in Ådland by contacting BKK, but there were no response. The investment cost for DH is assumed 200 000 NOK including a customer central. The uncertainty will be taken into consideration if the results show that DH is a relevant option.

4.2 Energy simulations

Table 4-1: Energy budget for the test house in Ådland

Energy post	Energy need		Specific energy need	
Space heating	16100	kWh/yr	7.19	kWh/m^{2}yr
Ventilation heat	0	kWh/yr	0.00	kWh/m^{2}yr
Hot water	60990	kWh/yr	27.23	kWh/m^{2}yr
Fans	7515	kWh/yr	3.35	kWh/m^{2}yr
Pumps	0	kWh/yr	0.00	kWh/m^{2}yr
Lightning	19415	kWh/yr	8.67	kWh/m^{2}yr
Technical equipment	32725	kWh/yr	14.61	kWh/m^{2}yr
Space cooling	0	kWh/yr	0.00	kWh/m^{2}yr
Ventilation cooling	0	kWh/yr	0.00	kWh/m^{2}yr
Total net energy need	136745	kWh/yr	61.05	kWh/m^{2}yr

Table 4-1 shows the energy budget for the test house. The energy budget is simulated in IDA-ICE using the model described above with the input parameters defined in Table 3-1.

Table 4-2: Delivered energy for the different energy supply packages, tot PEFs

		Delivered energy [kWh/m^2yr]				
Energy carrier ↓	**Energy → package**	**Bio+PV**	**CHP+PV**	**DH+PV**	**CHP+ ST+PV**	**HP+ ST+PV**
Solar heat generated [a]		0.00	0.00	0.00	10.41	10.59
Electricity imported [b]		12.89	11.98	13.34	12.68	18.13
District heating		0.00	0.00	39.35	0.00	0.00
Bio fuel (pellets)		36.00	35.61	0.00	23.98	0.00
Tot PE demand		81.86	78.67	67.56	66.81	54.40
Electricity exported [c]		-27.19	-26.26	-22.49	-22.36	-18.34
PE exported		81.56	78.78	67.48	67.07	55.02
Net PE consumed		**0.30**	**-0.11**	**0.08**	**-0.27**	**-0.62**

[a] The delivered amount of the different energy carriers are calculated after the generated solar heat has been accounted for

[b] Electricity used minus the self-consumed part of the generated electricity

[c] Electricity generated minus the self-consumed part

Table 4-3: Delivered energy for the different energy supply packages, non-renewable PEFs

		Delivered energy [kWh/m^2yr]				
Energy carrier ↓	**Energy → package**	**Bio+PV**	**CHP+PV**	**DH+PV**	**CHP+ ST+PV**	**HP+ ST+PV**
Solar heat generated [a]		0.00	0.00	0.00	10.41	10.59
Electricity imported [b]		14.11	13.13	13.19	13.62	18.13
District heating		0.00	0.00	39.34	0.00	0.00
Bio fuel (pellets)		35.99	35.61	0.00	23.97	0.00
Tot PE demand		43.87	41.25	61.84	40.21	47.14
Electricity exported [c]		-16.72	-16.21	-23.85	-15.17	-18.34
PE exported		43.48	42.14	62.02	39.43	47.68
Net PE consumed		**0.39**	**-0.89**	**-0.18**	**0.77**	**-0.54**

[a] The delivered amount of the different energy carriers are calculated after the generated solar heat has been accounted for

[b] Electricity used minus the self-consumed part of the generated electricity

[c] Electricity generated minus the self-consumed part

Table 4-2 and Table 4-3 show the amount of delivered and exported energy for the different energy supply packages per square meter of floor area (2240 m^2). The total primary energy demand is calculated using the appropriate PEFs given in Table 2-1. As shown in the tables some energy supply packages have a net negative annual primary energy consumption which means they export more than they consume, while some packages have positive annual primary energy consumption. This is not completely fair for the cost optimal evaluation, and should therefore be kept in mind when viewing the final results.

The tables show that a larger amount of electricity is exported for the cases when total PEFs are used except for the DH+PV case. This is natural since a higher relative increase in PEFs for fuel compared to the relative increase in the PEF for electricity means that a higher amount of exported electricity is required to obtain the ZEB balance, which is the case for pellets but not district heat. The amount of exported and imported electricity in the package HP+ST+PV is unchanged. This is because this is an all-electric package thus independent on PEFs. The amount of consumed fuel for heating (pellets, DH) is about the same in both PEF-cases, which is expected since the heating systems are dimensioned only to cover the heating demand and not to export energy to the grid.

For the packages using pellets (Bio and CHP) the tables show that a higher amount of electricity is imported in the cases where non-renewable PEFs are used, while the consumed amount of pellets is the same. This is not due to higher energy consumption within the building, but due to the fact that the non-renewable PEF-cases require a smaller PV area to reach the ZEB target. Less electricity generation means less self-consumed electricity, thus a larger amount of electricity must be imported.

The solar heat generation is within an expected range. At 45 degrees tilting angle the 100m^2 ST area produced approximately 30000 kWh, A well dimensioned ST system should produce an annual amount of 300-700 kWh/m^2 at optimal tilting angle according to Inger Andresen [33]. The results obtained in this study are therefore acceptable. The size of the ST systems is a bit undersized and is covering only about 30% of the buildings heating demand. Normally they are dimensioned to cover between 40-70% of the total heating demand [33]. The reason for this is primarily the lack of appropriate sized base heating systems in the earlier obtained database [26] applicable for larger buildings. When a more comprehensive database is obtained, a more optimal relationship between the sizes of the base heating systems and the ST area can be used.

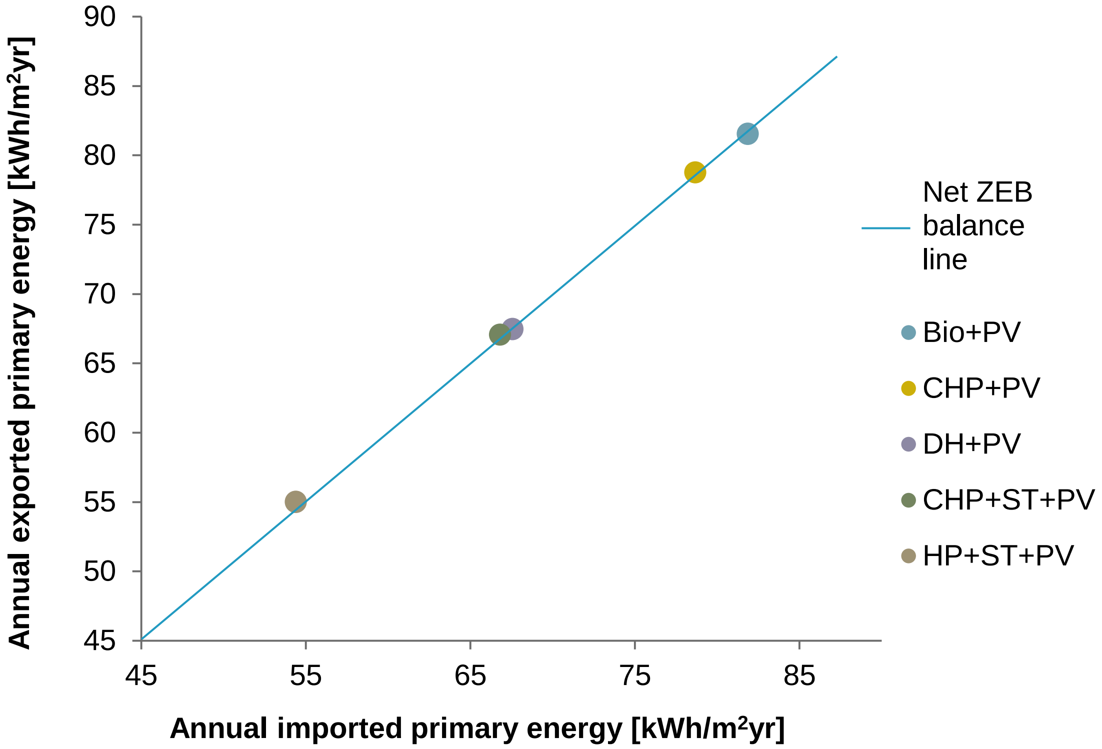


Figure 4-3: Exported and imported primary energy for the different packages with total PEFs

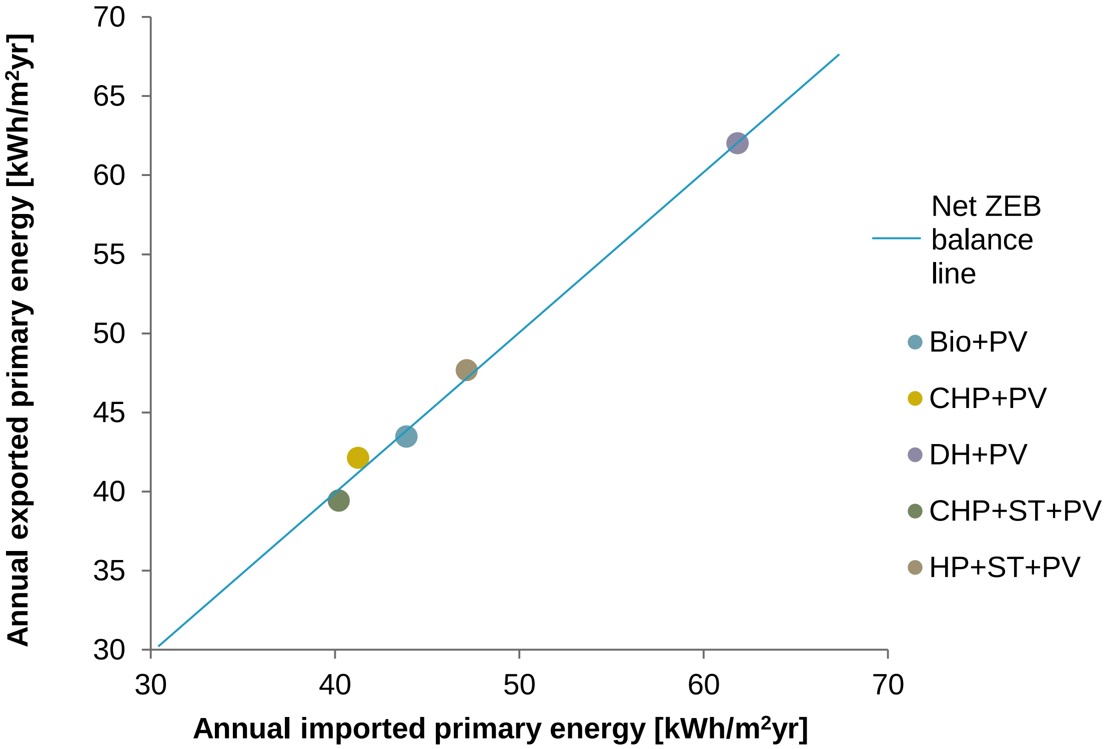


Figure 4-4: Exported and imported primary energy for the different packages with non-renewable PEFs

Figure 4-3 and Figure 4-4 gives a graphical illustration of the data from Table 4-2 and Table 4-3. The packages above the net zero balance line is plus houses, i. e. exporting more energy than consumed. The packages below the line use more energy than they export. It's important to keep in mind when viewing these results that the difference in primary energy consumption for the different packages does not imply a higher energy use in the building or a higher comfort. The energy budget given in Table 4-1 is fixed and applies to all these energy packages. The difference in primary energy demand is a result of different PEFs, different system efficiencies, different fuel types etc.

Ideally a building should use as little primary energy as possible. If the net annual primary energy consumption is zero for two energy supply packages, and the global cost is about equal, the package with the least primary energy demand should be preferred. The primary energy demand is highly dependent on the type of PEF used, as illustrated in Figure 4-3 and Figure 4-4. The packages Bio+PV and CHP+PV have almost the double primary energy demand when total PEFs are applied compared to non-renewable PEFs. This is primarily because the renewable energy components have been ignored in the non-renewable PEFs, as described earlier, causing a particularly large difference between the non-renewable PEF and the total PEF for pellets.

4.3 Cost optimal analyses, financial perspective

As given in the theory about the European cost optimal methodology, global cost at a financial level should consider all prices paid by the customer including VAT and other relevant taxes. In this study also subsidies have been included. Excel 2010 has been used for the calculations. The investment cost includes the investment at the starting year, replacement costs during the calculation period, and residual values if appropriate. The price development for the different technologies and annual costs like maintenance has been set equal to the inflation.

Figure 4-5 and Figure 4-6 show the results of the cost optimal analysis in a financial perspective. Figure 4-5 shows the result when total PEFs have been used, while for the results in Figure 4-6 non-renewable PEFs have been applied. The result is shown as specific global cost, i. e. total global cost divided by the total heating floor area of 2240 m^2.

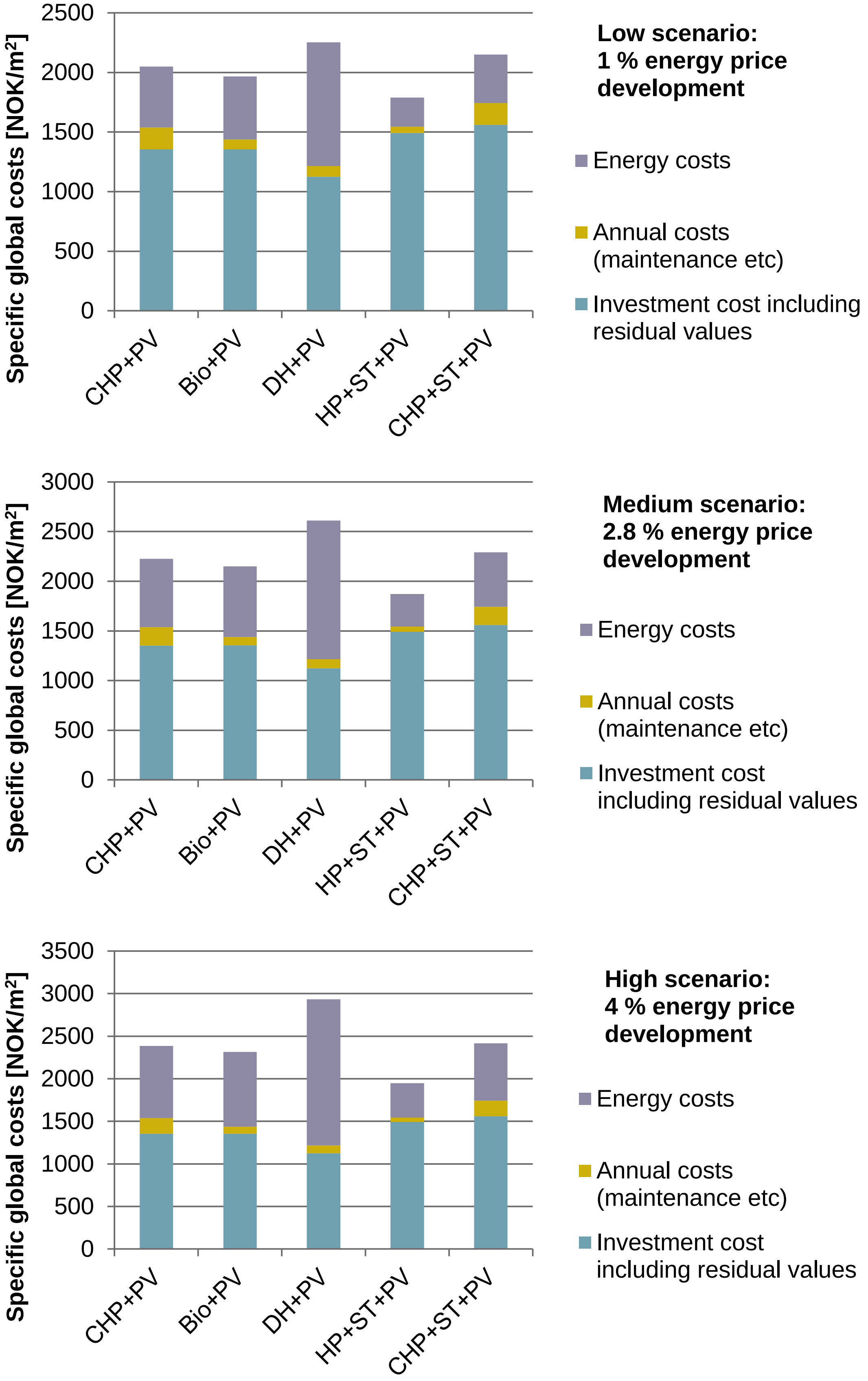


Figure 4-5: Global cost calculations for the different energy price development rates, financial perspective, total PEFs

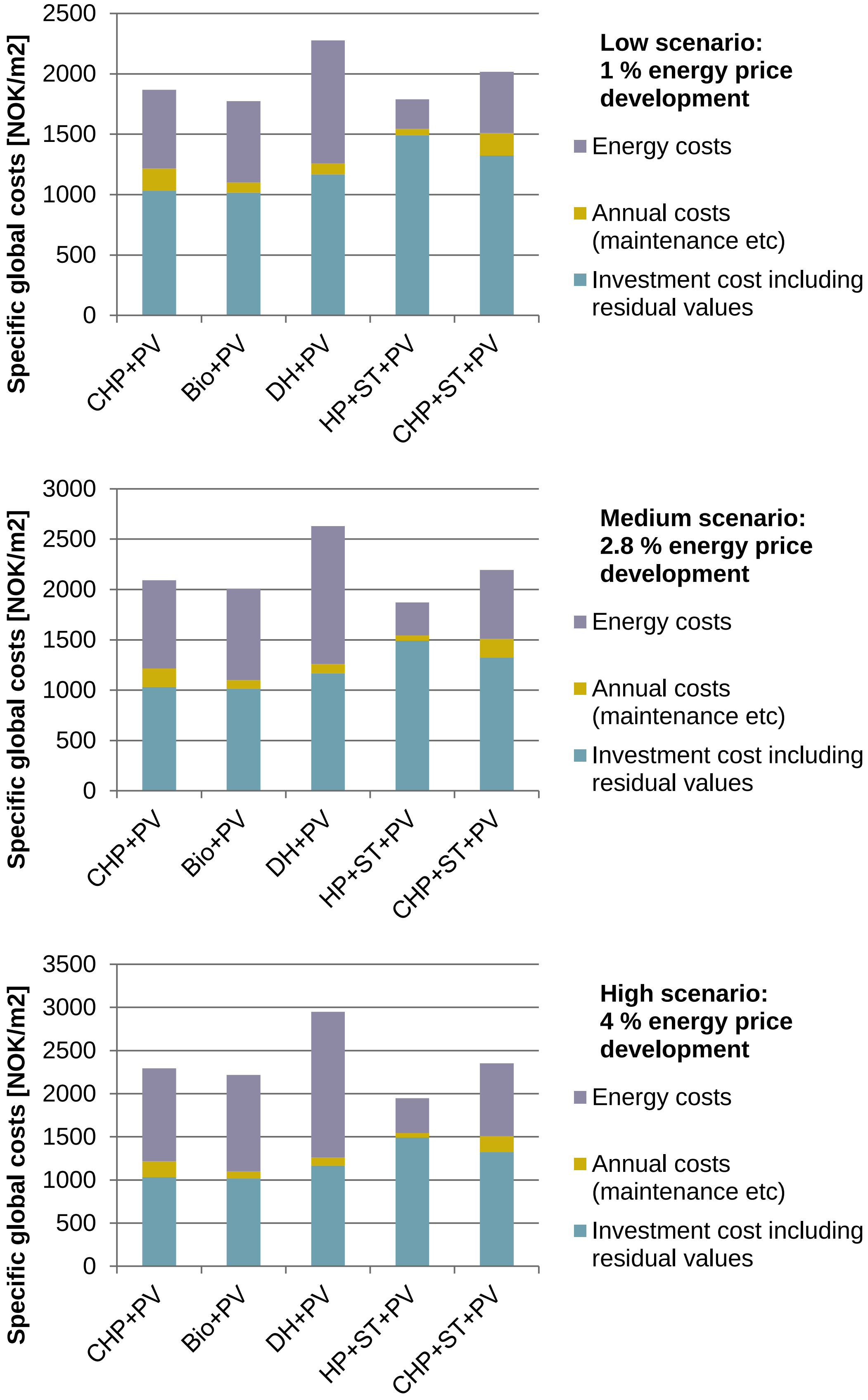


Figure 4-6: Global cost calculations for the different energy price development rates, financial perspective, non-renewable PEFs

Table 4-4: The cost optimal alternatives for the financial analysis

Energy price development rate ↓	Financial analysis	
	Tot PEFs	N.r. PEFs
1 %	HP+ST+PV	Bio+PV
2.8 %	HP+ST+PV	HP+ST+PV
4 %	HP+ST+PV	HP+ST+PV

For the cases with total PEFs it's clear that the package HP+ST+PV is the optimal alternative for all energy price developments (as given in Table 4-4). The second best alternative is Bio+PV closely followed by CHP+PV. The package DH+PV have the lowest investment cost mainly because district heat has the lowest PEF, and therefore this package requires a smaller PV area to reach the ZEB target. But because of the high energy cost for district heat this energy supply package cannot compete with the other packages. The two packages with solar thermal collectors, HP+ST+PV and CHP+ST+PV benefits from the low energy cost, but have a drawback with higher investment cost. These two alternatives are the opposite of DH+PV in the sense that they are more suitable for high energy price developments. CHP+PV and Bio+PV are in the middle range in both investment cost and energy cost.

For the cases with non-renewable PEFs the result is fairly equal to the cases with total PEFs. The main difference is that CHP+PV and Bio+PV now have lower investment than the other packages. This can be explained by looking at the export/import-balance in Table 4-2 and Table 4-3. Since the non-renewable PEF is much smaller than the total PEF for pellets, that the amount of exported electricity can be reduced significantly (hence reduced PV area) and still reach the ZEB target. This causes the package Bio+PV to compete with HP+ST+PV, and is actually the best alternative for low energy price development.

The package DH+PV has a small increase in investment cost for non-renewable PEFs compared to tot PEFs. This is because the PEF for district heat is identical in both cases while the PEF for electricity is a little less for non-renewable PEFs, hence a little more electricity must be exported to compensate for the district heat for non-renewable PEFs. Since the PEF for district heat is very uncertain (highly dependent on combusted fuel mix) a small test were performed to see how well DH+PV would do if the PEF for district heat decreased. But even for a PEF as low as 0.2 (same as for pellets) the package is not within the cost optimal range. The energy prices are too high compared to that of HP+ST+PV.

As mentioned earlier, and shown in Table 4-2 and Table 4-3, the net annual primary energy consumption is not zero for all packages. For some packages the numbers are negative while for others they are positive. As proposed, the consequence of this should be investigated when viewing the results. The largest difference in PE consumption is 3715 kWh/yr, between the packages CHP+PV and CHP+ST+PV for non-renewable PEFs. 3000 kWh of primary energy, which is about 1000 kWh of electricity, requires approximately 9.9 m^2 PV area for a total global cost of approximately 33000 NOK. This would contribute to 14.7 NOK/m^2 in specific global cost. This is a very small amount in the total global cost picture, and is not enough to change the results above.

Table 4-5: The cost optimal energy supply packages when changing the investment costs, financial analysis

			Cost optimal energy supply package		
	% change in investment cost ↓		Energy price development scenario		
			Low (1%)	Medium (2.8%)	High (4%)
Total primary energy factors	Pellet boiler	+25%	HP+ST+PV	HP+ST+PV	HP+ST+PV
		-25%	HP+ST+PV	HP+ST+PV	HP+ST+PV
	CHP	+25%	HP+ST+PV	HP+ST+PV	HP+ST+PV
		-25%	HP+ST+PV	HP+ST+PV	HP+ST+PV
	DH system	+25%	HP+ST+PV	HP+ST+PV	HP+ST+PV
		-25%	HP+ST+PV	HP+ST+PV	HP+ST+PV
	Solar collectors	+25%	HP+ST+PV	HP+ST+PV	HP+ST+PV
		-25%	HP+ST+PV	HP+ST+PV	HP+ST+PV
	Heat pump	+25%	HP+ST+PV	HP+ST+PV	HP+ST+PV
		-25%	HP+ST+PV	HP+ST+PV	HP+ST+PV
	Photovoltaic	+25%	HP+ST+PV	HP+ST+PV	HP+ST+PV
		-25%	HP+ST+PV	HP+ST+PV	HP+ST+PV
Non-renewable primary energy factors	Pellet boiler	+25%	HP+ST+PV	HP+ST+PV	HP+ST+PV
		-25%	Bio+PV	HP+ST+PV	HP+ST+PV
	CHP	+25%	Bio+PV	HP+ST+PV	HP+ST+PV
		-25%	Bio+PV	HP+ST+PV	HP+ST+PV
	DH system	+25%	Bio+PV	HP+ST+PV	HP+ST+PV
		-25%	Bio+PV	HP+ST+PV	HP+ST+PV
	Solar collectors	+25%	Bio+PV	HP+ST+PV	HP+ST+PV
		-25%	HP+ST+PV	HP+ST+PV	HP+ST+PV
	Heat pump	+25%	Bio+PV	HP+ST+PV	HP+ST+PV
		-25%	HP+ST+PV	HP+ST+PV	HP+ST+PV
	Photovoltaic	+25%	Bio+PV	HP+ST+PV	HP+ST+PV
		-25%	Bio+PV	HP+ST+PV	HP+ST+PV

Table 4-5 gives the cost optimal energy supply package when varying the investment costs for the different systems. This is useful to see how sensitive the results are on uncertainties in investment costs. The result in Table 4-4 were obtained by changing one cost at the time, either increase it or decrease it by 25%, and then calculate a new cost optimal energy package. The changed costs include the product cost, mounting, equipment and all other relevant costs for the investment. The table shows that the results are very stable with respect to uncertainties in investment cost in the five cases where HP+ST+PV is the optimal package (as given in Table 4-4). In the case where Bio+PV was the optimal package (low energy price development and n.r PEFs) Table 4-5 shows that the result is not so stable. The difference in global cost between Bio+PV and HP+ST+PV is so low that when changing one investment cost in favor of HP+ST+PV, this becomes the optimal alternative. It's important to keep in mind that only one investment cost was changed at a time. Changing multiple investments simultaneously was not investigated in this study.

The major investments are ST and PV, and the only significant changes in the results happen when changing these. This means that it's especially important to have accurate cost data on ST and PV since uncertainties in these costs have a greater impact on the total global cost picture.

4.4 Cost optimal analyses, macroeconomic perspective

The following results are the global cost analysis in a macroeconomic perspective. As given in the theory, the relevant prices to be taken into account in the macroeconomic perspective are the same prices as for the financial perspective excluding all applicable taxes, VAT and subsidies. In addition to the cost categories as in the financial perspective, the cost of greenhouse gas emissions are included. The annual CO_2-emissions for the different energy supply packages are given in Table 4-6.

Table 4-6: Annual CO_2-emission for the different energy supply packages

	Annual CO_2-emission [tonne/yr]				
	CHP+PV	Bio+PV	DH+PV	HP+ST+PV	CHP+ST+PV
Tot PEFs	11.7	12.5	32.1	16.0	12.0
N.r. PEFs	12.7	13.6	32.0	16.0	12.8

The annual CO_2-emissions are multiplied with the relevant price given in chapter 2.5.1 about CO_2-prices, and discounted back to the starting year. The discount rate, inflation rate and the various price escalation rates are the same as in the financial analysis. The results for total PEFs and non-renewable PEFs are shown in Figure 4-7 and Figure 4-8 respectively.

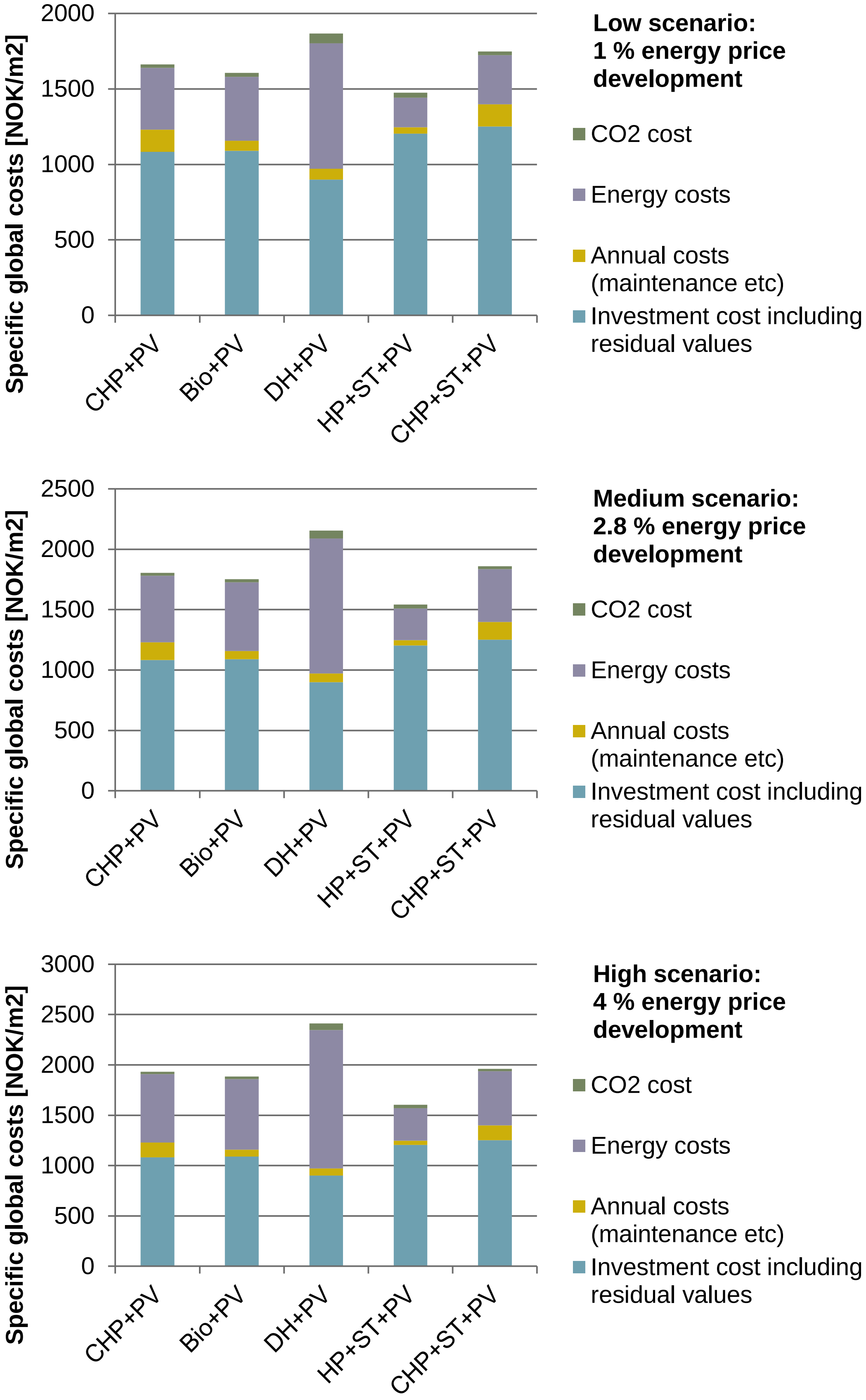


Figure 4-7: Global cost calculations for the different energy price development rates, macroeconomic perspective, total PEFs

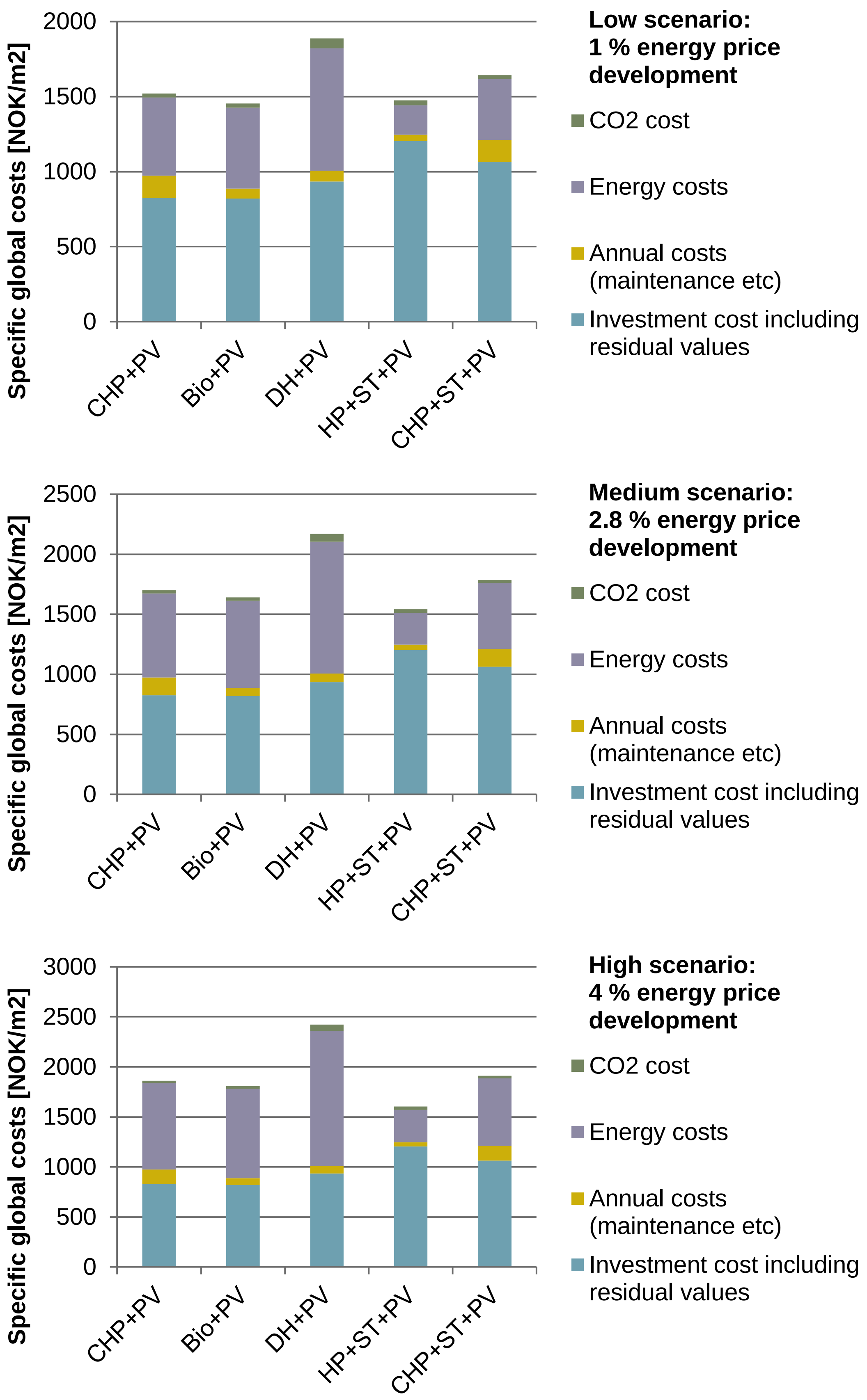


Figure 4-8: Global cost calculations for the different energy price development rates, macroeconomic perspective, non-renewable PEFs

Table 4-7: The cost optimal alternatives for the macroeconomic analysis

Energy price development rate ↓	Macroeconomic analysis	
	Tot PEFs	N.r. PEFs
1 %	HP+ST+PV	Bio+PV
2.8 %	HP+ST+PV	HP+ST+PV
4 %	HP+ST+PV	HP+ST+PV

As Figure 4-7 and Figure 4-8 show, the results are almost identical to the financial analysis. As in the financial analysis HP+ST+PV is the best alternative in all cases except for low energy price development with non-renewable PEFs where Bio+PV comes out on top. There are several reasons why the results from the financial and the macroeconomic analysis are so equal. First of all, the VAT of 25% applies to all the relevant costs (investment, energy, maintenance, etc.), thus removing it will only rescale the result, not change it. Other relevant taxes/fees, as for example the electricity certificate (0.017 NOK/kWh) which applies only to specific cost categories, are not large enough to change the results in any significant way. Neither are subsidies which apply to the bio boiler, the heat pump and the solar thermal collectors. Another reason why the financial and the macroeconomic results are so equal is that the CO_2-costs are insufficient to have any mayor impact on the results. As shown in Table 4-6, the only package with a significantly higher CO_2-emission than the others is DH+PV, although this is anyway not a relevant package because of its high energy costs. But as Figure 4-7 and Figure 4-8 show, the bars representing the CO_2-cost is so small that it barely affects the results. The CO_2-prices must be higher if CO_2-emission shall have any influence in the macroeconomic analysis.

Table 4-8: The cost optimal energy supply packages when changing the investment costs, macroeconomic analysis

	% change in investment cost ↓		Cost optimal energy supply package		
			Energy price development scenario		
			Low (1%)	Medium (2.8%)	High (4%)
Total primary energy factors	**Pellet boiler**	**+25%**	HP+ST+PV	HP+ST+PV	HP+ST+PV
		-25%	HP+ST+PV	HP+ST+PV	HP+ST+PV
	CHP	**+25%**	HP+ST+PV	HP+ST+PV	HP+ST+PV
		-25%	HP+ST+PV	HP+ST+PV	HP+ST+PV
	DH system	**+25%**	HP+ST+PV	HP+ST+PV	HP+ST+PV
		-25%	HP+ST+PV	HP+ST+PV	HP+ST+PV
	Solar collectors	**+25%**	HP+ST+PV	HP+ST+PV	HP+ST+PV
		-25%	HP+ST+PV	HP+ST+PV	HP+ST+PV
	Heat pump	**+25%**	HP+ST+PV	HP+ST+PV	HP+ST+PV
		-25%	HP+ST+PV	HP+ST+PV	HP+ST+PV
	Photovoltaic	**+25%**	HP+ST+PV	HP+ST+PV	HP+ST+PV
		-25%	HP+ST+PV	HP+ST+PV	HP+ST+PV
Non-renewable primary energy factors	**Pellet boiler**	**+25%**	HP+ST+PV	HP+ST+PV	HP+ST+PV
		-25%	Bio+PV	HP+ST+PV	HP+ST+PV
	CHP	**+25%**	Bio+PV	HP+ST+PV	HP+ST+PV
		-25%	Bio+PV	HP+ST+PV	HP+ST+PV
	DH system	**+25%**	Bio+PV	HP+ST+PV	HP+ST+PV
		-25%	Bio+PV	HP+ST+PV	HP+ST+PV
	Solar collectors	**+25%**	Bio+PV	Bio+PV	HP+ST+PV
		-25%	HP+ST+PV	HP+ST+PV	HP+ST+PV
	Heat pump	**+25%**	Bio+PV	HP+ST+PV	HP+ST+PV
		-25%	HP+ST+PV	HP+ST+PV	HP+ST+PV
	Photovoltaic	**+25%**	Bio+PV	HP+ST+PV	HP+ST+PV
		-25%	Bio+PV	HP+ST+PV	HP+ST+PV

A sensitivity analysis on the investment cost was performed also for the macroeconomic analysis, shown in Table 4-8. The result shows almost the same stability as in the financial perspective. The only deviation is when increasing investment on ST by 25% for medium price development and non-renewable PEFs; then Bio+PV is the best option. This indicates a smaller difference in global cost between the two best alternatives, but overall the results are fairly equal.

5 Discussion

This chapter is divided into three sections. First the model and the cost data will be discussed in terms of accuracy and possible improvements for future studies. Then, in light of this discussion, the results will be evaluated. This will include the most important points from the smaller discussion in the result section (chapter 1).

5.1 Model

As mentioned earlier, there were made some simplifications when modeling in IDA-ICE, primarily to reduce the simulation time: The windows were modeled as two large windows per floor instead of many smaller ones; the intermediate floors were modeled as one floor and multiplied by the number of intermediate floors; every floor was modeled as one empty zone. When the overall goal is to find cost optimal energy supply systems for the building, the main purpose with the model will be to simulate a realistic energy demand. Indoor air quality, thermal comfort, air flow between rooms, etc. are not of interest in this study. For this reasons the simplifications written above are acceptable. A more serious simplification is the absence of surroundings in the model, which primarily was because data about surroundings was not available for this master thesis. This may affect the solar radiation on the building, but even more importantly the performance of solar thermal collectors and PV. This applies especially to PV placed in the façade or on a possible garage roof which normally lies lower than the building roof. In all packages used in this study the PV area was too large for the building roof, and therefore has to be placed somewhere else. Possible shading caused by surroundings will therefore more or less affect all energy supply packages, and it’s unlikely that the result from the cost optimal analysis will change because of this.

The models for the energy supply systems used in this study were all integrated in IDA-ICE. After changing different calibration parameters and coefficients (especially important for HP) the performances of the models corresponded fairly well with data given by the manufacturers. This is important for the products to perform realistically, and hence get more accurate results. The PV in all packages is faced south with a tilting angle of 30°. As mentioned, an alternative way to install the PV is an east-west oriented system with a small tilting angle. Even though the production is usually a little less than for a south faced system, an east-west oriented system will produce more in the morning and in the evening resulting in a higher proportion of self-consumed electricity.

As mentioned earlier, the ST system in both the packages CHP+ST+PV and HP+ST+PV is a bit undersized. They are in both cases covering approximately 30% of the total heating demand, which is a little less than what normally would be preferred. This was mainly due to a limited selection of base heating systems for larger buildings in the previously obtained database. A future improvement could be to vary the ST area and the size of the base heating system, and find an optimal relationship. This would probably not change the results much since HP+ST+PV already is the cost optimal alternative in most of the scenarios considered.

Another possible improvement for future studies is to use more realistic user profiles. In this study the user behavior is very simplified; lightning and equipment are assumed on from 06-22 and off otherwise. Realistic user profiles are useful for many reasons, such as getting more representative estimates for self-consumption of generated electricity. To get realistic user profiles it can be convenient to generate multiple stochastic user profiles and use average values. It's unlikely that more realistic user profiles would've changed the result obtained in this master thesis, but it's convenient for correctly dimensioning energy supply systems, storage tanks, etc.

5.2 Cost data

When discussing the uncertainties in the cost data it's convenient to differ between the costs in terms of relevance for the total global cost. When looking at the results in Figure 4-5 to Figure 4-8 it's clear that the annual costs such as maintenance cost contributes to a small proportion of the total global cost. This also applies to mounting cost. Both these numbers are very uncertain and will vary a lot from building to building, but since they are such a small part of the total global cost picture they are not the most important concerns. The uncertainties in product costs on the other hand, are a much larger part of the total global costs, especially for the packages with ST. At the same time product costs are easier to predict. The product cost used in this study should reflect today's marked fairly accurate. It's also worth mentioning that ST and PV are the major investments in all energy supply packages, and thus also the most important costs to get as realistic as possible. The investment costs for the heating systems (HP, Bio boiler, CHP, DH) are in fact only between 1/5 and 1/10 of the investment for PV and ST. This became clear in the sensitivity analysis for the investment cost given in Table 4-5 and Table 4-8. The only major impact on the result came when changing the investment cost for ST and PV by ±25 %. This also illustrates the importance of updating the cost database regularly, especially for PV since this industry is changing so fast.

As mentioned earlier the investment cost for DH had to be estimated since a price example from BKK was not obtained in time for this master thesis. But as the results in Table 4-5 and Table 4-8 show, the package DH+PV is anyway not a good alternative because of the high energy cost.

It's also important to mention that not all energy supply packages require the same hot water tank volume, especially the packages containing ST requires a large tank volume. The cost for hot water tanks should therefore be included in the calculations. This has been neglected in this master thesis, but should be considered in future studies.

Regarding energy prices one important simplification has been made, namely neglecting the fact that the electricity price is season dependent; high in winter and low in summer. In this master thesis a constant annual electricity price has been used. An alternative, more accurate approach could be to use two different electricity prices, one for winter and one for summer following the same price development. This is of importance because the building is generating and exporting much more electricity during summer, and importing more during winter. Otherwise today's energy prices should be bound with little uncertainty. The uncertainty lies in the future energy prices, decided by the energy price development rate. A sensitivity analysis was performed on this rate, showing that the packages containing ST are best suited for high energy price development, while packages with fewer heating technologies but higher fuel consumption were best for low energy price development. But still there are some important simplifications that have been made. First of all the same energy price development rate applies to all energy carriers (electricity, district heat, pellets). The energy price development for electricity and district heat might be decided by the same rate since they both are dependent on the electricity spot price. The price development for pellets on the other hand might be different. For a more comprehensive analysis in the future, different rates may be considered.

5.3 Results

The results above show that when using total PEFs in the ZEB-balance HP+ST+PV is the cost optimal alternative among the considered energy supply packages. This applies both for the financial and the macroeconomic perspective and for all energy price developments. The sensitivity analysis shows that the package is very stable with respect to uncertainties in investment costs.

When using non-renewable PEFs the package HP+ST+PV is also the optimal alternative for medium and high energy price developments. For low energy price developments however, the package Bio+PV comes out on top. This is the conclusion both in the financial and the macroeconomic analysis. The sensitivity analysis on investment cost shows that the result is stable for high energy price development. For low energy price development however, the difference in global cost between HP+ST+PV and Bio+PV is so close that the result may change for small changes in investment costs.

DH+PV is the least optimal package in all the considered scenarios. This is primarily because the price per kWh for district heat cannot compete with the price per kWh for bulk pellets or energy delivered from a high efficient brine-to-brine HP. As discussed earlier, the PEF for district heat is highly dependent on the combusted fuel mix. Therefore it was investigated how well DH+PV would perform for lower PEFs, since this will induce a lower required PV area and thus a lower investment. But even for a PEF as low as for pellets (non-renewable PEFs) DH+PV could not compete for the cost optimal spot. The energy price is too high.

The results from the cost optimal analyses are dependent on the type of PEFs and on future energy price developments. As opposed to total PEFs, non-renewable PEFs exclude renewable energy components. The consumed primary energy for renewable energy sources is therefore determined only by the losses in the energy value chain (processing, transformation, distribution, etc.). When using non-renewable PEFs in the ZEB definition it’s highly advantageous to have an energy supply system utilizing renewable energy sources. In the author’s opinion, non-renewable PEFs are the correct type of PEFs to use since this promotes the use of renewable energy sources which is important if future energy targets shall be reached.

It’s important to keep in mind that PEFs for Norwegian conditions have not been established yet, and as mentioned German PEFs are used in this master thesis. The most significant error probably lies in the PEF for electricity. This is because most of the electricity generated in Germany comes from coal plants, while almost all electricity generated in Norway comes from hydroelectric power plants. This means that PEFs for electricity in Norway probably are less than those used in this master thesis. But a smaller PEF for electricity should benefit all electric energy supply packages (like HP+ST+PV) since packages running on fuel would have to export more electricity to obtain the ZEB balance. All electric packages on the other hand are independent on PEFs. For this reason it’s unlikely that the cost optimal analysis in this master thesis would change too much even when using PEFs developed for the Norwegian energy marked.

6 Conclusion

The main objective in this master thesis has to been to find a cost optimal energy supply solution to a zero emission building. The zero emission building used for the testing was a four floor residential block in Ådland, Bergen. Five different energy supply packages were considered: Bio+PV, CHP+PV, DH+PV, CHP+ST+PV, HP+ST+PV

For total PEFs the package HP+ST+PV proved to be the optimal alternative for all three possible energy price developments considered, both in a pure financial and a macroeconomic perspective. This is mainly due to the low annual energy cost, which is a result of a high efficient brine to water HP in combination with “free heat” delivered by the ST.

For the cases with the non-renewable PEFs, which promote the use of energy supply systems based on renewable energy, the results were a little different. For medium and high energy price developments the package HP+ST+PV once again proved to be the cost optimal alternative both in the financial and the macroeconomic analysis, mainly because of the low annual energy cost. For low energy price development however, the package Bio+PV was the optimal alternative. This is because pellets is considered a renewable energy source and consequently the PEF for pellets is very low. This means that less electricity must be exported for the building to reach the ZEB target and therefore the investment on PV will be lower. This is an interesting result which shows that for future high energy price developments it will in most cases pay off to invest a little extra in ST to decrease future energy costs. While for low energy price developments it may be best to invest in a simpler and cheaper package with a lower investment cost but consequently also a little higher annual energy cost.

The results show that the optimal alternative is dependent on type of PEFs used. Since no PEFs have been defined in Norway yet, it’s difficult to give an exact conclusion on which package is the best, but overall HP+ST+PV has proven to be the preferred alternative. In Norway the PEF for electricity would most likely be lower than the German values since most of the electricity production comes from hydroelectric plants. But since this should favor all electric energy supply packages it’s unlikely that the cost optimal alternative would change for PEFs defined for Norway.

The sensitivity analysis that was performed on the investment costs showed that the result is very stable for possible uncertainties in the cost data. The model in IDA-ICE contained some simplifications, but there are little to suggest that these had any major influence on the results.

7 Further work

Some of the possible changes and improvements for future cost optimal analyses were proposed in the discussion above.

As mentioned in the theory about zero emission buildings there are no clear definition for ZEBs yet. There are many ZEB definitions with different metrics like primary energy factors and CO_2-factors. In Norway primary energy factors are not defined yet, and there has even been some discussion about whether PEFs should be the weighting factors in the ZEB definitions or not. A decision also has to be made regarding whether the macroeconomic or the financial calculation is to become the national benchmark. If future energy targets shall be reached it's important that there exist clear definitions for ZEBs, and also guidelines for how to calculate the ZEB balance.

Regarding the main objective in this master thesis, to find a cost optimal energy supply solution to a zero emission building, the results have clearly showed that for the building block in Ådland the package HP+ST+PV had proven to be a highly relevant alternative. But there are still some packages which have not been investigated, like Bio+ST+PV or DH+ST+PV. It's also important to mention that for a more comprehensive database some of the packages should be reconsidered. Especially CHP+ST+PV and CHP+PV, since the CHP used in the calculations is a bit oversized for the building block in Ådland, and because the cost data for this technology are obteined from other countries than Norway.

The Ådland building park consists of many buildings as shown in Figure 3-1 and Figure 3-2. In this study one of the buildings were considered in the ZEB balance. A more cost efficient approach to provide energy for the ZEBs in Ådland would be to create an energy central delivering heat and electricity to multiple buildings. This is more cost efficient because larger systems are cheaper per watt, and because the efficiencies usually are higher. Also maintenance cost will be less than for many smaller systems. Clusters of ZEBs, like the Ådland building park, will likely be more relevant in some years. As for today, it's also relevant to design cost optimal energy supply solutions for single ZEBs.

As mentioned "the tool" shall include both a simulation tool (IDA-ICE) and an information database. It would be very useful if the database was integrated in the simulation tool (IDA-ICE), and thus global costs would be calculated automatically. This shouldn't be too complicated to implement especially if a good and comprehensive database is in place. Input factors could be energy prices, energy price developments, appropriate calculation rates, calculation period etc. While investment costs, lifetimes, efficiencies and other technical data were included in the database. This would make it very easy for consultants, entrepreneurs and engineers to get a quick overview over the most relevant energy supply packages for zero emission buildings at an early construction phase.

8 Bibliography

[1] European Parliament and European Council, *EU renewable energy directive.* 2009: p. 47.

[2] ADAPTConsulting, *Vekting av elektrisitet i energipolitikken*. 2012. p. 54.

[3] The Research Centre on Zero Emission Buildings (ZEB). *The Research Centre on Zero Emission Buildings*. 2012 [cited 16th of June, 2013]; Available from: http://zeb.no/index.php/about-zeb.

[4] Norconsult, *Nullutslippsboliger Ådland, Ytrebygda, Konsekvensutredning*. 2010. p. 49.

[5] Berner, M., Frydenlund, F., Alonso, M.J., and Novakovic, V., *Energy supply solutions for ZEB buildings - from the consulting and contracting engineers point of view*, in *ZEB Report*. 2012.

[6] NTNU and SINTEF, *Enøk i Bygninger*. 2007: Gyldendal undervisning.p. 476

[7] Sartori, I. and Dokka, T.H., *From Passive House to Zero Emission Building: How much electricity generation is needed?* . 2010, 3rd Nordic Passive House Conference 2010 - Towards 2020 Sustainable Cities and Buildings: Aalborg, Denmark. p. 6.

[8] Sartori, I., Napolitano, A., and Voss, K., *Net zero energy buildings: A consistent definition framework*. 2012. p. 13.

[9] Aune, M. and Sørensen, K.H., *Mellom klima og komfort*. 1st ed. 2007: Tapir Akademisk Forlag p. 47-48

[10] Olje- og energidepartementet, *Energigjennomgangspakken: Europaparlaments- og rådsdirektiv 2010/31/EU av 19. mai 2010 om energieffektivitet av bygninger (omarbeiding)*, Olje- og energidepartementet, Editor. 2010.

[11] Strandskog, T., *Høringsuttalelse om revidert Europaparlaments- og rådsdirektiv 2010/31/EU om energieffektivitet i bygninger (bygningsenergidirektivet)*. 2010, Norsk Teknologi: Oslo. p. 4.

[12] European Parliament and European Council, *Energy Performance of Buildings Directive.* Office Journal of the European Union, 2010: p. 23.

[13] Standard norge, *NS 3031: Beregninger av bygningers energiytelse, Metode og data.* 2007. p. 74.

[14] European Commission, *EU cost-optimal methodology, guidelines.* Office Journal of the European Union, 2012: p. 28.

[15] European Commission, *EU cost-optimal methodology, regulations.* Official Journal og the European Union, 2012: p. 19.

[16] The European Committee for Standardization (CEN), *NS-EN 15459: Bygningers energiytelse. Økonomisk evalueringsprosedyre for energisystemer i bygninger.* 2007. p. 50.

[17] Hass, J., Weir, M.D., and Thomas, G.B., *Calculus Part 1*. 2008: Pearson.p. 516-518

[18] International Energy Agency (IEA), *Renewables information*. 2009. p. 404.

[19] The European Committee for Standardization (CEN), *NS-EN 15603:2008: Energy performance of buildings. Overall energy use and definition of energy ratings*. 2008. p. 62.

[20] ProgramByggerne. *SIMIEN Wiki*. 2012 [cited 1st of March, 2013]; Available from: http://www.programbyggerne.no/SIMIEN/start.

[21] EQUA Solutions. *IDA Indoor Climate and Energy*. 2013 [cited 1st of March, 2013]; Available from: http://www.equa-solutions.co.uk/en/software/idaice.

[22] Kurnitskia, J., Saarib, A., Kalameesc, T., Vuolled, M., Niemeläd, J., and Tarke, T., *Cost optimal and nearly zero (nZEB) energy performance calculations for residential buildings with REHVA definition for nZEB national implementation*, in *Elsevier*. 2011. p. 10.

[23] Nunes, P., Aelenei, L., and Graca, G.C., *Overview of Cost Optimal Methodology Framework to respond to Net Zero-Energy Building Challenge*. 2010. p. 1.

[24] Stene, J., *Oppvarmingssystemer for boliger av lavenergi- og passivhusstandard*. 2008, SINTEF Energiforskning AS. p. 30.

[25] Frydenlund, F., *Survey of Available Technologies for Renewable Energy Supply to Buildings*. 2010, The Research Center on Zero Emission Buildings. p. 196.

[26] Løtveit, S.V., *Information database for supply in decision making on ZEB energy system in early design stage*. 2012, Department of Physics: Norwegian University of Science and Technology. p. 60.

[27] Twidell, J. and Weir, T., *Renewable Energy Resources*. 2nd ed. 2006: Taylor & Francis.p. 351-354

[28] Nordahl, S.H., *Design of Roof PV Installation in Oslo*, in *Department of Electrical Power Engineering*. 2012, NTNU: Trondheim. p. 161.

[29] KYOCERA SOLAR Deutschland. *KYOCERA SOLAR Europe, Datasheet for the model: KD245GH-2PB*. 2012 [cited 1st of March, 2013]; Available from: http://www.kyocerasolar.de/index/products/download/English.html.

[30] Markvart, T., *Solar Electricity*. 2nd ed. 2000: John Wiley & Sons.p. 43-45

[31] Weiss, W. and Mauthner, F., *Solar Heat Worldwide*, in *IEA Solar Heating & Cooling Programme, May 2012*. 2012, AEE - Institute for Sustainable Technologies. p. 63.

[32] SINTEF Byggforsk and Kan Energi AS, *Mulighetsstudie Solenergi i Norge*. 2011: Oslo. p. 77.

[33] Andresen, I., *Planlegging av solvarmeanlegg for lavenergiboliger og passivhus. En introduksjon*. 2008. p. 42.

[34] Svensk Vindkraftförening, *MARKNADSÖVERSIKT SMÅ VINDKRAFTVERK I SVERIGE* 2011. p. 26.

[35] EnergiHuset. *Pellets*. 2013 [cited 22nd of April, 2013]; Available from: http://www.energihuset.no/index.php?valg=pellets2.

[36] Teknisk Nyheter DA, *Energirapporten, årgang 9 nummer 38*. 2012. p. 15.

[37] Nord Pool. *Elspot prices*. 2013 [cited 15th of April, 2013]; Available from: http://www.nordpoolspot.com/Market-data1/Elspot/Area-Prices/ALL1/Hourly/.

[38] BKK. *Priser og vilkår, Borettslag/sameie*. 2013 [cited 20th of May, 2013]; Available from: http://www.bkk.no/bedrift/produkter/fjernvarme/priser-vilkar/article33667.ece.

[39] Elvedin, G., *Questions regarding plus customers (Personal Communication)*, S.V. Løtveit, Editor. 2013.

[40] Norges vassdrags- og energidirektorat, *Håndtering av plusskunder og vedtak om dispensasjon fra foreskrift 302 om økonomisk og teknisk rapportering m.v.* 2010. p. 4.

[41] Olje- og energidepartementet, *FOR-1990-12-07-959: Forskrift om produksjon, omforming, overføring, omsetning, fordeling og bruk av energi m.m. (energilovforskriften)*. 1990.

[42] Olje- og energidepartementet, *FOR 1999-03-11 nr 302: Forskrift om økonomisk og teknisk rapportering, inntektsramme for nettvirksomheten og tariffer*. 1999.

[43] Biørnstad, H.T., *Vurdering av plusskunder sine rammebetingelser i framtidens distribusjonsnett (SmartGrid) - med fokus på AMS og produksjonsteknologi*, in *Institutt for Elkraftteknikk*. 2012, Norges teknisk-naturvitenskapelige universitet (NTNU). p. 135.

[44] Equa Simulation AB, *Validation of IDA Indoor Climate and Energy 4.0*. 2010. p. 19.

[45] EQUA Simulation AB. *What is New*. 2013 [cited 20th of April, 2013]; Available from: http://www.equa-solutions.co.uk/en/software/what-is-new.

[46] Jensen, T., Haugen, S., and Magnussen, I., *Samfunnsøkonomisk analyse av energiprosjekter, Håndbok*. 2003, Energi og Markedsavdelingen i NVE. p. 79.

[47] Norges Bank. *Inflasjon*. 2013 [cited 16th of April, 2013]; Available from: http://www.norges-bank.no/no/prisstabilitet/inflasjon/.

[48] Statistisk sentralbyrå. *Elektrisitetspriser*. 2013 [cited 2nd of May, 2013]; Available from: https://www.ssb.no/statistikkbanken/SelectTable/hovedtabellHjem.asp?KortNavnWeb=elkraftpris&CMSSubjectArea=energi-og-industri&StatVariant=&PLanguage=0&checked=true.

[49] Enseling, A. and Loga, T., *Implementing the cost-optimal methodology in EU countries. Case study Germany*. 2013, Institut Wohnen und Umwelt GmbH (IWU). p. 61.

[50] The European Committee for Standardization (CEN), *NS-EN 12975-2, Solvarmesystemer og -komponenter. Solfangere. Del 2: Prøvingsmetoder*. 2006. p. 136.

[51] Gilje, J.H., *Info i forbindelse med sommerjobb hos sintef (Personal Communication)*, S.V. Løtveit, Editor. 2012, SGP Varmeteknikk AS.

[52] BKK. *Konsesjonsområde for fjernvarme i Bergen*. 2013 [cited 11th of June, 2013]; Available from: http://www.bkk.no/om_oss/anlegg-utbygging/fjernvarme/article31634.ece.

[53] The Passive House Institute (PHI). *About Passive House - What is a Passive House?* 2012 [cited 8th of May, 2013]; Available from: http://www.passiv.de/en/02_informations/01_whatisapassivehouse/01_whatisapassivehouse.htm.

[54] Myhre, L., *Bakgrunn for krav i NS 3700:2010*. 2013, Boligprodusentenes Forening. p. 5.

[55] Eriksson, J., *Systemmodell för dimensionering och optimering av energicentral med borrhålslager*. 2010, ÅFORSK – Ångpanneföreningens Forskningsstiftelse. p. 44.

Appendix A

Heat pumps, cost and technical data

Table A-0-1: Cost data for three Dimplex water/water HPs, obtained from the earlier project work [26]

Dimplex, model	SI 11TU		SI 14TU		SI 22TU	
Product price	60648	NOK	65436	NOK	84487	NOK
Price buffer tank	4191.6	NOK	5216.4	NOK	5216.4	NOK
Div equipment	8778	NOK	8778	NOK	13876	NOK
Mounting	26200	NOK	26200	NOK	32775	NOK
Price for energy well	76294	NOK	92044	NOK	139294	NOK
Subsidies	10000	NOK	10000	NOK	10000	NOK
Tot inv. cost	166112	NOK	187674	NOK	265648	NOK
Tot inv. cost	16.0	NOK/W	14.1	NOK/W	11.9	NOK/W
Nominal perf.	10.4	kW	13.3	kW	22.3	kW
Power consumption	2.8	kW	3.5	kW	6.2	kW
Maintenance cost	650	NOK/yr	650	NOK/yr	650	NOK/yr
Lifetime	20	yr	20	yr	20	yr

Table A-0-2: Performance data on the three Dimplex water/water HPs, outlet temperature = 45°C, obtained from the earlier project work [26]

Model	SI 11TU	SI 14TU	SI 22TU
Inlet temperature, -5°C			
Heat capacity	9.0	11.2	19.0
Power consumption	2.8	3.5	6.3
COP	**3.2**	**3.2**	**3.0**
Inlet temperature, 0°C			
Heat capacity	10.4	13.2	22.5
Power consumption	2.8	3.5	6.3
COP	**3.7**	**3.8**	**3.6**
Inlet temperature, 5°C			
Heat capacity	12.0	15.2	25.0
Power consumption	2.8	3.5	6.3
COP	**4.3**	**4.3**	**4.0**
Inlet temperature, 10°C			
Heat capacity	13.6	17.2	27.5
Power consumption	2.8	3.6	6.1
COP	**4.8**	**4.8**	**4.5**
Inlet temperature, 15°C			
Heat capacity	15.2	19.6	30.5
Power consumption	2.8	3.6	6.4
COP	**5.4**	**5.4**	**4.8**
Inlet temperature, 20°C			
Heat capacity	17.0	22.2	33.0
Power consumption	2.8	3.6	6.6
COP	**6.0**	**6.2**	**5.0**

Appendix B

Pellet boilers, cost data

Table B-0-1: Cost data for pellet boilers, obtained from the earlier project work [26] with some adjustments

Fuel	Pellets	Pellets	Pellets
Model	**ETA PU 15**	**ETA PC 20**	**ETA PC 25**
Product price	67000 NOK	71500 NOK	75000 NOK
Pellets silo system	100000 NOK	125000 NOK	150000 NOK
Div eq., mounting	20000 NOK	20000 NOK	20000 NOK
Subsidies	0 NOK	10000 NOK	10000 NOK
Tot. investment cost	187000 NOK	206500 NOK	235000 NOK
Tot. investment cost	12.6 NOK/Wp	10.3 NOK/Wp	9.4 NOK/Wp
Efficiency max load	0.935	0.948	0.952
Efficiency min load	0.957	0.918	0.922
Average efficiency	0.946	0.933	0.937
Max heating performance	14.9 kW	20 kW	25 kW
Min heating performance	4.4 kW	6 kW	7.3 kW
Power consumption	80 W	73 W	80 W
Annual maintenance cost	2317 NOK	3111 NOK	3888 NOK
Lifetime	15 yr	15 yr	15 yr

Appendix C

Solar thermal collectors, cost and technical data

Packages

Table C-0-1 and Table C-0-2 give technical and economic data for two complete ST packages delivered by SGP Varmeteknikk AS. The cost data were obtained in the earlier project work [26], but most of the technical data has been gathered to satisfy the required input in IDA-ICE. The STs are certified according to the standard NS-EN 12975-2 [50].

Table C-0-1: Cost data for two complete ST packages, obtained from the earlier project work [26]

Supplier	**SGP Varmeteknikk AS**		**SGP Varmeteknikk AS**	
Type	**Vacuum pipes (CPC 9+)**		**Flat panels (Neo 2.1)**	
Investment cost *	49700	NOK	42400	NOK
Area	5.4	m^2	7.6	m^2
Size per panel	1.79		1.9	m^2
Mounting cost	22995	NOK	22995	NOK
Subsidies***	10000	NOK	10000	NOK
Total investment cost*	**63298**	**NOK**	**55998**	**NOK**
Maintenance cost	650	NOK/yr	650	NOK/yr

* Price for accumulator tank is not included

Table C-0-2: Technical data for two complete ST packages provided by SGP Varmeteknikk AS

Supplier	**SGP Varmeteknikk AS**		**SGP Varmeteknikk AS**	
Type	**Vacuum pipes (CPC 9+)**		**Flat panels (Neo 2.1)**	
Lifetime	25	yr	25	yr
Optical efficiency	0.61	-	0.773	-
Heat loss coefficient 1	0.84	W/m^2K	3.676	W/m^2K
Heat loss coefficient 2	0.0053	W/m^2K^2	0.0143	W/m^2K^2
Liquid type	Ethylene glycol (Tyfocor)	-	Ethylene glycol (Tyfocor)	-
Liquid freezing point	-32	°C	-32	°C
Buffer tank	OSO RTV E 300	-	OSO RTV E 300	-

Larger systems

The data given in Table C-0-3 and Table C-0-4 was obtained from an excel sheet used to calculate investment cost and performance data on larger ST systems, developed by Jo Helge Gilje (SGP Varmeteknikk AS). The data are from some years back, but price wise it's not so different from today [51].

Table C-0-3: Cost data for larger ST systems provided by [51]

Solar panel	CPC 9+ vacuum tubes		Neo 2,1 flate plate	
Size	1.79	m^2	1.9	m^2
Price per panel incl mounting material	8000	NOK	5500	NOK
Price for rack (flat roof)	500	NOK	1250	NOK
Equipment per installation	500	NOK	500	NOK
Mounting cost per installation	20	% of investment	20	% of investment
Optical efficiency	0.61	-	0.773	-

Table C-0-4: Control units for larger ST systems provided by [51]

Control unit	Min size of system		Max size of system		Price	
SolexMini HZL	0	m^2	20	m^2	15300	NOK
Solex HZL I	20	m^2	30	m^2	18900	NOK
Solex HZL II	30	m^2	50	m^2	22000	NOK
SolexMax HZL	50	m^2	100	m^2	28560	NOK
SolexMax 2 x kaskade HZL	100	m^2	215	m^2	73800	NOK
SolexMax 3 x kaskade HZL	215	m^2	320	m^2	107760	NOK
SolexMax 4 x kaskade HZL	320	m^2	430	m^2	165000	NOK

Appendix D

Photovoltaic, cost and technical data

Table D-0-1 and Table D-0-2 show three cost alternatives for PV. The data have been obtained from a master thesis by Siv Helene Nordahl from 2012, Design of Roof PV Installation in Oslo [28], updated with today's price rates. Most of the data are based on previous calculations done by Multiconsult. Maintenance is considered necessary once a year, while the inverter repair is considered necessary every five years.

Table D-0-1: Investment cost for the three PV alternatives. Rate per March 13th, 2013: 7.443 NOK/€

Supplier	REC Eltek		REC SMA		SunPower SMA	
Module price	750	€/kWp	750	€/kWp	1140	€/kWp
Length	1.665	m	1.665	m	1.559	m
Width	0.991	m	0.991	m	1.046	m
Power	250	Wp	250	Wp	327	Wp
Effciency	15.15	%	15.15	%	20.05	%
Inverter	297.14	€/kWp	210	€/kWp	210	€/kWp
Mounting system	250	€/kWp	250	€/kWp	188.9	€/kWp
Montage	200	€/kWp	200	€/kWp	151.12	€/kWp
DC cables	214	€/kWp	214	€/kWp	161.69	€/kWp
AC cables	131.2	€/kWp	131.2	€/kWp	99.13	€/kWp
Communication	40	€/kWp	40	€/kWp	30.22	€/kWp
Total BoS cost	1132.34	€/kWp	1045.2	€/kWp	841.06	€/kWp
Module + BoS cost	**1882.34**	**€/kWp**	**1795.2**	**€/kWp**	**1981.06**	**€/kWp**
	14010.9	**NOK/kWp**	**13361.7**	**NOK/kWp**	**14745.0**	**NOK/kWp**

Table D-0-2: Annual costs for the three PV alternatives

Supplier	REC Eltek	REC SMA	SunPower SMA
Module maintenance	1593 NOK/yr	1458 NOK/yr	2955 NOK/yr
Inverter repair	2158 NOK/five yr	2031 NOK/five yr	2180 NOK/five yr

Appendix E

Combined heat and power

Table E-0-1: Investment, operation and maintenance cost for different CHP systems, adapted from: Survey of Available Technologies for Renewable Energy Supply to Buildings [25]

	Reciprocating engines	**Micro-turbines**	**Stirling engines**	**PEM Fuel Cell**
Specific investment costs [€/kWe]	785- 2 200[a]	550-850	0,8-28	>3000
Maintenance interval [h]	3 500-20 000	20 000-30 000	5 000	2000-5 500
Maintenance costs (electrical kW) [€/kWh]	0.008-0.012	0.005-0.013	0.005-0.012	0.016-0.024
Availability [%]	85-95	95	90-95	95
Life time [years]	10-15	15-20	[b]	4-8
Fuel	Natural or bio gas, LNG, LPG, diesel or bio diesel, fuel oil	Natural or biogas, diesel fuel oil, gasoline alcohol	Natural or biogas, diesel, PG several liquid or solid fuel	Hydrogen, methanol, natural gas

[a] with higher specific cost for smaller cogeneration systems from 1kW

[b] no experience

Table E-0-2: Price model for two stirling type CHP systems, obtained from the earlier project work [26]

Combustion	**External, stirling engine**		**External, stirling engine**	
Supplier	**WhisperGEN**		**BAXI**	
Model	**MkV AC Gas Fired**		**Ecogen**	
Application	**Residential buildings**		**Residential buildings**	
Fuel	**Mainly natural gas**		**Mainly natural gas**	
Pellets silo system price	100000	NOK	150000	NOK
Tot investment cost incl install.	226208.9	NOK	265840.7	NOK
Efficiency	0.95	-	0.95	-
Min el production	-	kW	0.3	kW
Normal/max el production	1	kW	1	kW
Min thermal production	5.5	kW	3	kW
Normal/max thermal production	14	kW	24	kW
Annual mainenance cost	3700	NOK/yr	11500	NOK/yr
Lifetime	15	yr	15	yr

Appendix F

Dimensioning of the energy supply systems for the building in Ådland

Table F-0-1: Dimensioning of energy supply systems using total PEFs

Bio+PV	CHP+PV	DH+PV	CHP+ST+PV	HP+ST+PV
- ETA PC 20 pellet boiler incl pellet silo system - 805 m^2 PV from REC, incl BoS with ELTEK inverter	- BAXI Ecogen stirling based CHP incl pellet silo system - 775 m^2 PV from REC, incl BoS with ELTEK inverter	- Pipes and customer central for DH - 705 m^2 PV from REC, incl BoS with ELTEK inverter	- BAXI Ecogen stirling based CHP incl pellet silo system - 695 m^2 PV from REC, incl BoS with ELTEK inverter - 100 m^2 vacuum tubes ST incl mounting material and control unit	- Dimplex SI 14TU water/water HP incl borehole and buffer tank - 625 m^2 PV from REC, incl BoS with ELTEK inverter - 110 m^2 vacuum tubes ST incl mounting material and control unit

Table F-0-2: Dimensioning of energy supply systems using non-renewable PEFs

Bio+PV	CHP+PV	DH+PV	CHP+ST+PV	HP+ST+PV
- ETA PC 20 pellet boiler incl pellet silo system - 575 m^2 PV from REC, incl BoS with ELTEK inverter	- BAXI Ecogen stirling based CHP incl pellet silo system - 555 m^2 PV from REC, incl BoS with ELTEK inverter	- Pipes and customer central for DH - 735 m^2 PV from REC, incl BoS with ELTEK inverter	- BAXI Ecogen stirling based CHP incl pellet silo system -535 m^2 PV from REC, incl BoS with ELTEK inverter - 100 m^2 vacuum tubes ST incl mounting material and control unit	- Dimplex SI 14TU water/water HP incl borehole and buffer tank - 625 m^2 PV from REC, incl BoS with ELTEK inverter - 110 m^2 vacuum tubes ST incl mounting material and control unit

Appendix G

Ådland building site in relation to the DH concession area

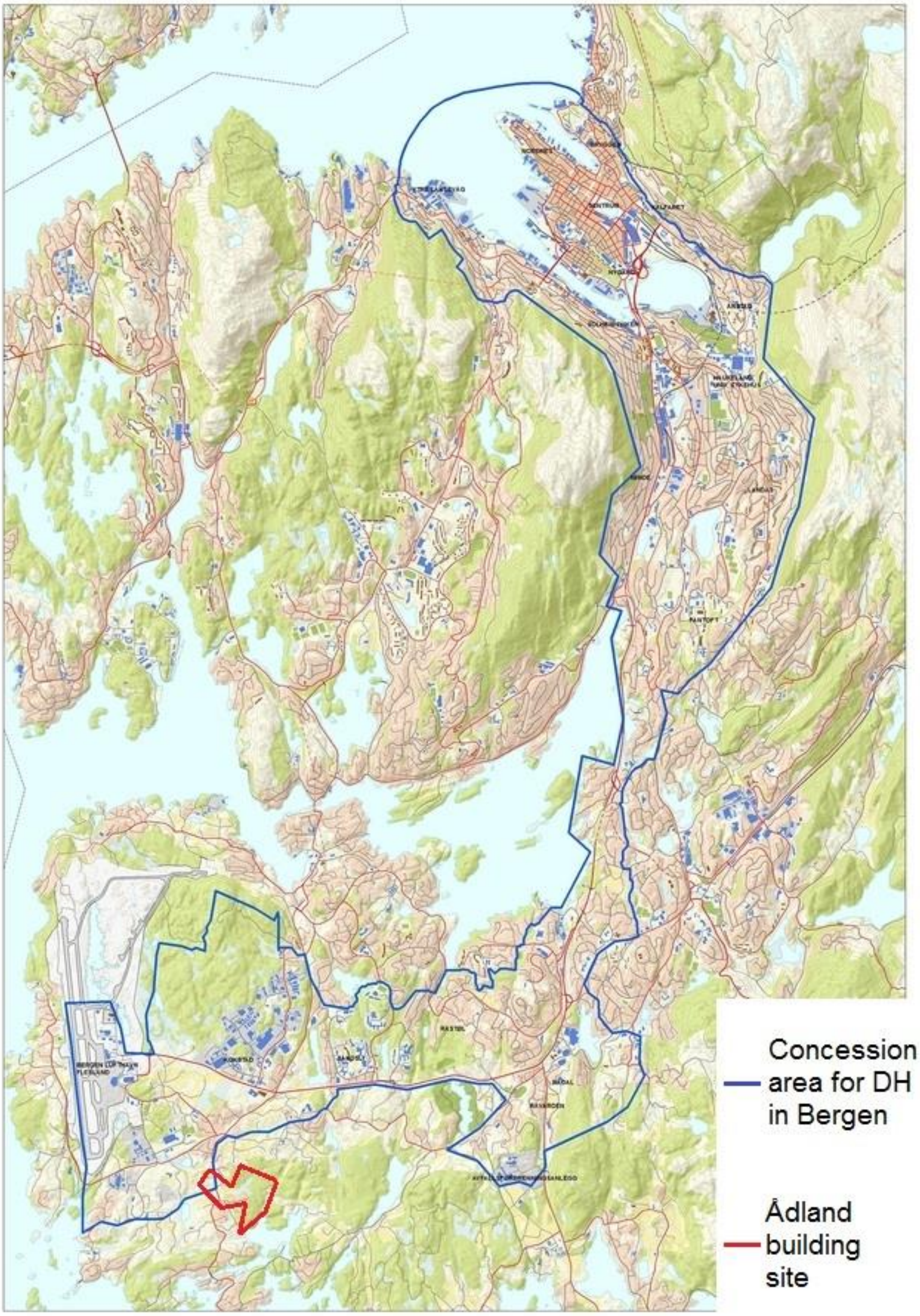


Figure G-0-1: Ådland building site and the concession area for DH in Bergen, adapted from an illustration on BKK's web page [52]

Appendix H

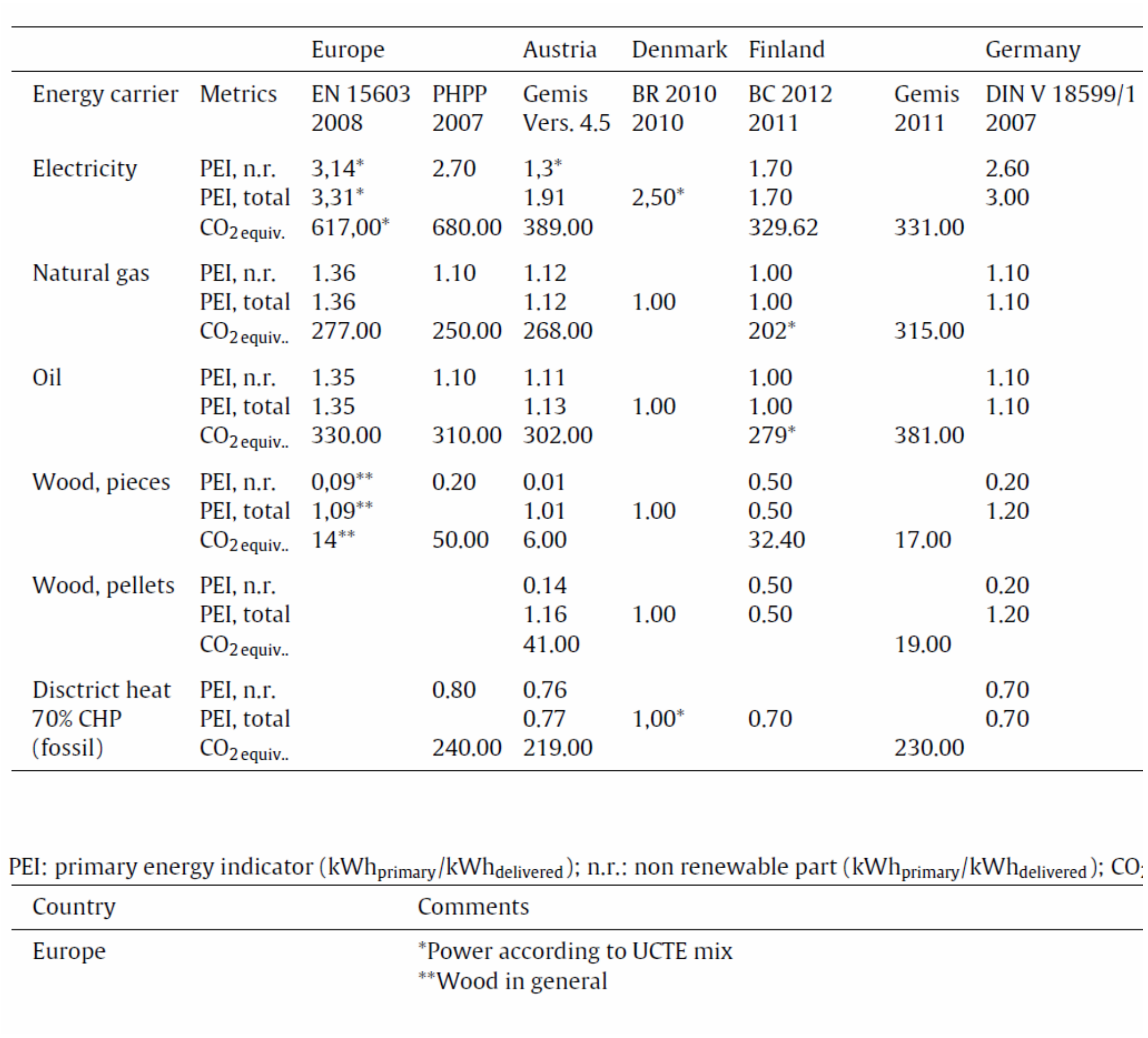
Guiding values for primary energy and CO_2 factors

Table H-0-1: Primary energy factors and CO2 production coefficients (informative values) obtained from the standard NS-EN 15603:2008 [19]

Energy carrier ↓	Primary energy factors f_{prim}		CO_2 production coefficient K
	Non-renewable	Total	Kg/MWh
Fuel oil	1.35	1.35	330
Gas	1.36	1.36	277
Anthracite	1.19	1.19	394
Lignite	1.40	1.40	433
Coke	1.53	1.53	467
Wood shavings	0.06	1.06	4
Log	0.09	1.09	14
Beech log	0.07	1.07	13
Fir log	0.10	1.10	20
Electricity from hydraulic power plant	0.50	1.50	7
Electricity from nuclear power plant	2.80	2.80	16
Electricity from coal power plant	4.05	4.05	1340
Electricity Mix UCPTE	3.14	3.31	617

Appendix I

Primary energy factors



		Europe		Austria	Denmark	Finland		Germany
Energy carrier	Metrics	EN 15603 2008	PHPP 2007	Gemis Vers. 4.5	BR 2010 2010	BC 2012 2011	Gemis 2011	DIN V 18599/1 2007
Electricity	PEI, n.r.	3,14*	2.70	1,3*		1.70		2.60
	PEI, total	3,31*		1.91	2,50*	1.70		3.00
	$\mathrm{CO}_{2\,\mathrm{equiv.}}$	617,00*	680.00	389.00		329.62	331.00	
Natural gas	PEI, n.r.	1.36	1.10	1.12		1.00		1.10
	PEI, total	1.36		1.12	1.00	1.00		1.10
	$\mathrm{CO}_{2\,\mathrm{equiv..}}$	277.00	250.00	268.00		202*	315.00	
Oil	PEI, n.r.	1.35	1.10	1.11		1.00		1.10
	PEI, total	1.35		1.13	1.00	1.00		1.10
	$\mathrm{CO}_{2\,\mathrm{equiv..}}$	330.00	310.00	302.00		279*	381.00	
Wood, pieces	PEI, n.r.	0,09**	0.20	0.01		0.50		0.20
	PEI, total	1,09**		1.01	1.00	0.50		1.20
	$\mathrm{CO}_{2\,\mathrm{equiv..}}$	14**	50.00	6.00		32.40	17.00	
Wood, pellets	PEI, n.r.			0.14		0.50		0.20
	PEI, total			1.16	1.00	0.50		1.20
	$\mathrm{CO}_{2\,\mathrm{equiv..}}$			41.00			19.00	
Disctrict heat	PEI, n.r.		0.80	0.76				0.70
70% CHP	PEI, total			0.77	1,00*	0.70		0.70
(fossil)	$\mathrm{CO}_{2\,\mathrm{equiv..}}$		240.00	219.00			230.00	

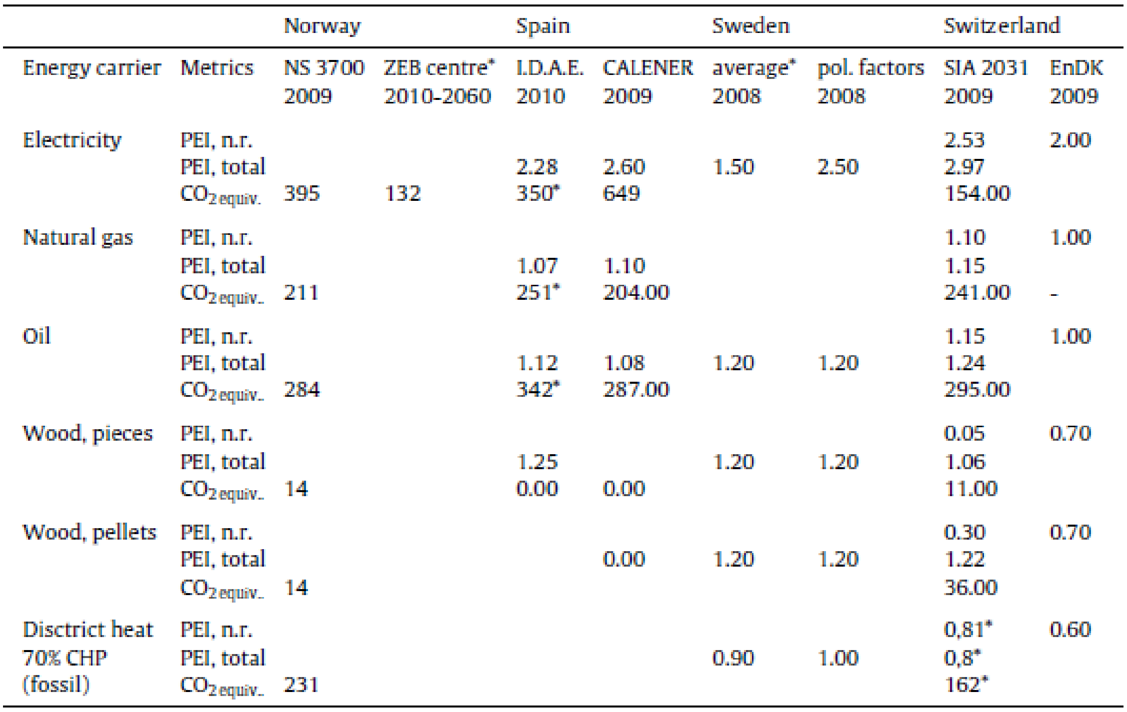
PEI: primary energy indicator ($\mathrm{kWh}_{\mathrm{primary}}/\mathrm{kWh}_{\mathrm{delivered}}$); n.r.: non renewable part ($\mathrm{kWh}_{\mathrm{primary}}/\mathrm{kWh}_{\mathrm{delivered}}$); CO

Country	Comments
Europe	*Power according to UCTE mix **Wood in general

Figure I-0-1: Primary energy factors and CO_2 factors, obtained from: Net zero energy buildings, a consistent definition framework [8]

Appendix J

CO_2 factors



		Norway		Spain		Sweden		Switzerland	
Energy carrier	Metrics	NS 3700 2009	ZEB centre* 2010-2060	I.D.A.E. 2010	CALENER 2009	average* 2008	pol. factors 2008	SIA 2031 2009	EnDK 2009
Electricity	PEI, n.r.							2.53	2.00
	PEI, total			2.28	2.60	1.50	2.50	2.97	
	$CO_{2\,equiv.}$	395	132	350*	649			154.00	
Natural gas	PEI, n.r.							1.10	1.00
	PEI, total			1.07	1.10			1.15	
	$CO_{2\,equiv.}$	211		251*	204.00			241.00	-
Oil	PEI, n.r.							1.15	1.00
	PEI, total			1.12	1.08	1.20	1.20	1.24	
	$CO_{2\,equiv.}$	284		342*	287.00			295.00	
Wood, pieces	PEI, n.r.							0.05	0.70
	PEI, total			1.25		1.20	1.20	1.06	
	$CO_{2\,equiv.}$	14		0.00	0.00			11.00	
Wood, pellets	PEI, n.r.							0.30	0.70
	PEI, total				0.00	1.20	1.20	1.22	
	$CO_{2\,equiv.}$	14						36.00	
Disctrict heat 70% CHP (fossil)	PEI, n.r.							0,81*	0.60
	PEI, total					0.90	1.00	0,8*	
	$CO_{2\,equiv.}$	231						162*	

Figure J-0-1: CO_2 factors for Norway, obtained from: Net zero energy buildings, a consistent definition framework [8]

Appendix K

Energy regulations for passive houses

A Passive House is a building standard which first was developed in Germany [53], which also developed a certification scheme for buildings and building elements. A Passive House has typical energy performance of only 25% of an average new building, and down to only 10% of a typical Central European building stock. This is achieved by efficient use of the sun, internal heat sources and heat recovery, highly insulated walls, roofs and floors, use of special windows and an efficient ventilation system.

Heating demand

Criteria for PHs in Norway are given in the Norwegian Standard NS 3700 for residential buildings. The criteria are based on the German PH standard, with a maximum heating demand of 15 kWh/m^2. Since the average temperature in Norway is significantly lower than in Germany the requirements in NS 3700 are climate adjusted. In locations with a lower average temperature of 6.3°C a higher heating demand than 15 kWh/m^2 are accepted. In addition NS 3700 are also area adjusted. This is because small buildings have a higher specific heat loss than larger buildings [54]. The heating demand restrictions for PHs are given in Table K-0-1.

Table K-0-1: Maximum heating demand for PHs, obtained from the standard NS 3700:2010

Annual average Temp Θ_{ym}	**A_{fl} < 250 m^2, [kWh/(m^{2}yr)]**	**A_{fl} ≥ 250 m^2, [kWh/(m^{2}yr)]**
≥ 6.3 °C	$15 + 5.4 \cdot \frac{(250 - A_{fl})}{100}$	15
< 6.3 °C	$15 + 5.4\left(\frac{250 - A_{fl}}{100}\right) + \left(2.1 + 0.59\left(\frac{250 - A_{fl}}{100}\right)\right)(6.3 - \theta_{ym})$	$15 + 2.1(6.3 - \theta_{ym})$

Minimum requirements for building components and leakage rates

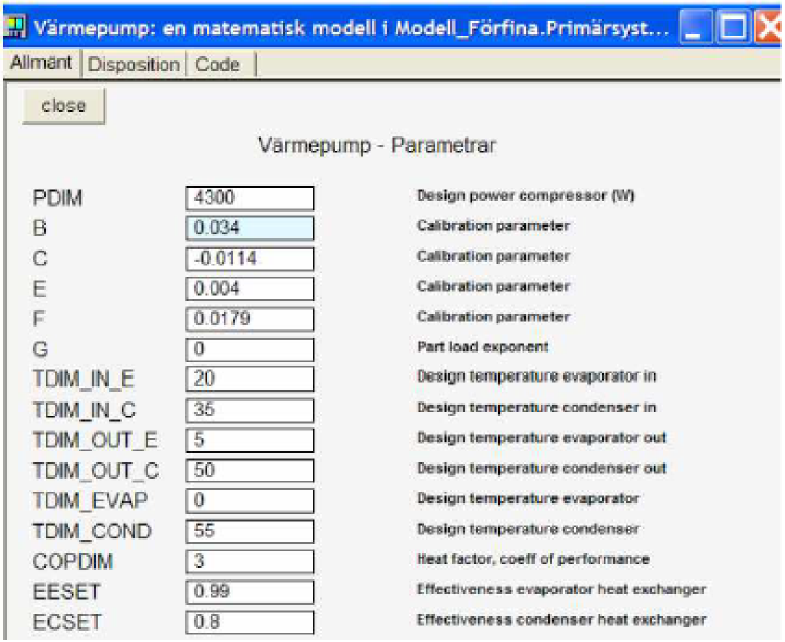
There are also requirements for building parts and components, as well as leakage rates. These are given in Table K-0-2.

Table K-0-2: Minimum requirements for building components and leakage rates, obtained from the standard NS 3700:2010

Passive house requirements		
U-value, external wall	≤ 0.15	W/(m^2K)
U-value, roof	≤ 0.13	W/(m^2K)
U-value, floor	≤ 0.15	W/(m^2K)
U-value, window	≤ 0.80	W/(m^2K)
U-value, door	≤ 0.80	W/(m^2K)
Thermal bridges	≤ 0.03	W/(m^2K)
Annual avg efficiency for heat recovery system	≥ 80	%
SFP-factor for ventilation system	≤ 1.50	kW/(m^3/s)
Leakage number at 50 Pa	≤ 0.60	h^{-1}

Appendix L

COP optimization, equations and code



Värmepump - Parametrar

PDIM	4300	Design power compressor (W)
B	0.034	Calibration parameter
C	-0.0114	Calibration parameter
E	0.004	Calibration parameter
F	0.0179	Calibration parameter
G	0	Part load exponent
TDIM_IN_E	20	Design temperature evaporator in
TDIM_IN_C	35	Design temperature condenser in
TDIM_OUT_E	5	Design temperature evaporator out
TDIM_OUT_C	50	Design temperature condenser out
TDIM_EVAP	0	Design temperature evaporator
TDIM_COND	55	Design temperature condenser
COPDIM	3	Heat factor, coeff of performance
EESET	0.99	Effectiveness evaporator heat exchanger
ECSET	0.8	Effectiveness condenser heat exchanger

Figur 19: Indataformulär för värmepump-modellen. Parametrarna B, C, E, F och G beror på vilken typ av värmepump som används. Realistiska värden anges i tabellen nedan. Alla parametrar som innehåller text-strängen DIM anger en driftpunkt. EESET och ECSET är effektiviteten hos värmeväxlarna på kalla respektive varma sidan

Parametrar för olika värmepumpar.	B	C	E	F	G
Kolvkompressor	0.0406	–0.0144	0.0180	0.0091	0
Skruvkompressor (Carrier)	0.0343	–0.0114	0.0040	0.0179	0.0032
Turbokompressor	0.0276	–0.0038	0.0225	0.0083	0
"Generell" kompressor	0.0340	–0.0100	0.0150	0.0120	0

Modellens grundekvationer listas nedan med parametrar enligt ovan:

COP=COPf:= 1+(A/D) × exp((C-F) × T_cond) × exp((B-E) × T_evap)

D=Pdim/(exp(F × Tdim_cond) × exp(E × Tdim_evap))

A=(COPdim-1)/((1/D) × exp((C-F) × Tdim_cond) × exp((B-E) × Tdim_evap))

För skruvkompressorn gäller dock

COP=(1+(COPf-1) × (1+G × log(abs(Ctrl × (COP-1)/(COPf-1)))

Där
Ctrl =styrsignalen till kompressorn
T_cond=aktuell kondensor temperatur
T_evap=Aktuell förångartemperatur
T_dim_cond=Dimensionerande kondensortemperatur
T_dim_evap=dimensionerande förångartemperatur
COPdim=Dimensionerande COP
Pdim=Dimensionerande kompressoreffekt.

Figure L-0-1: How the different calibration parameters influence the COP-values in IDA-ICE, obtained from a report by Jörgen Eriksson [55]

The following code was developed in C++ to optimize the calibration parameters in IDA-ICE so that the heat pumps act according to the data given in Appendix A. The function generating COP values in IDA-ICE is given in Figure L-0-1.

```cpp
#include <iostream>
#include<cmath>
#include<time.h>

using namespace std;
int const steps = 100;

double const tDimInEvap = -8;      //design temperature evaporator in
double const tDimInCond = 48;      //design temperature condenser in
double const tDimOutEvap = -13;    //design temperature evaporator out
double const tDimOutCond = 53;     //design temperature condenser out
double const tDimEvap = 0;         //design temperature evaporator
double const tDimCond = 45;        //design temperature condenser
double const copDim = 3.6;         //COP at design conditions
double const eeset = 0.99;   //effectiveness evaporator heat exchanger
double const ecset = 0.80;   //effectiveness condenser heat exchanger
double const tCond = 53;           // T_condenser - T_water = 8

double const temp1 = -5;
double const temp2 = 5;
double const temp3 = 15;
double const temp4 = 20;
double const evap1 = -13;          // T_brine - T_evap = 8
double const evap2 = -3;
double const evap3 = 7;
double const evap4 = 12;
double const cop1 = 3.0;           //COP values given by supplier
double const cop2 = 4.0;           //COP values given by supplier
double const cop3= 4.8;            //COP values given by supplier
double const cop4= 5.0;            //COP values given by supplier

//double getA (double b, double c, double e, double f);
//double getD (double b, double c, double e, double f);
double getCop (double b, double c, double e, double f, double t);
double getError(double b, double c, double e, double f);
int main(){
      clock_t tStart = clock();
      double cop;
      double d;
      double a;
      double b = 0.0406;           //Initial calibration parameter
      double c = -0.0144;          //Initial calibration parameter
      double e = 0.0180;           //Initial calibration parameter
      double f = 0.0091;           //Initial calibration parameter
      double temp = -20;
      double leastError;
      double test;
      double bestb;
      double bestc;
```

```
	double beste;
	double bestf;

	leastError = getError(b,c,e,f);
	cout << 0.001*4;
	cout << "Error at beginning: " << leastError << endl;

	for(int i=0; i<0.5*steps; i++){
		for(int j=0; j<(2*steps); j++){
			for(int k=0; k<(2*steps); k++){
				for(int l=0; l<(2*steps); l++){
					test = getError(b-0.025+(0.001*i),c-
0.025+(0.00025*j),e-0.025+(0.00025*k),f-0.025+(0.00025*l));
					if (test < leastError){
						leastError=test;
						bestb = b-0.025+(0.001*i);
						bestc = c-0.025+(0.00025*j);
						beste = e-0.025+(0.00025*k);
						bestf = f-0.025+(0.00025*l);}
				}
			}
		}
	}

	cout << "Error after running: " << leastError << endl;
	cout << "b= "<< bestb << " "<< "c= "<< bestc << " "<< "e= "<<
beste << " "<< "f= "<< bestf << endl;
	printf("Time taken: %.2fs\n", (double)(clock() -
tStart)/CLOCKS_PER_SEC);
	system("pause");
}
//double getA (double b, double c, double e, double f){
//	return((copDim-1)/((1/getD(b,c,e,f))*exp((c-f)*tDimCond)*exp((b-
e)*tDimEvap)));
//}
//double getD (double b, double c, double e, double f){
//	return(6/(exp(f*tDimCond)*exp(e*tDimEvap)));
//}
double getCop (double b, double c, double e, double f, double t){
	double d=6/(exp(f*tDimCond)*exp(e*tDimEvap));
	double a=(copDim-1)/((1/d)*exp((c-f)*tDimCond)*exp((b-
e)*tDimEvap));
	return(1+((a/d)*exp((c-f)*tCond)*exp((b-e)*t)));
}
double getError(double b, double c, double e, double f){
	return(abs(cop1-getCop(b,c,e,f,evap1))+abs(cop2-
getCop(b,c,e,f,evap2))+abs(cop3-getCop(b,c,e,f,evap3))+abs(cop4-
getCop(b,c,e,f,evap4)));
}
```

Appendix M

ZEB ambition levels

Table K-0-1: Different ambition level for ZEBs, obtained from the ZEB center's web page [3]

Abbreviation	Description
ZEHB	Zero Energy Heating Building. The energy standard of the construction and technical installations should at least satisfy the energy goals as defined in the passive house standard NS 3700/NS3701, if special circumstances argue against it. The entire energy supply for space and DHW heating should be based on renewable energy sources with zero net emissions of climate gases during the building operation.
ZEB-O	Zero Energy Building –Operation. The energy standard of the construction and technical installations should be at least as good as for ZEHB. The entire energy supply for building operation should be based on renewable energy sources with zero net emissions of climate gases during the building operation
ZEB-O-EQ	Same as ZEB-O, but where the energy post for equipment is not taken into account in the zero emission balance calculation
ZEB-O&M	Zero Energy Building –Operation and Materials. The energy standard of the construction and technical installations should be at least as good as for ZEB-O. The entire energy supply for building operation should be based on renewable energy sources with zero net emissions of climate gases during the building operation. In addition, the building should produce a sufficient amount of excess renewable energy to compensate for the embodied energy and relate climate gas emissions for production of all the materials and technical installations in the build
ZEB-O&M-EQ	Same as ZEB-O&M, but where the energy post for equipment* is not taken into account in the zero emission balance calculation.