Stud. Techn. Marie Folstad

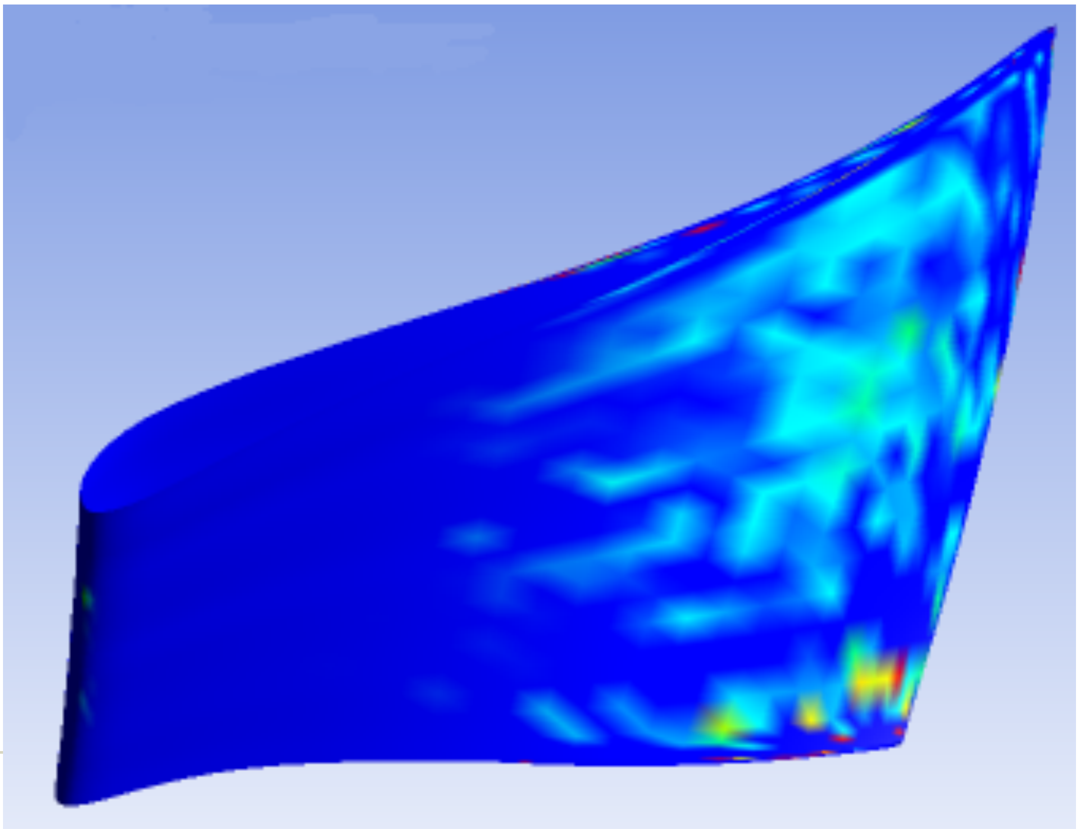
Typologies and energy demand modelling of the Norwegian building stock – Part 1

Apartment blocks built before 1980

Trondheim, December 20, 2013

Project thesis

NTNU
Norwegian University of
Science and Technology
Faculty of Engineering Science and Technology
Department of Energy and Process Engineering



Innovation and Creativity

Norwegian University of Science and Technology

Faculty of Engineering Science and Technology
Department of Energy and Process Engineering

EPT-P-2013-45

NTNU

PROJECT WORK

for

student Marie Folstad

Autumn 2013

Typologies and energy demand modelling of the Norwegian building stock - Part 1
Typologier og modellering av energibehov i norsk bygningsmasse – Del 1

Background and objective

The building stock represents a large share of the national energy demand, and is subject to ambitious policies in terms of technological, cultural and structural efforts in order to enhance energy efficiency and shifts towards less carbon-dominated energy carriers. These include national and EU regulations regarding energy use per floor area, in new construction projects as well as in renovation projects. Current trends show that there are large improvements to be made in existing buildings, and that such efforts are increasingly important as the standing building stock is ageing. Moreover, such efforts are not necessarily easily implemented, due to practical (technological), cultural and/or economic reasons. In new construction current trends show that advanced building technologies and careful planning bring highly energy-efficient solutions into the forefront of the market, such as "passive houses", "net (or nearly) zero energy houses", and "plus houses", each type with their specific requirements when it comes to the annual energy balance of the house.

An increasing number of projects and case studies have proven the success of new solutions, both for new construction projects and for renovation projects. However, there is a lack of knowledge to what extent such solutions and cases will be representative for the total building stock, and how scenarios for changes within the building stock (size, composition/types, age, renovation activity, technologies, etc.) will most likely influence the *aggregated* energy demand (the amount of direct and indirect energy, and the energy mix of what is consumed), at present and in future. In order to examine such issues it is necessary to take a systems analysis perspective to the building stock and its energy demand and supply.

The objective of this MSc project (which is later to be followed by an MSc thesis) is to carry out a systems analysis of *a defined part (chosen building types) of the Norwegian building stock* in order to better understand *trends in future annual energy demand and greenhouse gas (GHG) emissions*. The work is connected to the EU's Intelligent Energy Europe funded EPISCOPE project, a follow-up of the recent TABULA project. The student shall, for the defined part of the Norwegian building stock, contribute to the development of a Norwegian building stock typology, and how its energy balance is influenced by different renovation and design standards. Together with other student projects, and on-going research at IndEcol, the student shall contribute to the dynamic modelling of the future aggregated building stock and its energy balance, with particular emphasis on the role and relative importance of the defined part of the building stock examined more in detail by the student.

The following tasks are to be considered:

1) Define and describe the part (chosen building types) of the Norwegian building stock that is selected for in-depth examination in your project.
2) Carry out a literature study relevant to the work of the project, including the issues (a-e) specified below. Give particular attention to what is published or reported on buildings of your chosen types and in a Norwegian and Scandinavian setting.
    a. Typologies and dynamics of aggregated building stocks
    b. Annual energy demand and important influencing factors
    c. Current national and EU regulations
    d. Common technologies and design solutions in new construction and renovation projects, and
    e. LCA and/or energy and carbon emission models and analysis
3) Give a summary overview of methods and results in the EPISCOPE/TABULA project, including the issues (a-c) specified below. Give particular attention to what is reported on buildings of your chosen types for Denmark and Sweden.
    a. Methods for classification of building typologies
    b. Methods, variables and equations for energy calculations
    c. Main results regarding energy balance (incl. its components), with and without renovation
4) Perform a case study research work, where you examine and report on the building typology characteristics and energy balance factors, with and without renovation, according to methods in the EPISCOPE/TABULA project, for a selection of sample buildings within your chosen building types. The number, type and location of sample buildings are to be chosen in dialogue with your supervisor(s), aiming towards representativeness on the national scale.
5) Check to what extent your results from sample buildings are in line with aggregated results and observations from "Energimerking.no", and discuss how this database can be used as a resource for up-scaling (within your chosen building types) beyond your sample building cases.
6) Propose and describe what you think a "typical standard renovation project" and an "advanced renovation project" will look like (technology and user-related changes) for the typical building types chosen in your work. Calculate and report on what will be the typical energy balance factors, with and without renovation, for your chosen building types.
7) Use the above results and your personal suggestions to contribute to IndEcol's dynamic building stock modelling work, and on this basis discuss what your think will be likely trends, and what should be priority strategies, for energy and GHG management in the future Norwegian building stock.

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The project work comprises 15 ECTS credits.

The work shall be edited as a scientific report, including a table of contents, a summary in Norwegian, conclusion, an index of literature etc. When writing the report, the candidate must emphasise a clearly arranged and well-written text. To facilitate the reading of the report, it is important that references for corresponding text, tables and figures are clearly stated both places.

By the evaluation of the work the following will be greatly emphasised: The results should be thoroughly treated, presented in clearly arranged tables and/or graphics and discussed in detail.

The candidate is responsible for keeping contact with the subject teacher and teaching supervisors.

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.

According to "Utfyllende regler til studieforskriften for teknologistudiet/sivilingeniørstudiet ved NTNU" § 20, the Department of Energy and Process Engineering reserves all rights to use the results and data for lectures, research and future publications.

The report shall be submitted to the department in 3 complete, bound copies.

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.

Submission deadline: *December 20, 2013.*

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

Department for Energy and Process Engineering, 22 August 2013.

Olav Bolland
Department Head

Helge Brattebø
Supervisor

Co-Supervisor(s): PhD-stipendiat Nina Sandberg and Postdoc/Researcher Igor Sartori

Preface

The objective of this MSc project is to carry out a system analysis of a defined part of the Norwegian building stock in order to better understand trends in future annual energy demand. The work is connected to the EU's Intelligent Energy Europe funded EPISCOPE project, a follow-up of the recent TABULA project.

In collaboration with the supervisor it was decided to remove point 2e, 5 and 7 from the project description as the model- and literature study was more complex than originally anticipated. These parts will be further studied in the master thesis instead. This project focuses on establishing three building typologies for apartment blocks built before 1980, where a defined model made by the author is used to calculate different energy flows in buildings. The effect of different energy measures are evaluated and recommendations based on energy savings and effectiveness are given.

Since the Norwegian building stock is very complex and consists of many different building typologies it was decided to include four students on this project. It was decided that two students should look at apartment blocks built before and after 1980 and two students should look at detached houses built before and after 1980. This report focuses on apartment blocks built before 1980. The project team has collaborated throughout the semester when it comes to literature study and I would therefore like to thank Ragni Storvolleng, Anja Myreng Skaran and Marta Baltruszewicz for a good working relationship.

I would also like to give a special thanks to my supervisor, Helge Brattebø, and co supervisor Nina Sandberg, who has followed up in great detail and supported me with relevant literature.

Marie Folstad

Trondheim, Norway
December 20th 2013

Abstract

Three building typologies are analyzed in this report, where the first one is apartment blocks built before 1956, the second one is apartment blocks built in the period 1956-1970, and the last typology is apartment blocks built in the period 1971-1980. A literature study of the quality of typical dwellings throughout time is completed and typical apartment blocks from each of the time periods are defined.

The model used to calculate the building's energy need for space heating and domestic hot water is based on the TABULA methodology, but are constructed as an energy balance model that uses the principles of a material flow analysis. For each building typology it is looked at three refurbishment packages, where one of them is already implemented at the majority of the building stock. This refurbishment package is called "historical refurbishment". The two other refurbishment packages are based on the technical regulations of 2010 and the passive house standard. A TEK10-refurbishment is defined as a standard renovation project, while a passive house refurbishment is defined as an advanced renovation project.

The reduction potential for improving a typical building constructed before 1956 from original state to a TEK10-level is 68 % for space heating. Improving it further down to a passive house level gives a reduction potential of 81 %, which shows that these buildings have a major improvement potential. Only a minority (16 %) of the apartment blocks from this period are however in original state, which means that a more realistic reduction potential is seen from historical refurbished state to TEK10- or passive house level. The reduction potential for a TEK10-refurbishment is then 46 % and 67 % for a passive house refurbishment.

As a consequence of new building regulations in 1949 and 1969 the quality of the building envelope improved. This was especially the case after 1969 as the building regulation of 1949 had low requirements for buildings made in concrete (Bøhn & Ulriksen, 2006). The typical apartment block in the period 1956-1970 therefore have almost the same net energy use for space heating as a typical apartment block built before 1956, hence giving similar reduction potential.

The typical apartment block constructed during the period 1970-1980 is of much better quality than the previous typologies and the building's net energy need for space heating in original state is therefore about half of what it was for the previous typologies. The net energy need is though still 100 kWh/m^{2}year, which is high compared to the passive house level of 15 kWh/m^{2}year (NS3700, 2013). A TEK10-refurbishment or a passive house refurbishment on the building envelope leads to a decrease in annual energy use for space heating of 40 kWh/m^2 or 60 kWh/m^2 respectively when the building is assumed to be in its original state. 71 % of the buildings are though refurbished, and net energy need for space heating in refurbished state is 71 kWh/m^{2}year. Annual reduction potential from this state is 20 kWh/m^2 for TEK10-refurbishment and 40 kWh/m^2 for passive house refurbishment.

Achieving the passive house requirement of an annual energy delivery to space heating of maximum 15 kWh/m^2 is seen as impossible without implementing a heat pump or heat recovery in the ventilation system as extra measures.

Sammendrag

Tre bygningstypologier er blitt analysert i denne rapporten. Den første bygningstypologien tar for seg leilighetsblokker bygd før 1956, den andre tar for seg leilighetsblokker bygd i perioden 1956-1970, mens den siste tar for seg leilighetsblokker bygd i perioden 1971-1980. En litteraturstudie i forhold til hvordan utviklingen av norske bygninger har vært i løpet av årene er blitt gjennomført og de tre bygningstypologiene er definert som typiske bygg fra hver angitte periode.

Modellen som blir brukt til å beregne bygningens energibruk til romoppvarming er basert på TABULA metodologi, men er konstruert som en energibalansemodell basert på prinsippene i en materialstrømsanalyse. For hver bygningstypologi blir det sett på tre renoveringspakker, hvor den første allerede er implementert i store deler av bygningsmassen. Denne renoveringspakken er kalt "historisk renovering". De to andre renoveringspakkene inkludert i rapporten er basert på teknisk forskrift av 2010 (TEK10) og passivhusstandarden (NS3700). En TEK10-renovering er definert som et standard renoveringsprosjekt, mens en passivhus-renovering er definert som et avansert renoveringsprosjekt.

Reduksjonspotensialet ved å oppgradere en typisk bygning bygd før 1956 fra original tilstand til TEK10-nivå er 68 % for romoppvarming. Ved å oppgradere bygningen videre til passivhusnivå fører til at reduksjonspotensialet økes til 81 %, noe som viser at det er store forbedringspotensialer for denne bygningstypen. Imidlertid vil kun et mindretall (16 %) av leilighetsblokkene fra denne perioden være i original tilstand, noe som betyr at et mer realistisk reduksjonspotensial vil være fra historisk renovert tilstand til TEK10- eller passivhusnivå. Reduksjonspotensialet for en TEK10-oppgradering av bygget vil da være 46 %, mens en passivhus-oppgradering av bygget vil gi et reduksjonspotensial på 67 %.

Kvaliteten på bygningskroppen har forbedret seg i løpet av analyseperioden som følge av nye byggeforskrifter i 1949 og 1969. Dette gjelder spesielt for bygninger som ble bygd etter byggeforskriften i 1969 ettersom byggeforskriften i 1949 hadde få krav til betongbygninger (Bøhn & Ulriksen, 2006). På grunn av dette har den typiske leilighetsblokken fra perioden 1956-1970 nesten samme romoppvarmingsbehov som en typisk leilighetsblokk bygd før 1956, og reduksjonspotensialet vil derfor være veldig likt.

Standarden på den typiske leilighetsblokken bygd mellom 1970 og 1980 er mye bedre enn for de tidligere periodene. Energibehovet til romoppvarming er omtrent halvparten av hva det var for en typisk bygning bygd i de tidligere periodene. Imidlertid er romoppvarmingsbehovet fremdeles forholdsvis høyt i forhold til passivhusnivået på 15 kWh/m^{2}år ettersom det ligger på rundt 100 kWh/m^{2}år (NS3700, 2013). Ved å utføre en TEK10-renovering på den originale bygningskroppen reduseres det årlige romoppvarmingsbehovet med 40 kWh/m^2. En passivhusrenovering fører til en videre årlig reduksjon på 20 kWh/m^2. Ettersom 71 % av bygningsmassen fra denne perioden allerede er oppgradert vil størsteparten av bygningsmassen ha et årlig reduksjonspotensial på 20 kWh/m^2 for TEK10-renovering, og 40 kWh/m^2 for passivhusrenovering.

Det å oppnå passivhuskravet om årlig levert energimengde til romoppvarming på maksimum 15 kWh/m^2 blir ansett som nærmest umulig uten å implementere en varmepumpe eller implementere varmegjenvinning av ventilasjonsluft.

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Key terms and variables:

This chapter describes the meaning of common key terms and variables used in this report.

Key terms

BRA	Is the Norwegian abbreviation of utility floor space and includes all used floor area in the building. If a building has three floors the BRA will be the sum of the floor area in each floor [m^2] (Kommunal- og regionaldepartementet, 2010)
$U - value$	Is the thermal transmittance and is a measure of heat loss in a building element such as a wall, floor or roof. A high U-value therefore corresponds to high transmission losses through the building envelope, while a low U-value corresponds to low transmission losses through the building envelope [W/m^{2}K] (Brennan, 2013)
MFA	Material flow analysis
GWP	GWP stands for global warming potential and is a metric used to compare the greenhouse effect of various components. GWP is defined as the sum of climate forcing of 1 kg emission of climate-driver relative to the sum of the climate forcing from 1 kg of CO_2. Methane has for instance a GWP value of 21 CO_2-equivilents since it has 21 times as strong global warming effect than CO_2 (Miljødirektoratet, 2013).
WHO	World health organization

Key variables

$A_{env,i}$	Is the area of building envelope i, where i can be wall, window, roof, door or floor [m^2]
$A_{window,i}$	Is the window area at orientation i, where i can be horizontal, east, west, north or south [m^2]
a_H	A time dependent parameter used to find the gain utilization factor ($\eta_{h,gn}$) Can be found by following equation: $a_H = a_{H,0} + \frac{\tau}{\tau_{H,0}}$ [-]
$a_{H,0}$	= 0.8 (Loga & Diefenbach, 2012)
$\alpha_{nd,h,i}$	Fraction of heat generator i for space heating system [-]
$\alpha_{nd,w,i}$	Fraction of heat generator i for domestic hot water system [-]

b_{tr} Adjustment factor soil [-]

c_m Internal heat capacity (used to calculate time constant of the building, τ) [Wh/m^{2}K]

$c_{p,air}$ Volume specific heat capacity of air [Wh/m^{2}K]

d_{HS} Length of heating season [days/year]

$e_{g,h,i}$ Heat generation expenditure factor of heat generator i for space heating system [-]

$e_{g,w,i}$ Heat generation expenditure factor of heat generator i for domestic hot water system [-]

F_{sh} Reduction factor external shading. One value for horizontal orientation (windows at roof) and one value for vertical orientation (windows at external walls) [-]

F_F Frame area fraction of a window [-]

F_W Reduction factor, considering radiation non-perpendicular to the glazing [-]

F_{nu} Dimensionless correction factor for non-uniform heating

$g_{gl,n}$ Total solar energy transmittance for radiation perpendicular to the glazing. Describes how much of the solar radiation that gets absorbed by the windows [-]

$h_{room,ve,ref}$ Ventilation reference room height (normally set to 2.5 m) [m]

H_{ve} Overall heat transfer coefficient by ventilation [W/K]

H_{tr} Overall heat transfer coefficient by transmission [W/K]

$I_{sol,i}$ Average global irradiation on surfaces with orientation i during heating season [kWh/m^{2}year]

ϕ_{int} Average thermal output of internal heat sources [W/m^2]

ϑ_{int} The internal temperature (set-point temperature for space heating) [°C]

ϑ_e The temperature of the external environment (average value during heating season) [°C]

$n_{air,use}$ Average air change rate during heating season, related to the utilization of the building [1/h]

$n_{air,infiltr.}$	Air change by infiltration [1/h]
$\eta_{ve,rec}$	Efficiency of ventilation heat recovery
$\eta_{h,gn}$	Gain utilization factor for heating (see chapter 3.1) [-]
$q_{nd,w}$	Annual energy need for domestic hot water per m^2 reference floor area (BRA) [kWh/m^2year]
$q_{s,w}$	Annual heat loss of the DHW storage per m^2 reference floor area (BRA) [kWh/m^2year]
$q_{d,w}$	Annual heat loss of the DHW distribution system per m^2 reference floor area (BRA) [kWh/m^2year]
$q_{g,w,h}$	Recoverable heat loss of the heat generators for domestic hot water [kWh/m^2year]
$q_{d,h}$	Annual effective heat loss of the space heating distribution system per m^2 reference floor area [kWh/m^2year]
$q_{s,h}$	Annual effective heat loss of the space heating storage system per m^2 reference floor area [kWh/m^2year]
$q_{d,w,h}$	Recoverable heat loss of the domestic hot water distribution system per m^2 reference floor area [kWh/m^2year]
$q_{s,w,h}$	Recoverable heat loss of the domestic hot water storage system per m^2 reference floor area [kWh/m^2year]
$t_{døgn}$	Hours per day, given as 0.024 kh/day
τ	Time constant of the building ($\tau = \frac{c_m \cdot A_{C,ref}}{H_{tr}+H_{ve}}$) [h]
y	Heat balance ratio ($= \frac{Q_{sol}+Q_{int}}{Q_{ht,ve}+Q_{ht,tr}}$) (see chapter 3.1 for more information of flows) [-]
ΔU_{thr}	Surcharge on all U-values (Thermal bridges) [W/m^2K]

1 Introduction

In 2009 the Norwegian building sector contributed to 37 % of the total energy use when energy use offshore is excluded. Since the end of the 1990s the energy use in dwellings have stabilized even though the population have increased. More energy efficient buildings, a warmer climate, higher energy prices and increased use of heat pumps can explain this development (Grini, 2012).

The Norwegian government has set a target to increase the renewable energy production by 30 TWh in 2016 compared to the level in 2001. The government has also set a goal to implement passive house standard as the national building standard in 2015 (Grini, 2012).

This project is connected to EU's Intelligent Energy Europe funded Episcope project, which is a follow-up of the recent TABULA project. The aim of the project is to identify the potential for energy savings in existing dwellings. The TABULA project uses a European standard reference calculation procedure for determining the heat need and the delivered energy demand. The goal of the TABULA project is to determine important parameters that play an important role for the energy consumption in buildings. The calculation method is kept as simple as possible to ensure that experts in each country easily can understand the content. This means that average values are used were applicable to reduce the need of more detailed methods (Loga & Diefenbach, 2012).

A building's energy need for heating is dependent on the quality of the building envelope, the heating system, and the domestic hot water system (Loga & Diefenbach, 2012). In this project it is focused on the energy use for space heating and domestic hot water in residential buildings. The energy need for cooling, lighting and electrical equipment will not be evaluated in the project, but may be of great interest at a later stage. The calculation method used is based on the TABULA calculation method, but is made as a material flow analysis model specified for Norwegian conditions. This is done to have better control over the results from the study. Several countries like Denmark and Sweden have already developed their own building typologies in TABULA. The aim of this project is to develop typologies and energy demand modeling of a specified Norwegian building stock, which can later be used as an input to TABULA.

The Norwegian building stock has a huge improvement potential as the majority of existing dwellings are built before 1980 (Prognosesenteret AS & Entelligens AS, 2012). In this part of the project it is focused on apartment blocks built before 1980, and the three time periods analyzed are:

- ← 1956
- 1956-1970
- 1971-1980

A case study for a typical apartment block from each of these time periods will be examined and an energy assessment before and after renovation will be made for each case.

A typical renovation project is set as a TEK10 refurbishment, while an advanced renovation project is set as a passive house refurbishment. The TEK10 and passive house refurbishment packages include extra insulation in external walls, floor, roof and windows so that the U-values of the building envelope decreases down to a TEK10- or passive house level respectively. Changes in the heating system, like changing to a heat pump, is not included in the original refurbishment packages but is mentioned as extra energy measures to see the effect of this implementation on the building's net energy need.

For the building envelope it is especially important what kind of material that is used, hence giving a high or low U-value for different building components. A low U-value describes good isolated walls, windows etc. with small transmission losses. Walls without insulation typical have a very high U-value. New buildings usually have better building envelope due to stricter national and international regulations.

The following chapter includes a literature study of a typical development for the specified building type. Current national and EU regulations are also given in this chapter, as well as common refurbishments technologies. A short introduction to the EPISCOPE/TABULA project and an introduction of common analysis methods used in the report are also given.

Chapter 3 describes the methodology used to calculate the energy flows. This chapter includes detailed information of the model as well as a thoroughly review of important parameters used. A typical and an advanced renovation project are defined, and the effect of the different renovation projects for all three building typologies are given in chapter 4. Parts of the discussion are included in this chapter as it was seen most appropriate to include some discussion next to the figures. A sensitivity analysis of important parameters is though given separately in chapter 5 to see which parameters that are most sensitive for change.

2 Literature study

2.1 Future energy situation

Prognosis for expected energy demand and delivery are made each year by the international energy Agency, IEA. Primary energy is defined as the amount of energy in form of oil, gas, coal, bio etc. that is required to produce 1 unit of delivered energy. The energy use is expected to increase which gives a major pressure on the world's energy resources in the future (Dokka, Wigenstad, & Lien, 2009).

Oil production has most likely reach its peak so to cover the future energy demand the world's energy consumption has to decrease or the renewable energy production has to increase significantly (Randers, 2006).

The Norwegian greenhouse gas emissions are expected to increase from 50 Mton CO_2-equvielents in 1990 to 70 Mton CO2-equivilents in 2060. UN Climate Change Convention have decided that the overall global mean surface temperature increase should not exceed 2°C above pre-industrial level in order to limit high risks, including irreversible impacts of climate change (Randers, 2006). As long as the concentration of climate gasses in the atmosphere do not exceed 400-450 ppm this goal can be reached. Today the concentration is about 380 ppm, which is an increase of 100 ppm since pre-industrial time. To be able to stabilize the greenhouse gas concentration in the atmosphere it is estimated that the global emissions have to be reduced by minimum 50 % within 2050 (Randers, 2006). This goal is unfortunately a bit unrealistic due to necessary economical and social development in developing countries. However, it is very important that industrialized countries, like Norway, start developing the technology so that energy- and emission efficient solutions are cheaper to use in the future.

To be able to reach an emission reduction as illustrated in Figure 1 drastic actions on several areas have to be done. The electricity price has to be increased significantly and the Government has to introduce a number of political incentives that promotes solutions with a low carbon footprint.

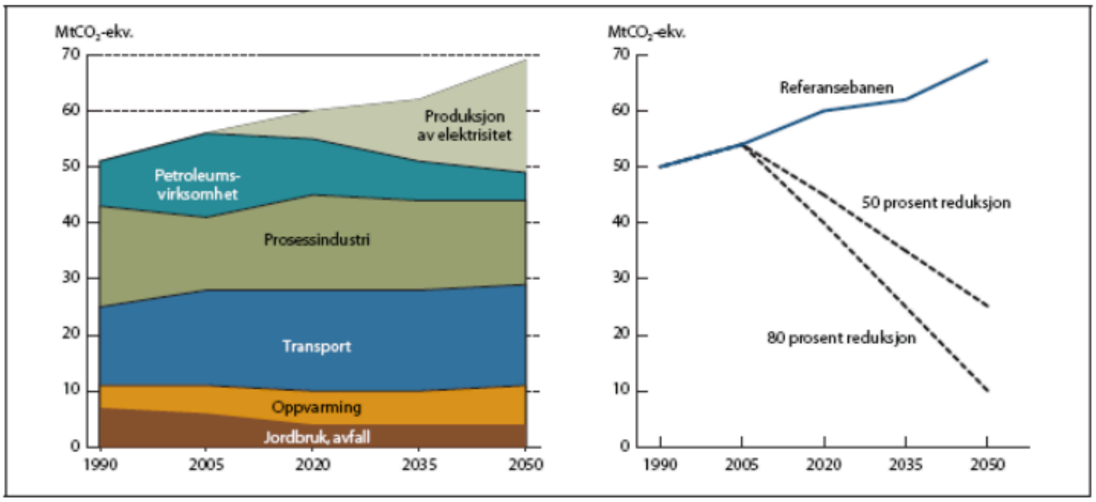


Figure 1: Expected green house gas emissions in Norway at reference scenario (business as usual) compared with 50 and 80 % emission reduction (Randers, 2006).

A big part of the energy demand is estimated to come from the building sector, and it is therefore important to make buildings as efficient as possible. The first step in making a building efficient is to construct a tight building envelope with low U-values. The technical installations should then be made as efficient as possible, for instance by including systems with heat recovery. The next step, see Figure 2, is to use as much "free energy" as possible. This includes utilization of solar and internal gains. The building's energy need after subtraction of "free energy" should be covered as far as possible by CO_2-neutral energy sources such as wind power, hydropower and heat pumps. Grid-based energy can be used if all renewable possibilities are considered not suitable for the specified building (Dokka, Wigenstad, & Lien, 2009).

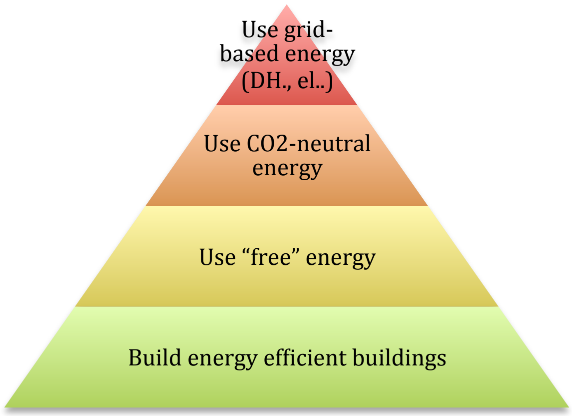


Figure 2: Strategy to reduce energy need and climate gas emissions

2.2 Current national and EU regulations

The current Norwegian technical regulation was renewed in 2010. The first national building regulation came in 1949 as an attempt to reduce the heat loss from newly constructed buildings. As the technology improved and the need for energy efficient buildings increased the building regulation became stricter. It is natural to assume that buildings built after 1949 satisfies the regulations made in 1949. During the time period 1949-2013 four new regulations have been made, one in 1969, one in 1985 (which was later revised in 1987), one in 1997, and one in 2007 (which was later revised in 2010) (Hille, Simonsen, & Aall, 2011).

Assuming that buildings are built after the regulations can more or less be expected for buildings built after 1987. However, in the first decades after the first regulation was implemented many buildings were probably built better than what the regulation required since the building regulation of 1949 did not have strict requirements when it came to insulation of walls etc. It is therefore appropriate to assume that a significant part of the building stock from the period 1950-1985 are insolated better than what was required by the building regulations (Hille, Simonsen, & Aall, 2011).

The current technical regulation has requirements when it comes to air quality and energy requirements in buildings. When it comes to ventilation it is required that the ventilation system is adapted to the pollution and moisture load in the room. The minimum requirement for ventilation airflow in a residential building is 1.2 m^3 fresh air per hour per m^2 floor area when the building is in use and minimum 0.7 m^3 fresh air per hour per m^2 floor area when the building is not in use. In kitchen and sanitary rooms there should be an exhaust unit with satisfactory efficiency (§13-1 and §13-2) (Kommunal- og regionaldepartementet, 2010).

When it comes to the building envelope it is required that transmission heat loss should be held to a minimum. The U-value for external walls, windows, roof and floor should not exceed 0.18, 1.2, 0.13 and 0.15 W/m^2K respectively. The window and door area should not exceed 20 % of heated usable area (BRA). For an apartment block the building regulation of 2010 requires that the net energy consumption should not exceed 115 kWh/m^2 heated BRA per year (Kommunal- og regionaldepartementet, 2010).

Table 1 shows the requirement given in TEK10 and the requirements that satisfy the passive house standard.

Table 1: Technical regulations 2010 and passive house requirement. (TEK10) (NS3700, 2013)

	TECHNICAL REGULATIONS (2010)	**Passive house requirement**
Transmission heat loss:		
U-value external walls	$\leq 0.18\ W/m^2K$	$0.10 – 0.12\ W/m^2K$
U-value window/door	$\leq 1.2\ W/m^2K$	$\leq 0.80\ W/m^2K$
U-value roof	$\leq 0.13\ W/m^2K$	$0.08 - 0.09\ W/m^2K$
U-value floor	$\leq 0.15\ W/m^2K$	$0.08\ W/m^2K$
Share of window- and door area	≤ 20 % of heated usable floor area (BRA)	≤ 20 % of heated usable floor area (BRA)
Normalized thermal bridge value	$0.06\ W/m^2K$ (this value is per m^2 BRA)	$0.03\ W/m^2K$ (this value is per m^2 BRA)

Infiltration and ventilation heat loss:		
Leakage rate	1.5 air exchanges per hour	0.6 air exchanges per hour
Yearly temperature efficiency of a heat exchanger in a ventilation system	≥ 70 %	≥ 80 %
Other regulations:		
Specific fan power in a ventilation system (SFP)	2,5 kW/(m^3/s)	1.5 kW/(m^3/s)

Today all buildings have to fulfill the technical regulations of 2010. To get qualified as a passive house the transmission and ventilation losses have to be reduced further. The name "passive house" is used because passive measures are used to reduce the energy need. These kinds of measures include extra insulation in walls, roof and floor, which gives a very good tightness of the building envelope. Passive houses are also constructed with high heat recovery of the ventilation heat. Since the building envelope is very tight it can be more challenging to achieve good air quality inside the house. Heat recovery in the ventilation system is therefore a must when achieving good air quality combined with low net energy use (Lavenergiprogrammet, 2013).

A passive house can be a bit more expensive to build than a normal TEK10-house due to more expensive windows and higher material use in form of higher amount of insulation. A passive house will however have lower net energy use than a TEK10-building. The net energy savings during the building's lifetime is therefore higher for a passive house.

The technical regulation of 2010 requires that buildings over 500 m^2 heated BRA should be constructed in a way that makes it possible to cover 60 % of the heating demand by other energy sources than direct electricity or fossil fuels. This requirement can be achieved by installing a solar collector or a heat pump (Kommunal- og regionaldepartementet, 2010).

The regulations of 2010 can be fulfilled in two ways; either the building must fulfill all the requirements in Table 1, or the net energy consumption have to be less than 115 kWh per m^2 heated usable floor area for an apartment block. The U-values for external walls, windows, roof and floor must though not exceed 0.22, 1.6, 0.18 and 0.18 respectively and the leakage rate should not exceed 3 air changes per hour (Kommunal- og regionaldepartementet, 2010).

Energy has always been an important political issue in the European Union and EU started as a European Coal and Steel Community. Today the overall energy strategy towards 2020 is to focus on a safe, sustainable and competitive energy policy. The so-called 20-20-20 targets says that EU should reduce their greenhouse gas emissions by 20 percent and increase the production of renewable energy by 20 percent by the year 2020. (Nestvold, 2012).

An important EU strategy to reduce the overall greenhouse gas emissions is energy efficiency in buildings. EU decided in 2007 that energy efficiency should be increased with 20 percent by the year 2020. Estimations done in 2012 shows that EU is far from achieving this goal, and will not be able to fulfill the targets unless new efforts are put into action (Nestvold, 2012). TABULA is one of the projects EU has introduced to survey the situation. It is also decided by EUs revised Energy Performance of Buildings Directive from 2010 that the standard of new buildings in 2020 should be almost zero emission buildings (Nestvold, 2012).

2.3 Typologies and dynamics of aggregated building stocks

In 2011 the Norwegian occupied building stock consisted of 258 millions m^2 BRA, where 169 millions m^2 were detached houses, 47 millions m^2 were small dwellings and 42 millions m^2 were apartments (Prognosesenteret AS & Entelligens AS, 2012). During the last 20 years major renovations have been done and 52 % of the total residential area has had one or more renovations like replacement of windows and extra insulation of walls. When demolition of the existing building stock is taken into consideration new residential units are estimated to stand for about 10 % of the overall dwelling stock area in 2020. This is not a very big number, which means that the majority of the building stock in 2020 will be existing buildings (Prognosesenteret AS & Entelligens AS, 2012).

70 000 new apartments have been built since 2006, and today apartment blocks stands for about 22 percent of the total Norwegian dwelling stock (Statistisk Sentralbyrå, 2013). Based on information from Enova an estimation of average area per apartment has been made for each time period evaluated in this project (see Table 2).

Table 2: Apartment blocks specification throughout time (Prognosesenteret AS & Entelligens AS, 2012)

Apartment block	Number of occupied dwellings	%-amount of all apartments	Utility floor space (m2)	%-amount of total apartment area	Average area per dwelling unit (m2)	Number of units per block	Number of blocks
Before 1956	161 554	27%	11 444 245	27%	71	8	20 194
1956-1970	106 324	18%	7 133 096	17%	67	16	6 645
1971-1980	90 441	15%	6 739 001	16%	75	24	3 768

When the standard of the different building typologies is taken into consideration different RME works (ie. renovation, reconstruction and extension of existing dwellings) that affects the building's energy need has to be included. The standard of the building components given in the report includes both original values and values after historical refurbishments.

Estimation on how many apartments that have been refurbished from each time period are given in Figure 3. As shown in the figure 84 % of the buildings built before 1956 have already gone through some renovations. However, the improvement potential for the 15 % that is not refurbished is most likely huge.

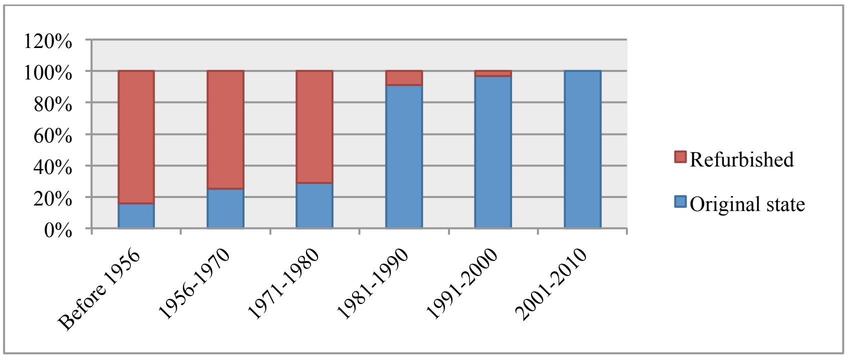


Figure 3: Status on existing dwellings, 2010 (Prognosesenteret AS & Entelligens AS, 2012)

The most common construction material used in Norwegian dwellings throughout time is wood. However this is mainly for detached houses and other small dwellings. For apartment blocks and other larger buildings there have been some regulations due to fire risk that has limited the use of wood. The building size is therefore crucial when examining what kind of material that is used. For apartment blocks and terraced houses about 54 percent of the buildings use concrete as their main material, while 23 and 22 percent use wood and steel respectively (Prognosesenteret AS & Entelligens AS, 2012).

Apartment blocks are defined as buildings that averagely consist of 18 apartments and four floors. However a more specific number of apartments are given for each time period (see Table 3). Apartments stand for about 16 % of the total dwelling stock area (BRA) (Prognosesenteret AS & Entelligens AS, 2012). An estimation of the building size (ground area) is estimated based on the fact that an apartment block consists of four floors.

Table 3: Estimation of ground area and size of apartment blocks throughout time (Prognosesenteret AS & Entelligens AS, 2012)

	Average area per dwelling unit (m^2)	Number of units per block	Number of floors	Size of building (length x width, m)	Heated floor area (BRA, m^2)	Ceiling height (m)
Before 1956	71	8	4	15.97 × 8.87	568	2.8
1955-1970	67	16	4	34.18 ×7.70	1072	2.7
1971-1980	75	24	4	39.79 × 11.24	1800	2.5

There have been several constructional development trends, and the most important ones that have influenced the annual energy demand are mentioned in this chapter. Early in the 1950s mineral wool became commercially available, and lightweight timber frame was introduced as a new construction method that replaced heavy framework and timber. For bigger buildings the period before 1956 was described as a transition period where the same construction system was used, but light clinker concrete, poured concrete, concrete beams and steel beams were introduced as materials (Prognosesenteret AS & Entelligens AS, 2012).

Typical for apartment blocks built during the time period 1956-1970 was increased use of retention walls and floor dividers in concrete instead of brick houses with retention walls in bricked bituminous and floor dividers mainly in wood. The building regulation in 1949 had stricter requirements for houses made in wood than for houses made in concrete or rock material, and since all apartment blocks were mainly made in concrete the U-value requirement was very low. This explains why apartment blocks built in this period generally have higher U-values on exterior walls than detached houses from the same period. In 1969 TEK69 came, which had several requirements for insulation in dwellings aiming to decrease the energy use. In 1978-80 there was an international energy crisis that led to stricter building regulations in 1983 with further revision in TEK85-87. Further up buildings built during the time period 1990-1997, 1998-2010 and after 2010 had to fulfill the building regulations of 1987, 1997 and 2010 respectively. It must be mentioned that the values in these regulations only give a minimum value and that some buildings may have been built with better insulation etc. than what the regulations required (Prognosesenteret AS & Entelligens AS, 2012).

2.3.1 Technical requirement for apartment blocks throughout time

A summary of the technical regulations throughout time is given in Table 4.

Table 4: Technical regulations throughout time (Bøhn & Ulriksen, 2006)

Building component	U-value requirement (W/m2K)				
	Regulation 1949	Regulation 1969	Regulation 1985	Regulation 1987	Regulation 1997
Wall	0.93-1.16[1]	0.58-1.28	0.45	0.30	0.22
Roof	0.93	0.46-0.58	0.23	0.20	0.15
Floor	-	0.46	0.23-0.30	0.20-0.30	0.15
Window	-	-	2.10-2.70	2.40	1.60

Since the building regulation of 1949 approved quite high U-values, many buildings during the time period 1950-1970 were built with better building envelope then what the regulation required. This is further discussed in chapter 3.4.

[1] See attachment xx for more information

2.4 Annual energy demand and important influencing factors

The energy use in buildings increased during the period 1950-1990 due to mainly increased comfort level. However, from 1990 the energy use in buildings stabilized. One of the main reasons for this stabilization is that the development in dwelling area per person stabilized. If the dwelling area per person had continued increasing in the same manner as before 1990 the total dwelling area today would be about 350 millions square meters, which is approximately 36 % larger than the actual level today. Another reason for this stabilization is more energy efficient buildings, which lead to lower energy use per square meter. The most important contributor on this field is the improvement done on the thermal envelope in old buildings. Other important contributors to energy efficiency are implementation of heat pumps and reduction in heat loss due to more efficient heat generators (Hille, Simonsen, & Aall, 2011).

The third most important impact factor is warmer climate. Figure 4 shows the development during the last 60 years (Hille, Simonsen, & Aall, 2011).

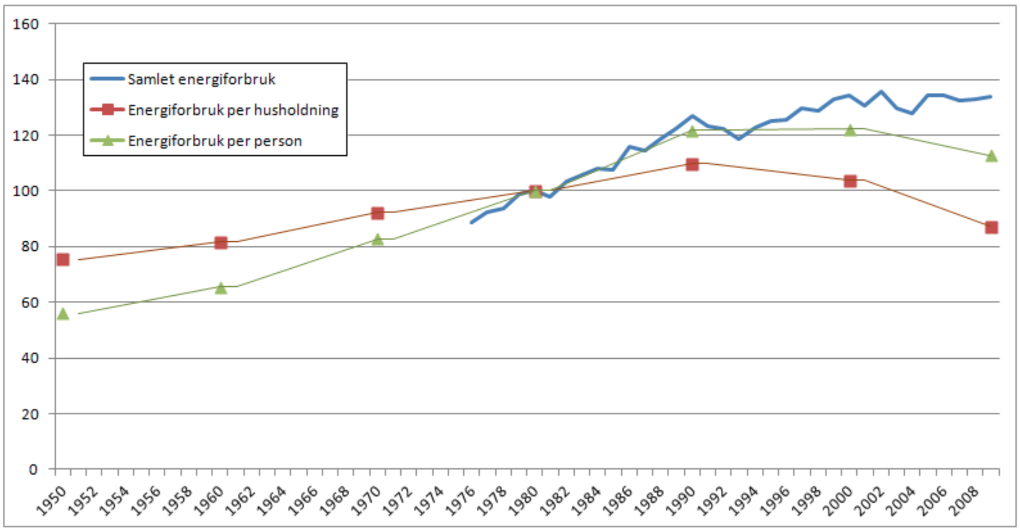


Figure 4: The relative development of the temperature dependent energy use in Norwegian households during the period 1950-2009 (Hille, Simonsen, & Aall, 2011)

Important direct influencing factors are:

- Residential area
- Building type
- Building envelope
- Indoor temperature
- Energy use for domestic hot water
- Energy use for lighting and electrical equipment
- Choice of heating system
- Use of heat pumps

Important indirect influencing factors:

- Changes in outdoor temperature
- Demographic changes
- Economical conditions
- Technological development
- Changes in knowledge, attitude and preferences
- Political incentives

2.5 Common technologies and design solutions in new construction and renovation projects

For old buildings it is common to improve the building envelope by adding additional insulation in external walls, floor and roof. The most common materials used for this kind of insulation are mineral wool and expanded polystyrene (EPS). The last material, EPS, is the most common plastic foam insulation used in building. EPS have excellent insulation properties, low moisture absorption and high comprehensive strength (EPS-gruppen, 2008). However, mineral wool is the most used insulation type and in this report it is decided to use this material when adding additional insulation to the building envelope as it has the lowest thermal conductivity value (0.037 W/mK) (Bøhn & Ulriksen, 2006). Mineral wool is the generic term for glass wool and rock wool. WHO has classified mineral wool as part of group 3, which implies that the material do not increase the cancer risk for humans (Norima, 2010).

Adding additional insulation to external walls can be done by either implementing exterior supplementary insulation or interior supplementary insulation. One of the benefits of adding supplementary insulation to the outside of the walls is that it is possible to live in the dwelling while refurbishments are done. Other benefits are that the utility floor area is not reduced, and the thermal bridges are often removed as a consequence of the refurbishment. Adding additional insulation to the outside of the walls also gives less risk of condensation of interior surfaces and therefore less risk of mold and fungal growth. The disadvantage of adding exterior supplementary insulation to the walls is that it is a comprehensive measure and should be viewed in the context of the need for renovation. Another disadvantage is that the windows have to be moved out of the walls in order to keep the original appearance of window frames. It can also be difficult to maintain "valuable" facades, windows and architectural details (Enova (2), 2012).

The benefits of adding supplementary insulation at the inside of the external walls are that there are no changes to the façade, the insulation work can be performed for only parts of the dwelling, and the supplementary insulation can be limited to the coldest room of the dwelling. The disadvantages with this refurbishment technique are that the utility floor area gets reduced, internal refurbishment may be needed since existing slabs and panels must be removed or rebuilt, installations against outer walls must be moved, thermal bridges are often intact after refurbishment, and it can be difficult to install a tight vapor barrier (Enova (2), 2012).

Enova generally recommends implementing supplementary insulation at the outside of the exterior walls (Enova (2), 2012). To upgrade a building to passive house standard it is almost always necessary to insulate at the outside of the exterior walls. Changing windows is also a common refurbishment that can have great effect on the building's energy savings and is often seen as a cost-effective measure.

It is natural to focus on energy-efficient solutions and comfort rise when refurbishment techniques of existing dwellings are chosen. It is often not necessary to satisfy all criteria in TEK10, but choose the measures that lead to a net saving potential economically. It will later be discussed whether a TEK10 or a passive house upgrade will be realistically possible to achieve (Prognosesenteret AS & Entelligens AS, 2012).

2.6 EPISCOPE/TABULA

TABULA stands for Typology Approach for Building Stock Energy Assessment and aims to create a harmonized structure for European building typologies.

EPISCOPE stands for Energy Performance Indicator Tracking Schemes for the Continuous Optimization of Refurbishment Processes in European Housing Stocks and aims to make the energy refurbishment processes in the European housing sector more transparent and effective with the aim to ensure that the climate protection targets will be attained and that corrective or enhancement actions can be taken in due time, if necessary (Build up, 2013).

"The purpose of the TABULA data structure is to facilitate the understanding of typical buildings, supply systems and refurbishment measures in the different European countries and to lay the basis for scenario calculations on a supranational level. It is not the intention to adapt this Excel workbook to national regulations. For your national calculations you will generally use your own tools and publish the building system datasets with respect to your national standards." (Loga, 2012)

2.6.1 Methods for classification of building typologies

Denmark and Sweden have already developed their own TABULA model and defined their own building typologies. Denmark has decided to divide the residential building stock into single-family houses, terraced houses and apartment blocks, while Sweden has decided to divide the building stock into single-family houses and multi-family houses. Denmark has also divided the building stock into 9 construction periods, where each construction period represents a period where the building technique and isolation level was approximately the same (Wittchen & Kragh, 2012).

2.6.2 Main results regarding energy balance in Denmark

Denmark has looked at different typologies for apartment blocks and has divided the periods a bit different than what is done in this report. The periods analyzed in the Danish TABULA of concern for this project are 1931-1950, 1951-1960, 1961-1972 and 1973-1978. By implementing extra insulation in roof, floor and external walls, and changing windows, the annual energy savings for a typical apartment block built in the period 1931-1950 are estimated to be 115 kWh/m^2 for the minimum renovation package and 124 kWh/m^2 for the low energy renovation package. Apartment blocks built during the time period 1931-1950 generally stand for 18 % of the Danish building stock (Wittchen & Kragh, 2012).

For apartment blocks built during the period 1951-1960 the annual energy savings are estimated to be 129 kWh/m^2 for the minimum renovation package and 151 kWh/m^2 for the low energy renovation package. These buildings generally stand for 10 % of the total dwelling area in Denmark. For the next specified period the quality of the dwellings improved, and these types of apartment blocks stand for about 18 % of the Danish dwelling stock area. The annual energy savings of refurbishment package "minimum" are 77 kWh/m^2, while the annual energy savings of refurbishment package "low-energy" are 87 kWh/m^2. For the last time interval relevant for this report, 1973-1978, the annual estimated saving potential for the minimum refurbishment package is estimated to be 44 kWh/m^2. For the low energy refurbishment package it is possible to reduce the energy demand with 53 kWh/m^2 per year (Wittchen & Kragh, 2012).

Since the Danish building stock is very similar to the Norwegian building stock it is natural to assume that the Norwegian energy saving potential will be in the same manner as the Danish energy saving potential. However, some differences must be anticipated due national differences. District heating has for instance been much more common in Denmark and Sweden due to higher electricity prices.

2.7 Analysis methods

2.7.1 Energy balance model/ Material flow analysis (MFA)

The model used to calculate the energy flows in this project is an energy balance model based on the principle of material flow analyses (MFA). MFA is a method used to quantify flows and stocks within a system defined in space and time. It is based on the law of the conservation of matter and that makes it simple to control the material/energy balance by comparing all inputs, stocks, and output of a process. When performing an MFA it is important to define proper system boundaries. The system may be a process, industry or region of concern. By making a flow chart with clear system boundaries and well-defined flows and stocks it is possible to graphically allocate the meaning of measurements or statistical data (Brunner & Rechberger, 2004). This is what is done in this project. The energy balance model is based on the TABULA calculation method and all the flows in the system are calculated based on equations given by TABULA (Loga & Diefenbach, 2012).

Since the model is based on energy flows and not material flows it cannot be defined as an MFA. However, an energy balance analysis uses the principles of an MFA and the MFA methodology is therefore of great concern. MFA is an appropriate tool to investigate the flows and stocks of any material-based system. When developing an MFA-model the following steps should be followed (Brunner & Rechberger, 2004):

1. Delineate a system of material flows and stocks by well-defined, uniform terms. In this project the building's space heating system is defined as one system and the building's domestic hot water (DHW) system is defined as another (see Figure 5).
2. Reduce the complexity of the system as far as possible while still guaranteeing a basis for sound decision making. The energy balance model is divided into one model for the space heating system and one model for the domestic hot water system to reduce the complexity of the system as far as possible. However, some of the outflows from the domestic hot water system is linked to the space heating system, so it can be discussed whether two separate systems are preferable in this case.
3. Assess the relevant flows and stocks in quantitative terms, thereby applying the balance principle and revealing sensitivities and uncertainties. Many of the flows in the report are calculated based on equations given in TABULA and are called model approach equations (see Table 6). To maintain a balance of input- and output flows several energy balance equations are necessary, and these are defined in Table 5.
4. Present the result as a basis for managing resources, the environment and wastes. In this case the results show the energy saving potential by implementing several refurbishment technologies. The environment will be affected by the energy use in buildings since the energy source often is electricity. The global warming factor for electricity in Norway is very low though since almost all electricity is based on hydropower. However, since this is not the case for the rest of the world it is better to use an average value for Europe (NS-EN 15603, 2008).

3 Methodology

3.1 Methods, variables and equations for energy calculations

All calculations done in this project are based on the method used in TABULA, and the same equations are used. Figure 5 describes the idea behind the following equations. It is focused on the energy use for space heating and domestic hot water. Cooling, air conditioning, lighting, and electric appliances are not considered, but may be of great interest at a later stage.

The method used for the calculation is the predefined TABULA method, which requires several input factors, which will be thoroughly examined in this chapter. The TABULA calculations are based on the method described in EN ISO 13790 on the basis of a one-zone model (Loga & Diefenbach, 2012). The model uses the principle of MFA, and is developed as an energy balance model that uses the MFA methodology.

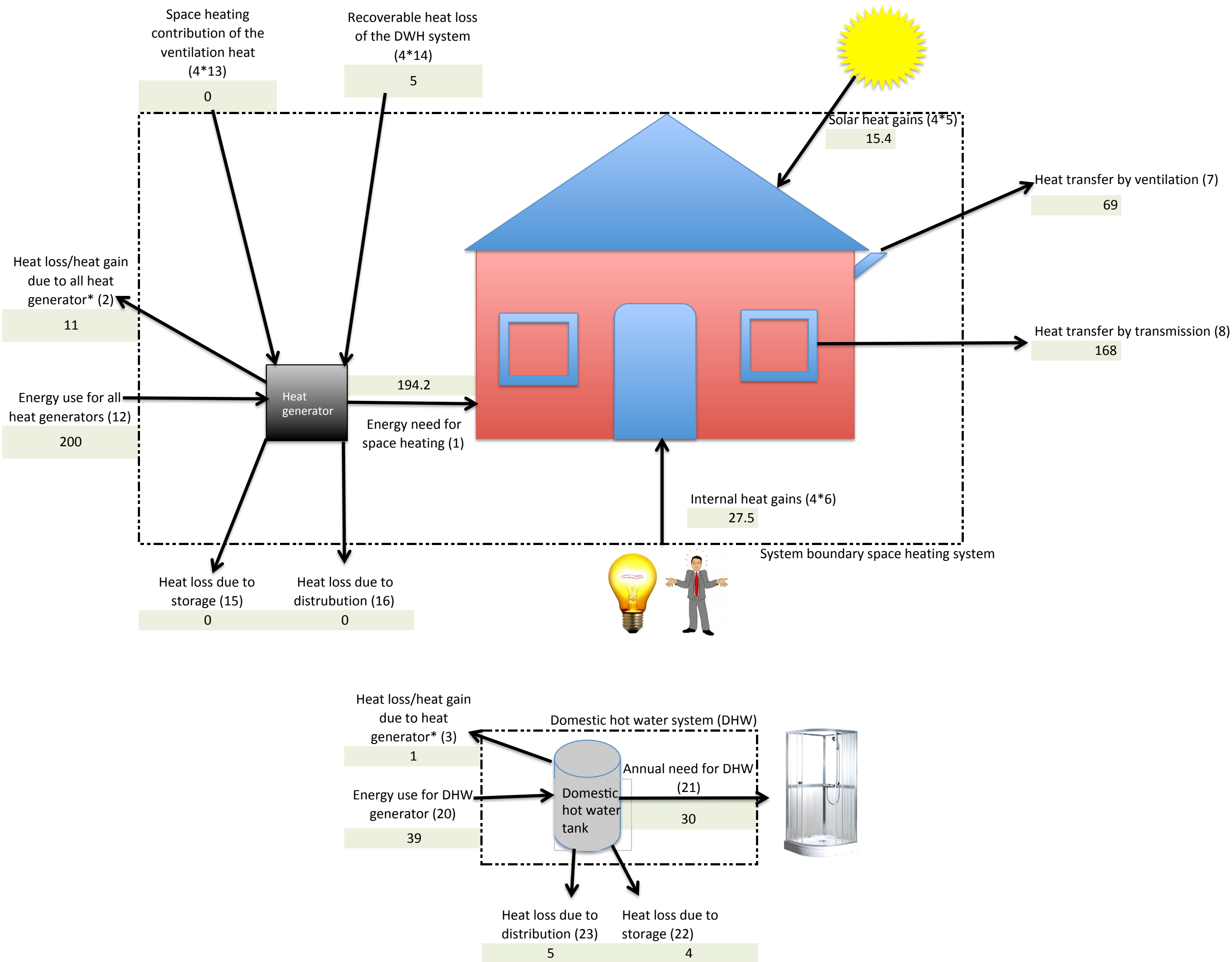


Figure 5: Energy balance flow chart (based on MFA-methodology)

All values in Figure 5 are given in kWh/m^{2}year. The number in parentheses behind the text for each flow is the relevant equation number that can be found in either Table 5 or Table 6. Some of the parentheses involve a multiplied number. This implies that the flow is found as the product of these two equations.

The flow values shown in the figure are the energy flows for a typical apartment block built before 1956 in Oslo climate which is set as the reference climate due to Norwegian standard (NS3031, 2011). Apartment blocks are considered within four climate zones and three age bands so that altogether 12 generic building types are defined in this part of the Norwegian typology. To calculate the different energy posts in each of the defined building typologies the following 23 equations are used, where three of them are energy balance equations and 20 are model approach equations (see chapter 2.7.1 for description of MFA-modeling).

Table 5: Energy balance equations (Loga & Diefenbach, 2012)

Equation number	Unknown variable name	Equation	Units	Description	Equation number in TABULA
1	$Q_{H,nd}$	$= Q_{ht,ve} + Q_{ht,tr} - n_{h,gn} \cdot (Q_{sol} + Q_{int})$	$kWh/year$	The buildings energy need for space heating	Combination of equation 1,2 and 8
2	$Q_{g,h}$	$= Q_{del,h} + n_{h,gn} \cdot (Q_{ve,h,rec} + Q_{w,h}) - Q_{H,nd} - Q_{s,h} - Q_{d,h}$	$kWh/year$	Heat loss/heat gain due to heat generator of the space heating system	Based on energy balance of the heat generator
3	$Q_{g,w}$	$= Q_{del,w} - Q_{nd,w} - Q_{s,w} - Q_{d,w}$	$kWh/year$	Heat loss/heat gain due to heat generators of DHW system	Based on energy balance of the DHW system

The following equations given in Table 6 are the model approach equations and these equations contain given or calculated parameters that are defined in "key variables" at page VI. Many of the parameters are building dependent and are different for each building typology.

Table 6: Model approach equations (Loga & Diefenbach, 2012)

Equation number	Unknown variable name	Equation	Units	Description	Equation number in TABULA
4	$\eta_{h,gn}$	$= \frac{1 - \gamma^{a_H}}{1 - \gamma^{(a_H+1)}}$	-	Gain utilization factor for heating	11
5	Q_sol	$= F_{sh} \cdot (1 - F_F) \cdot F\_W \cdot g_{gl,n} \cdot (A_{window,hor} \cdot I_{sol,hor} + A_{window,east} \cdot I_{sol,east} + A_{window,west} \cdot I_{sol,west} + A_{window,north} \cdot I_{sol,north} + A_{window,south} \cdot I_{sol,south})$	$kWh/year$	Solar heat load during the heating season	10
6	Q_{int}	$= t_{døgn} \cdot \varphi_{int} \cdot d_{hs} \cdot A_{C,ref}$	$kWh/year$	Internal heat gains during heating season	9
7	$Q_{ht,ve}$	$= t_{døgn} \cdot H_{ve} \cdot F_{nu} \cdot (\vartheta_{int} - \vartheta_e) \cdot d_{hs}$	$kWh/year$	Heat transfer by ventilation during heating season	6

8	$Q_{ht,tr}$	$= t_{døgn} \cdot H_{tr} \cdot F_{nu} \cdot (\vartheta_{int} - \vartheta_e) \cdot d_{hs}$	$kWh/year$	Heat transfer by transmission during the ventilation season	3
9	$Q_{del,h,1}$	$= \alpha_{nd,h,1} \cdot e_{g,h,1} \cdot (Q_{H,nd} - \eta_{h,gn} \cdot (Q_{w,h} + Q_{ve,h,rec}) + Q_{d,h} + Q_{s,h})$	$kWh/year$	Energy use for heat generator 1 of the heating system	19 and 20
10	$Q_{del,h,2}$	$= \alpha_{nd,h,2} \cdot e_{g,h,2} \cdot (Q_{H,nd} - \eta_{h,gn} \cdot (Q_{w,h} + Q_{ve,h,rec}) + Q_{d,h} + Q_{s,h})$	$kWh/year$	Energy use for heat generator 2 of the heating system	19 and 20
11	$Q_{del,h,3}$	$= \alpha_{nd,h,3} \cdot e_{g,h,3} \cdot (Q_{H,nd} - \eta_{h,gn} \cdot (Q_{w,h} + Q_{ve,h,rec}) + Q_{d,h} + Q_{s,h})$	$kWh/year$	Energy use for heat generator 3 of the heating system	19 and 20
12	$Q_{del,h}$	$= Q_{del,h,1} + Q_{del,h,2} + Q_{del,h,3}$	$kWh/year$	Energy use for all the heat generators of the heating system	
13	$Q_{ve,h,rec}$	$= \eta_{ve,rec} \cdot Q_{ht,ve}$	$kWh/year$	The space heating contribution of the ventilation heat recovery	21
14	$Q_{w,h}$	$= (q_{g,w,h} + q_{s,w,h} + q_{d,w,h}) \cdot A_{C,ref}$	$kWh/year$	Recoverable heat loss of the domestic hot water system	18
15	$Q_{s,h}$	$= q_{s,h} \cdot A_{C,ref}$	$kWh/year$	Annual effective heat loss of the heating system storage	
16	$Q_{d,h}$	$= q_{d,h} \cdot A_{C,ref}$	$kWh/year$	Annual effective heat loss of the space heating distribution system	
17	$Q_{del,w,1}$	$= \alpha_{nd,w,1} \cdot e_{g,w,1} \cdot (Q_{nd,w} + Q_{d,w} + Q_{s,w})$	$kWh/year$	Energy use for domestic hot water heat generator 1	16 and 17
18	$Q_{del,w,2}$	$= \alpha_{nd,w,2} \cdot e_{g,w,2} \cdot (Q_{nd,w} + Q_{d,w} + Q_{s,w})$	$kWh/year$	Energy use for domestic hot water heat generator 2	16 and 17
19	$Q_{del,w,3}$	$= \alpha_{nd,w,3} \cdot e_{g,w,3} \cdot (Q_{nd,w} + Q_{d,w} + Q_{s,w})$	$kWh/year$	Energy use for domestic hot water heat generator 3	16 and 17
20	$Q_{del,w}$	$= Q_{del,w,1} + Q_{del,w,2} + Q_{del,w,3}$	$kWh/year$	Energy use for all the domestic hot water heat generators	
21	$Q_{nd,w}$	$= q_{nd,w} \cdot A_{C,ref}$	$kWh/year$	Annual energy need for domestic hot water	
22	$Q_{s,w}$	$= q_{s,w} \cdot A_{C,ref}$	$kWh/year$	Annual heat loss of the domestic hot water storage	
23	$Q_{d,w}$	$= q_{d,w} \cdot A_{C,ref}$	$kWh/year$	Annual heat loss of the domestic hot water distribution system	

Some of the parameters used in the model approach equations are considered of great importance and will be explained further. To calculate the annual ventilation losses (see equation 7 in Table 6) the parameter H_{ve} is required. This parameter is a calculated parameter and can be found by using the following equation:

$$H_{ve} = c_{p,air} \cdot (n_{air,use} + n_{air,infiltr.}) \cdot A_{C,ref} \cdot h_{rom,ve,ref} \qquad [W/K]$$

Where

$c_{p,air}$ is the volume-specific heat capacity of air and is set to be 0.34 Wh/m^{2}K [Wh/m^{2}K]

$n_{air,use}$ is average air change rate during heating season, related to the utilization of the building [1/h].

$n_{air,infiltr.}$ is air change by infiltration [1/h]

Values for $n_{air,use}$ and $n_{air,infiltr.}$ for the building typologies analyzed in this project are given in Table 8. These values are based on average values given by TABULA (Loga & Diefenbach, 2012).

To calculate the annual heat losses due to transmission through walls etc. (see equation 8 in Table 6) the parameter H_{tr} is required. This parameter is found by using the following equation:

$$H_{ve} = \sum_i b_{tr,i} \cdot A_{env,i} \cdot U_{eff,i} + \left(\sum_i A_{env,i}\right) \cdot \Delta U_{thr} \qquad \text{[W/K]}$$

where

$b_{tr,i}$ is the adjustment factor soil [-]

$A_{env,i}$ is the area of envelope element, i, where i can be wall, window etc. [m^2]

$U_{eff,i}$ is the effective U-value of element i [W/m^2K]

ΔU_{thr} is the surcharge on all U-values, taking into account the additional losses caused by thermal bridging [W/m^2K]

Information on values for different important parameters is given in the following chapters. More detailed information of all parameters can be found in appendix B

3.2 Explanation of choices made for each building typology

3.2.1 Climate zones

The heating season normally last from 20th of September to 10th of May, but can have some variations depending on the climate zone. The four climate zones considered in this project are:

1. Southern Norway, coast (given as climate zone 2 in appendix B)
2. Northern Norway, coast (given as climate zone 6 in appendix B)
3. Mid-Norway, inland (given as climate zone 5 in appendix B)
4. Oslo (due to standard reference climate used in NS3031) (given as climate zone 9 in appendix B)

The values from the first three climate zones are calculated based on information given by Enova (Arnstad, 2004). Climate values for Oslo are based on values from NS3031. Since Oslo is used as the standard reference climate in NS3031, it is also used as the reference climate in this report and the main results are given for this climate. However, the other climate zones are used to evaluate the effect of the outdoor climate.

Length of heating season (d_{hs}) is estimated to be approximately 237, 286, 274 and 237 days for climate zone one, two, three and four respectively (Arnstad, 2004) (NS3031, 2011). The average temperature during heating season (ϑ_e) is calculated to be 3.4°C for climate zone one, 1.4°C for climate zone two, -0.26 °C for climate zone three and 1.2 °C for climate zone four (see appendix B). For each climate zone an average global irradiation (I_{sol}) during heating season for each orientation is estimated. These values are based on numbers given by Enova and NS3031 and can be seen in Table 7. All values in the table are given in kWh/m^{2}year.

Table 7: Average global irradiation (I_{sol}) during heating season (See appendix B)

	$I_{sol,hor}$	$I_{sol,east}$	$I_{sol,west}$	$I_{sol,north}$	$I_{sol,south}$
Southern Norway, coast	314	237	237	109	503
Northern Norway, coast	457	337	337	142	613
Mid-Norway, inland	405	359	359	153	647
Oslo climate	333	238	238	111	410

3.2.2 Building dependent parameters

Based on information given in chapter 2.3 different building dependent parameters are given for each of the three building typologies. An overview of these parameters can be found in Table 8.

Table 8: Building dependent parameters for each time period (Prognosesenteret AS & Entelligens AS, 2012) (Loga & Diefenbach, 2012)

	Before 1956	1956-1970	1971-1980
General information			
BRA ($A_{C,ref}$)	568	1056	1800
Number of units per block (units)	8	16	24
Length x width ($m \times m$)	15.97×8.87	34.18×7.70	39.79×11.24
Number of floors	4	4	4
Ceiling height (m)	2.8	2.8	2.5
Area values for each construction element (m2)			
Wall ($A_{env,wall}$)	438.8	771.7	738.6
Floor ($A_{env,floor}$)	142	264	450
Roof ($A_{env,roof}$)	142	264	450
Window ($A_{env,window}$)	113.6	158.4	270
Door ($A_{env,door}$)	4	8	12
Area for different windows orientations (m2)			
Horizontal ($A_{window,hor}$)	0	0	0
South ($A_{window,south}$)	68.16	95.04	162
West ($A_{window,west}$)	0	0	0
East ($A_{window,east}$)	0	0	0
North ($A_{window,north}$)	45.44	63.36	108
Effective U-value for construction (original)			
Wall	0.82	0.96	0.34
Floor	0.55	0.38	0.24
Roof	0.81	0.33	0.21
Window	2.6	2.6	2.6
Door	2.5	2.5	2
Indoor climate			
Heated part of the apartment	77%	80%	82%
Unheated part of the apartment	23%	20%	18%
Temperature heated part	22	22	22
Temperature unheated part	15	15	15
Average temperature (ϑ_{int})	20.39	20.6	20.74
Average air change rate related to the utilization of the building ($n_{air,use}$)	0.4	0.4	0.4
Air change by infiltration ($n_{air,infiltr}$)	0.4	0.4	0.2

Buildings built before 1956 typical have a window area that correspond to 20 % of the utility floor area (BRA), while buildings built during the time period 1956-1970 and 1971-1980 typical have a window area that correspond to 15 % of the utility floor area, hence giving the values in Table 8. Based on qualified assumptions given by Enova it is estimated that 60 % of the window area is oriented on the southern side of the building, while 40 % of the window area is oriented on the northern side of the building. This means that the eastern and western sides of the building are constructed without windows. (Prognosesenteret AS & Entelligens AS, 2012).

Figure 6: Typical apartment block from 50s

The air exchange in a building is a result of ventilation ($n_{air,use}$) and infiltration ($n_{air,infiltr}$). Air exchange trough infiltration is caused by leaks in the building envelope, and is generally high for old apartment blocks. The majority of old apartment blocks (built before 1970) use a natural ventilation system, which means that the ventilation of air happens through thermal buoyancy and wind. A natural ventilation system will have highest effect when the difference between indoor and outdoor temperature is high. When outdoor temperature is high during summer the ventilation rate is low, which often gives a bad indoor climate during parts of the summer. A mechanical ventilation system where fans are used to draw exhaust air out of the building was common in apartment blocks at the 1970s. The fresh air is flowing through valves in the exterior walls. Balanced ventilation systems are most common in modern buildings. A balanced ventilation system uses energy from the warm exhaust air to reheat the cold outdoor air, which gives a good indoor climate as well as a lower energy use for heating (Prognosesenteret AS & Entelligens AS, 2012).

Apartment blocks built before 1956 were typical built with only a wood stove for space heating. Some were also built with a central distribution system where an electric boiler was placed in an unheated basement. However, the majority (60 %) of the buildings were built with a wood stove (Pettersen , Lars, Wigenstad, & Dokka, 2005). Today all buildings that were originally built with a wood stove as the only heating source have also implemented direct electric heaters. For domestic hot water it is assumed that there is a water heater in each apartment that is directly connected to the electricity grid (Ulseth, 2013).

Using direct electric heaters became more and more popular in the 1960s due to decreasing electricity prices. Oil was still a cheap resource, but constructing apartment blocks with a waterborne system was more costly than constructing blocks with direct electric heaters.

Approximately 71 % of the apartments were now using direct electricity as their main heating source. The rest were built with oil boilers and a central heating system (Pettersen , Lars, Wigenstad, & Dokka, 2005). It will only be looked at buildings that use direct electrical heaters. On a later stage it may be of great interest to look at apartment blocks that already has a waterborne system installed, as these buildings have more flexibility when it comes to choosing alternative energy sources for heating.

In 1973 an oil crisis hit the western world, which led to a 70 % increase in the oil price (Lundberg, 2013). Use of oil boilers in buildings therefore decreased significantly in this period, and existing buildings that already had oil boilers installed changed to electricity boilers. New buildings built after 1970 were mainly constructed with direct electric heaters as this was seen as the cheapest option (Ulseth, 2013). The building regulation of 1969 required that all dwellings that were not connected to a shared central heating plant should be constructed with a pipe so that every apartment had a possibility to install a fireplace. This was done in case of electricity shortage. For these buildings it is expected that 10 % of the heating demand is covered by a wood stove (Bøeng, 2005).

Heat pumps have become more and more popular over the last couple of years, and in 2009 18.5 % of the Norwegian households had installed heat pumps. In comparison only 4 % had heat pumps installed in 2004 (SSB, 2011). For apartment blocks that originally use direct electric heaters it has been popular to replace these heaters with air-to-air heat pumps. This kind of renovation was however not very common before 2000 (Ulseth, 2013).

Table 9 shows the chosen combination of energy sources for the building in original state for each time period analyzed in this report.

Table 9: Amount of different energy sources for each building typology (Pettersen , Lars, Wigenstad, & Dokka, 2005) (Bøeng, 2005)

	Before 1956	1956-1970	1971-1980
Energy source			
Direct electricity to space heating ($\alpha_{nd,h,1}$)	90%	90 %	90%
Direct electricity to DHW ($\alpha_{nd,w,1}$)	100%	100%	100%
Wood Stove ($\alpha_{nd,h,3}$)	10%	10%	10%

To calculate the delivered heat to a given heat generator TABULA use a heat generation expenditure factor. This is basically 1 divided by the efficiency of the heat generator and shows how much useful energy that is required per used unit of heat. An old oil boiler will therefore have a high expenditure factor, while a heat pump will have a low expenditure factor. The expenditure factors for different heat generators used in typical original apartment blocks from each of the time periods are given in Table 10. The expenditure factors for heat pumps are given in Table 11 since this is one of the potential renovation technologies that will be analyzed in this project. It must be mentioned that these values are estimates and not directly measured values, so they have to be used with some uncertainty.

Table 10: Heat generation expenditure factor of heat generators in the original building state (NS3031, 2011)

	Before 1956	1956-1970	1971-1980
Heat generation expenditure factor of heat generator			
Direct electricity, DHW ($e_{g,w,1}$)	1.02	1.02	1.02
Direct electricity, space heating ($e_{g,h,1}$)	1.0	1.0	1.0
Wood, space heating ($e_{g,h,3}$)	1.563[2]	1.563[2]	1.563[2]

Table 11: Heat generation expenditure factor of heat pumps (NS3031, 2011)

Heat generation expenditure factor of heat generator	2006 →
Air-to-air heat pump, space heating ($e_{g,h,renovation}$)	0.463
Air-to-water heat pump, DHW ($e_{g,w,renovation}$)	0.48

The internal heat loads from persons, lighting, domestic hot water and other electrical equipment from dwellings (ϕ_{int}) are based on values given in NS3031 and are set equal to 5.25 W/m^2 (NS3031, 2011).

Heat loss due to heat storage and distribution needs to be included when the required amount of produced heat from a heat generator is calculated. Also the space heating contribution of the ventilation heat as well as the recoverable heat loss from the DHW system should be included. The heat losses lead to an increased level of heat production, while the recoverable heat losses lead to a decreased level of required production. It is beneficial to have as much heat recovery as possible hence giving a lower production of heat from the generator. However, it is limited how low this production can get without changing the building's energy need for space heating. Figure 7 shows the basic principle of the space heating system and the connected heat losses. It must be mentioned that the heating system in the figure actually is inside the dwelling, so this figure is just made as an illustration of the basic principle.

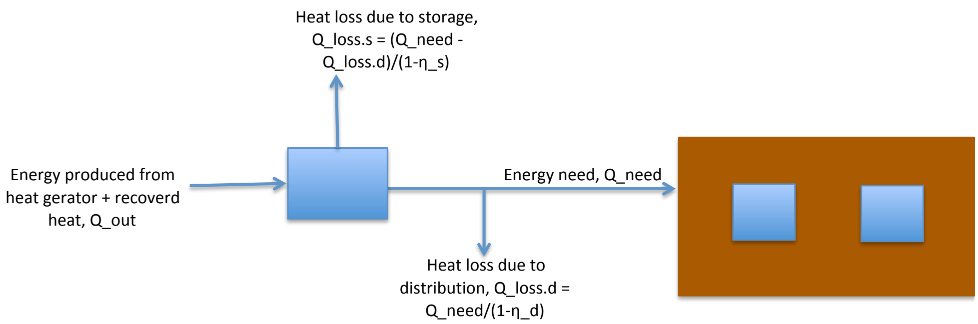


Figure 7: Heating system principles

Standard values from TABULA for annual heat losses from heat storage and distribution are given for both space heating and domestic hot water system. For a typical original apartment block built before 1956 electric heaters are used for space heating as mentioned earlier, and the distribution system is therefore assumed to be decentral. The domestic hot water system (DHW) uses an electrical heater to heat the water and uses a hot water storage tank to store

[2] Numbers from (Pettersen , Lars, Wigenstad, & Dokka, 2005)

the heat. This technology is the most common one for all time periods evaluated in this report, and the distribution and storage systems are therefore the same for all building typologies. Table 12 shows common values for these energy flows. Since Denmark and Sweden did not have good values for decentral electric hot water systems, German values are used. In Denmark and Sweden district heating is much more common and developed than in Norway, and it was more common to build buildings with centralized heating system due to higher electricity prices.

Table 12: Heat losses due to heating system (TABULA, 2013)

	Before 1956 (kWh/m^{2}a)	1956-1970 (kWh/m^{2}a)	1971-1980 (kWh/m^{2}a)
Heat loss of the space heating storage ($q_{s,h}$)	0	0	0
Heat loss of the space heating distribution ($q_{d,h}$)	0	0	0
Heat loss of the DHW heat storage ($q_{s,w}$)	3.6	3.6	3.6
Contribution of the DHW heat storage loss to space heating ($q_{s,w,h}$)	2.4	2.4	2.4
Heat loss of the DHW distribution ($q_{d,w}$)	4.6	4.6	4.6
Contribution of the DHW heat distribution loss to space heating ($q_{d,w,h}$)	3.0	3.0	3.0

For historical, TEK10- and passive house refurbishments German values for buildings built after 1995 are used. Heat losses due to DHW distribution are therefore set to be 1.4 kWh/m^{2}a, while the contribution of this heat loss to space heating is set to be 0.8 kWh/m^{2}a. For heat losses from the DHW storage tank the value for historical refurbishment is set to be 2.9 kWh/m^{2}a. The contribution of this heat loss to space heating is set to be 1.9 kWh/m^{2}a.

Need for domestic hot water $q_{nd,w}$ is assumed to be the same for all building typologies and is set to be 30 kWh/m^2 per year as given in NS 3031: 2007+A1:2011.

3.3 Case study of a typical apartment block built before 1956

Table 13: U-value before and after different refurbishments, before 1956 (Prognosesenteret AS & Entelligens AS, 2012) (Kommunal- og regionaldepartementet, 2010) (NS3700, 2013)

Envelope type	Original	Historical upgrade	TEK10 upgrade	Passive house upgrade
	W/m^2K			
Exterior walls	0.82	0.41	0.18	0.12
Roof	0.81	0.31	0.15	0.09
Floor	0.55	0.26	0.15	0.08
Window	2.6	2.0	1.2	0.8

In Norway there are about 20 194 apartment blocks built before 1956 that have the properties given in Table 8. Typical for these buildings in original state are that they have (Prognosesenteret AS & Entelligens AS, 2012):

- Exterior walls that either are uninsulated brick or concrete with 75 mm wood wool board
- Roof and floor that consists of 150x120 mm beams with stub clay. Both roof and floor are not directly connected to the external environment. They are connected to an unheated basement or attic. This is however taken into consideration when the effective U-values are calculated
- Windows made of 4 mm glass, 16 mm cavity and then 4 mm of glass again (two tier Insulating Glass). This type of window typical has a U-value of 2.6 W/m^2K (Thyholt, 2002).

Since there were no building regulations before 1949 it can be discussed whether windows with a U-value of 2.6 W/m^2K gives a correct picture of the average situation for apartment blocks in original state from this period. A window with a single glass typical have a U-value of 5 W/m^2K (Enova, 2012). A U-value of 2.6 W/m^2K is however used in this project, as this was the value given in relevant literature (Prognosesenteret AS & Entelligens AS, 2012).

The Thermal bridge value for the building in original state is set to be 0.15 W/m^2K due to concrete ceilings etc. that are penetrating insulation. It is assumed that air infiltration has high effect on the building in original state due to leaks in the building envelope. The additional air exchange rate caused by infiltration is therefore set to be 0.4 1/h (Loga & Diefenbach, 2012).

The case study includes an analysis of the building in original state, in historical refurbished state (84 % are already partly refurbished), in TEK10 state and in passive house state. A historical upgrade includes (Prognosesenteret AS & Entelligens AS, 2012):

- 50 mm extra mineral wool insulation in external walls
- Replacing the stub clay in roof and floors with 100 mm mineral wool
- Replacing existing windows with better isolated windows (U-value ~ 2.0 W/m^2K)

About 73 % of the apartment blocks from this time period have already switched to more energy efficient windows (Prognosesenteret AS & Entelligens AS, 2012). This value is chosen based on assumptions that the historical refurbishments happened on the 90s. The average U-value for windows from this period was 2.0 W/m^{2}K (Prognosesenteret AS & Entelligens AS, 2012). After a historical refurbishment is completed the thermal bridge value is expected to decrease down to a medium level of 0.1 W/m^{2}K. This is based on qualified assumptions done by the project team and is based on information given in TABULA. As a consequence of the refurbishments it is anticipated that the additional air exchange rate caused by infiltration will decrease down to 0.2 1/h, which indicates that the effect of air infiltration goes from high to medium (Loga & Diefenbach, 2012).

A TEK10-refurbishment is considered as a typical standard renovation project while a passive house-refurbishment is considered as an advanced renovation project. For this typical apartment block a standard renovation project includes (Prognosesenteret AS & Entelligens AS, 2012):

- 200 mm of mineral wool as extra insulation in walls
- Replacing stub clay with 100 mm mineral wool and adding 150 mm extra mineral wool at cold attic
- Replacing stub clay with 200 mm mineral wool in floors (see appendix A).
- Replacing existing windows with coupled windows with two coated glasses and argon gas in two cavities. These windows typical have a U-value of 1.2 W/m^{2}K (Enova, 2012).

The insulation thickness is calculated up to closest upper 50, which means that if the required extra insulation thickness is calculated to be 170 mm the insulation thickness is set to be 200 mm. This is done to ensure that the TEK10 requirement is fulfilled in real life, not just in theory (see Appendix A).

TEK10 requires a thermal bridge value lower or equal to 0.06 W/m^{2}K. It is therefore anticipated that the thermal bridge value will decrease down to TEK10-level after a TEK10-refurbishment (Kommunal- og regionaldepartementet, 2010). Since TEK10 require a leakage rate lower than 1.5 air exchanges per hour, it is assumed that the TEK10-refurbishments will lead to a reduction in additional air exchange rate so that this requirement is fulfilled. A leakage rate (n_50) of 1.5 1/h gives an additional air exchange rate of 0.1 1/h, which indicate a reduction of 0.3 1/h (Loga & Diefenbach, 2012).

To achieve a passive house standard or as close as possible to a passive house standard the following refurbishments have to be performed (Appendix A):

- 300 mm extra mineral wool insulation in the external walls (gives a U-value of 0.12)
- Replacing of stub clay with 400 mm mineral wool in roof and floors
- Replacing existing windows with windows with three layers of insulating glass with two coated glass, argon gas, warm edge and insulated frame. These types of windows typical have a U-value between 0.7 and 0.9 W/m^{2}K (Enova, 2012).

In the calculations it is also anticipated that these measures lead to a decrease in thermal bridge value, so that the passive house requirement of a value below 0.03 W/m^{2}K is achieved (NS3700, 2013). The passive house standard require a leakage rate lower than 0.6 1/h, which gives an additional air exchange rate of 0.05 1/h (Loga & Diefenbach, 2012). It is assumed that the building will achieve this kind of tightness after the refurbishments.

3.4 Case study of a typical apartment block built during the period 1956-1970

Table 14: U-value before and after different refurbishments, 1956-1970 (Prognosesenteret AS & Entelligens AS, 2012) (Kommunal- og regionaldepartementet, 2010) (NS3700, 2013)

Envelope type	Original	Historical upgrade	TEK10 upgrade	Passive house upgrade
	W/m^2K			
Exterior walls	0.96	0.29	0.18	0.12
Roof	0.33	0.24	0.15	0.09
Floor	0.28	0.18	0.15	0.08
Window	2.6	2.0	1.2	0.8

6 645 of the apartment blocks that exist today are from this period. Characteristics of buildings from this period are that they have (Prognosesenteret AS & Entelligens AS, 2012):

- Exterior walls in concrete with 100 mm aerated concrete,
- Roof that are made in concrete with 100 mm mineral wool.
- Floors that are made in concrete and insulated with 50 mm mineral wool.
- Windows that are made of 4 mm glass, 16 mm cavity and then 4 mm of glass again (two tier Insulating Glass). This type of window typical has a U-value of 2.6 W/m^2K (Thyholt, 2002). 2.6 W/m^2K is a normal U-value of windows installed during the 60s (Enova, 2012).

The Thermal bridge value for the building in original state is set to be 0.15 W/m^2K due to concrete ceilings etc. that are penetrating insulation. The building is assumed to have high effect of air infiltration in original state and the additional air exchange rate caused by infiltration is therefore set equal to 0.4 1/h (Loga & Diefenbach, 2012).

The case study will include an analysis of the building in original state, in historical refurbished state (75 % is already partly refurbished), in TEK10 state and in passive house state. A historical upgrade includes (Prognosesenteret AS & Entelligens AS, 2012):

- 100 mm extra mineral wool insulation in the external walls
- 50 mm extra mineral wool on the upper side of the external roof and floor.
- Replace existing windows with better insulated windows (U-value ~ 2 W/m^2K)

About 66 % of the apartment blocks from this time period have already switched to more energy efficient windows (Prognosesenteret AS & Entelligens AS, 2012). Average U-values for the envelope elements after historical upgrade can be found in Table 14. After a historical refurbishment is completed the thermal bridge value is expected to decrease down to a medium level of 0.1 W/m^2K as for buildings built before 1956. As a consequence of the refurbishment it is anticipated that the additional air exchange rate caused by infiltration is decreased down from 0.4 to 0.2 1/h, which indicates that the effect of air infiltration goes from high to medium (Loga & Diefenbach, 2012).

For this typical apartment block a TEK10-renovation project includes (Prognosesenteret AS & Entelligens AS, 2012):

- 200 mm of mineral wool as extra insulation in walls
- 150 mm extra mineral wool on the underside of the floor and roof (see Appendix A)
- Replacing existing windows with coupled windows with two coated glasses and argon gas in two cavities. These windows typical have a U-value of 1.2 W/m^2K (Enova, 2012).

As for the previous typology it is assumed that the thermal bridge value and the air exchange rate due to infiltration are reduced down to TEK10-level.

To achieve a passive house standard or as close as possible to a passive house standard the following refurbishments have to be performed (see Appendix A):

- 300 mm extra mineral wool insulation in the external walls
- 300 mm extra mineral wool insulation in roof
- 350 mm extra mineral wool insulation on the underside of the floor
- Replacing existing windows with windows with three layers of insulating glass with two coated glass, argon gas, warm edge and insulated frame. These types of windows typical have a U-value between 0.7 and 0.9 W/m^2K (Enova, 2012).

As for the previous typology it is assumed that the thermal bridge value and the air exchange rate due to infiltration are reduced down to passive house-level.

3.5 Case study of a typical apartment block built during the period 1971-1980

Table 15: U-value before and after different refurbishments, 1971-1980 (Prognosesenteret AS & Entelligens AS, 2012) (Kommunal- og regionaldepartementet, 2010) (NS3700, 2013)

Envelope type	Original	Historical upgrade	TEK10 upgrade	Passive house upgrade
	W/m^2K			
Exterior walls	0.34	0.18	0.18	0.12
Roof	0.21	0.14	0.15	0.09
Floor	0.26	0.21	0.15	0.08
Window	2.6	1.6	1.2	0.8

There are 3 768 apartment blocks today that are from this time period. Typical for these buildings in original state are that they have (Prognosesenteret AS & Entelligens AS, 2012):

- Exterior walls that consist of timber frame in wood, 100 mm mineral wool and 50 mm thermal bridge breaker
- Roof made in concrete with 180 mm mineral wool
- Floor made in concrete and insulated with 100 mm mineral wool. The floor is not directly connected to the external environment. It is connected to an unheated cellar. This is however taken into consideration when the effective U-value is calculated,
- Windows are assumed to be the same as for the previous building typologies.

The Thermal bridge value for the building in original state is set to be equal to 0.1 W/m^2K due to the assumption of medium effect of constructional thermal bridging. It is assumed that the building have medium effect of air infiltration in original state and the additional air exchange caused by infiltration is therefore set to be 0.2 1/h (Loga & Diefenbach, 2012).

A historical upgrade includes (Prognosesenteret AS & Entelligens AS, 2012):

- 50 mm extra mineral wool insulation + brick veneer in the external walls (satisfy TEK10)
- Replacing 180 mm mineral wool with 250 mm mineral wool in roof (satisfy TEK10)
- 50 mm extra mineral wool in floor
- Replacing existing windows with better isolated windows (U-value ~ 1.6 W/m^2K)

About 67 % of the apartment blocks from this time period have already switched to more energy efficient windows. The average U-value for windows after historical upgrade is assumed to be the same as for windows installed during the time period 2001-2010, and is therefore set equal to 1.6 W/m^2K (Prognosesenteret AS & Entelligens AS, 2012).

After a historical refurbishment is completed the thermal bridge value is expected to remain at a medium level of 0.1 W/m^2K. However, since many parts of the building envelope satisfy TEK10 after this refurbishment it can be anticipated that this value can be decreased down to TEK10-level. For the calculations a value of 0.1 W/m^2K is kept though. The additional air exchange rate caused by infiltration is also expected to remain at a medium level with a value of 0.2 1/h (Loga & Diefenbach, 2012).

For this typical apartment block a TEK10-renovation project includes (Prognosesenteret AS & Entelligens AS, 2012):

- 50 mm extra mineral wool insulation + brick veneer in the external walls
- Replacing 180 mm mineral wool with 250 mm mineral wool in roof
- 100 mm extra mineral wool at the underside of the floor (see appendix A)
- Replacing existing windows with coupled windows with two coated glasses and argon gas in two cavities. These windows typical have a U-value of 1.2 W/m^{2}K (Enova, 2012).

As for the previous typologies it is anticipated that the thermal bridge value and the air exchange rate due to infiltration will be reduced down to TEK10-level.

To achieve a passive house standard or as close as possible to a passive house standard the following renovations has to be performed (Appendix A):

- 150 mm extra mineral wool insulation + brick veneer in the external walls
- Replace 180 mm mineral wool with 400 mm mineral wool in roof
- 300 mm extra mineral wool at underside of the floor
- Replacing existing windows with windows with three layers of insulating glass with two coated glass, argon gas, warm edge and insulated frame. These types of windows typical have a U-value between 0.7 and 0.9 W/m^{2}K (Enova, 2012).

As for the previous typologies it is anticipated that the thermal bridge value and the air exchange rate due to infiltration will be reduced down to TEK10-level

3.6 Supplementary measures to the refurbishment packages

Since TEK10 requires that all new buildings over 500 m^2 heated useable floor area should cover at least 60 % of their heating demand by other sources than electricity and fossil fuels (Kommunal- og regionaldepartementet, 2010) the refurbishment may include investing in a heat pump. However, this is not seen as the standard TEK10-refurbishment since installing a heat pump in itself will not improve the building's thermal envelope. It will however be a very effective measure since it decreases the amount of delivered energy to the building.

Installing ventilation heat recovery is not included in the basis refurbishment packages either, but is included as a supplementary measure as it can reduce the energy need further

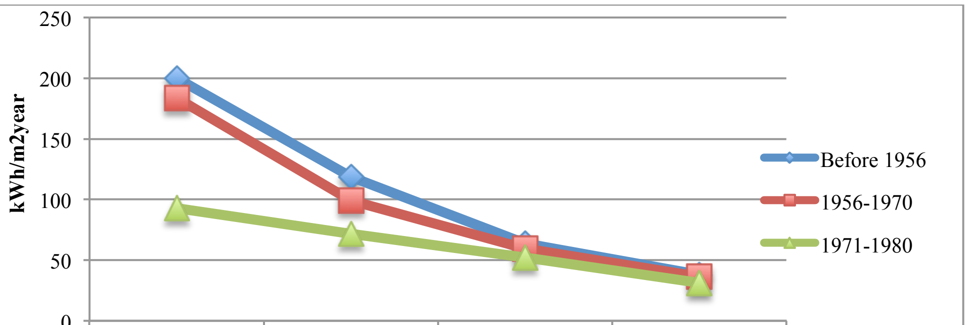
4 Results from case studies

The main results given in this report are for the standard reference climate given in NS3031. The reference climate is always used when comparisons to official regulations are carried out. For energy labeling of buildings it is necessary to use a reference climate to be able to compare different buildings. If local climates are used a building built in Southern Norway will get a better energy label than the same building built in Northern Norway. The Government has decided to set Oslo as the reference climate (NS3031, 2011). It can be discussed if the reference climate should be set as a weighted average climate according to the emphasis of the building stock. However, this average weighted climate would probably be remotely similar to the Oslo climate. It may though be of great interest in further studies to look at this to get a more "real" representation of the total energy use in the Norwegian building stock.

In chapter 5.1 changes in energy flows due to changes in climate are discussed. The three climate zones that are compared to the Oslo climate are Southern Norway (coast), Mid-Norway (inland) and Northern Norway (coast).

4.1 Reduction potential for space heating

As shown in Figure 8 the delivered energy to space heating in apartment blocks built before 1956 and during the period 1956-1970 in original state is very high. After historical refurbishments the delivered energy to space heating is estimated to decrease with approximately 40 %. This is a major improvement and is basically caused by reduction in transmission losses through walls, roof and floor due to decreased U-values. Extra insulation in walls etc. gives a major improvement of the building's thermal envelope. These measures are also relatively cheap to apply compared to the effect they have on the building's total energy savings.



	Original	Historical refurbishment	TEK10-refurbishment	Passive house refurbishment
Before 1956	200	118.4	63.8	38
1956-1970	183.7	99.2	59.6	36.2
1971-1980	92.8	71.5	51.9	31.3

Figure 8: Energy delivered to space heating, before and after the refurbishments (kWh/m²year)

After a TEK10-refurbishment is applied to the building's thermal envelope, resulting in U-values that fulfill the technical regulations, the total energy delivered to space heating is estimated to decrease with 68 % for the two oldest building typologies. If a passive house refurbishment is applied an energy saving of 81 % is possible (see Figure 8). This means that the annual energy need for space heating for a typical apartment block built before 1956 can be reduced from 200 kWh/m^2 to 38 kWh/m^2. The reduction potential for the two oldest building typologies are similar, as seen in Table 16, but for apartment blocks built in the period 1971-1980 the net energy need for space heating is considerably lower in original state as a consequence of much lower U-values for the building envelope. The building envelope has also become more compact which makes it more energy efficient. From being an apartment block that consisted of 8 apartments in 1956, the typical apartment block from this period consist of 24 apartments, but still have the same number of floors. In original state the annual energy use for space heating is calculated to be 92.8 kWh/m^2. For buildings built during the time period 1956-1970 the net annual energy need for space heating is calculated to be 192.5 kWh/m^2. This improved development of building typology can be explained by new building regulations in 1969 that had stricter regulations when it came to the quality of the building envelope (dsb, 1969)

Table 16: Annual energy savings from original state (kWh/m^{2}year)

	Annual savings from original state (kWh/m^{2}year)	
	TEK10-refurbishment package	Passive house refurbishment package
Before 1956	136.2	162
1956-1970	124.1	147.5
1971-1980	40.9	61.5

Since most of the apartment blocks from these periods are in historical refurbished state (see Figure 3 in chapter 2.3) a more realistic reduction potential is from historical refurbished state to TEK10- or passive house-state, which corresponds to an annual energy reduction of 54.6 kWh/m^2 or 80.4 kWh/m^2 respectively for apartments block built before 1956 (see Table 17).

Table 17: Annual energy savings from historical state (kWh/m^{2}year)

	Annual savings from historical refurbished state (kWh/m^{2}year)	
	TEK10-refurbishment package	Passive house refurbishment package
Before 1956	54.6	80.4
1956-1970	39.6	63
1971-1980	19.6	40.2

As a consequence of the refurbishments the transmission losses decrease significantly. As shown in Figure 9 the ventilation system plays a more important role as the building envelope improves. After the passive house refurbishments heat loss due to ventilation stand for about 57 % of the building's total heat loss. Implementing heat recovery in the ventilation system gives more effect at this stage than continuing improvement of the building envelope.

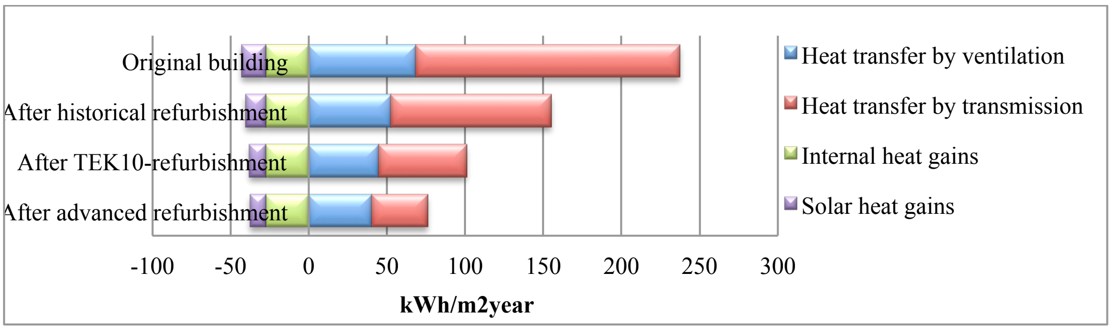
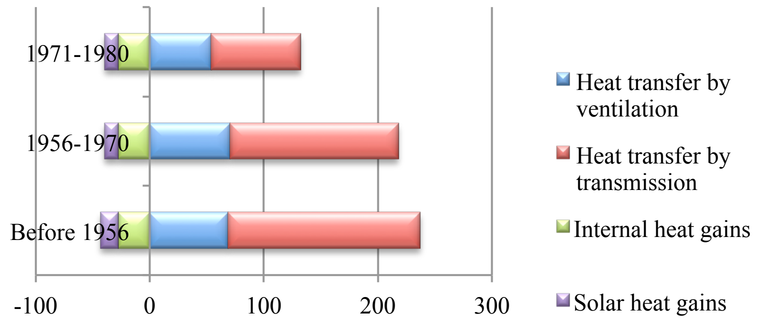


Figure 9: Heat transfer/gain for space heating (<1956)

Apartment blocks have become more energy efficient during time. This is basically due to better building envelope. As seen in Figure 10 heat losses due to the ventilation system are almost the same for all the typologies. Apartment blocks built in the period 1971-1980 have somewhat lower ventilation heat loss than the two other typologies. This is due to smaller infiltration losses.



	Before 1956	1956-1970	1971-1980
Heat transfer by ventilation	69	70	54
Heat transfer by transmission	168	148	78
Internal heat gains	-28	-28	-28
Solar heat gains	-15	-12	-12

Figure 10: Comparison of apartment blocks from each time period in original state (kWh/m^{2}year)

The main reduction potential for all building typologies in original state is due to transmission losses as these losses stand for up to 70 % of the total heat losses. Improvement of the building envelope should therefore be the priority strategy.

4.2 Comparison to results from Enova

Enova have estimated a net energy demand for space heating as given in Table 18 for the different building typologies. However, Enova defines the standard dwellings as an average of dwellings in original state and dwellings in “historical refurbished”-state

Table 18: Comparison to numbers given by Enova (Prognosesenteret AS & Entelligens AS, 2012)

Delivered energy to space heating (kWh/m^{2}year)				
	Original	Historical upgraded	Weighed average	Enova
Before 1956	200	118.4	132	159
1956-1970	183.7	99.2	120.3	139
1971-1980	92.8	71.5	77	54.9

For apartment blocks built before 1956 about 84 % of the dwellings are refurbished. With these assumptions the average energy need for space heating is calculated to be 132 kWh/m^{2}year, which is more similar to the value given in the Enova report (Prognosesenteret AS & Entelligens AS, 2012). The differences can be explained by inclusion of window replacement in the historical refurbishments in this report. In the Enova report the standard dwelling is defined as a weighted average between the dwelling in original state and the dwelling in historical refurbished state. 2.6 W/m^{2}K is therefore a weighed average of the window’s U-value for the average building from this period (Prognosesenteret AS &

Entelligens AS, 2012). If the U-value is kept equal to 2.6 W/m^2K in both original and historical refurbished state the weighed average is calculated to be 142 kWh/m^2year, which is more similar to what Enova calculated. Reasons for this error can be explained by slightly different thermal bridge values and air infiltration values as well as different heating system. The values for thermal bridge and air infiltration in this report are based on standard values given by TABULA (Loga & Diefenbach, 2012).

It can be discussed whether it was a good choice to use average U-values for windows from the Enova report as those values did not give a correct picture of the U-value in a typical building in original state and a typical building in historical refurbished state. The U-value of the original window is probably a bit higher than 2.6 W/m^2K, maybe around 4 W/m^2K. Since TEK87 require a U-value lower than 2.4 W/m^2K and TEK97 require a U-value lower than 1.6 W/m^2K (see Table 4) it is probably a good estimate to set the average U-value after historical refurbishment equal to 2.0 W/m^2K for the two first building typologies.

An average energy need for the "typical" apartment block from the period 1971-1980 can be calculated based on the fact that approximately 71 % of these buildings are already refurbished (Prognosesenteret AS & Entelligens AS, 2012). The weighed average is then 77 kWh/m^2year, which is about 22.1 kWh/m^2year higher than the value given by Enova (Prognosesenteret AS & Entelligens AS, 2012). This error can be explained by slightly different parameter values. Since the average air change rate during heating season related to the utilization of the building is based on average values given in TABULA this can result in slightly different values of this energy flow. Average values for combination of heating sources are also used in the Enova report, which means that the "typical" building is estimated to use 5 different heating sources, where one of them are heat pumps. Including use of heat pumps can lower the net energy need and can therefore explain the differences between the results given in this report and the results given in the Enova report (Prognosesenteret AS & Entelligens AS, 2012).

Since the air change rate due to utilization of the building is very dependent on the user when a natural ventilation system is used, this parameter is given with a big uncertainty. It can be discussed whether using an average value from TABULA was a good choice as the air change rate due to utilization of the building is lower when the leakage rate is high. It was however seen as an appropriate simplification as it was difficult to know how this air rate changed as the building improved. This is further discussed in chapter 5.

4.3 Reduction potential for domestic hot water system

The historical refurbishment includes an upgrade of the storage tank and the distribution system, so that the annual heat loss due to storage gets reduced from 3.6 kWh/m^2 to 2.9 kWh/m^2 (TABULA, 2013) and the annual heat loss due to distribution gets reduced by 70 % due to better insulated water pipes (see Table 12 in chapter 3.2.2). The heat losses due to distribution and storage are assumed to be the same for historical, TEK10 and passive house refurbishments (see Figure 11). Since the gross energy need for domestic hot water is expected to be equal before and after all refurbishment packages it is not possible to reduce annual delivered energy to domestic hot water below 30 kWh/m^2. However, it may be interesting to look at the effect of changing to a water-saving shower at a later stage, but this is not included in this report.

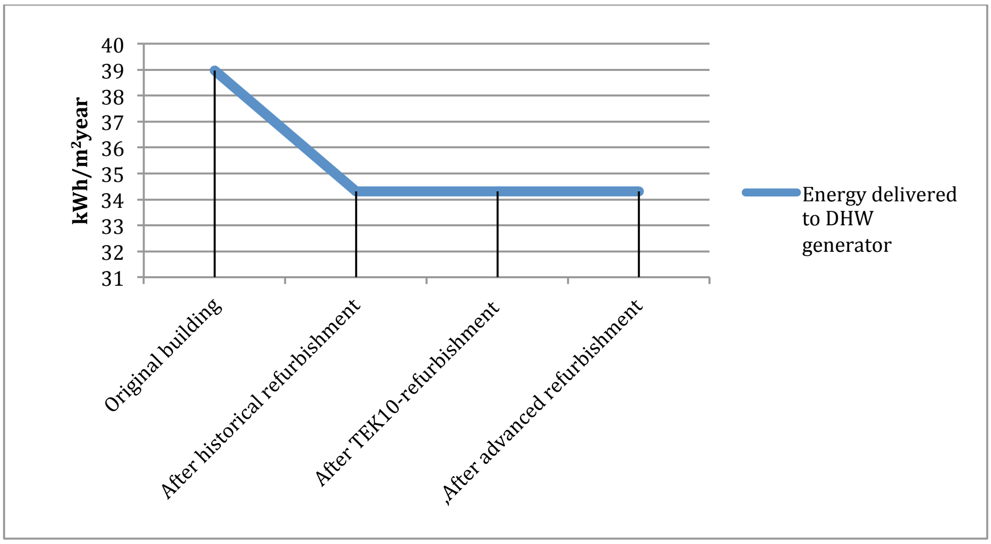
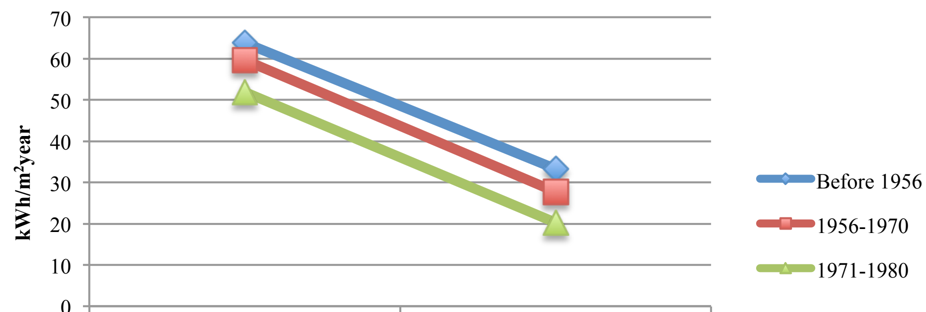


Figure 11: Energy delivered to domestic hot water system (DHW)

4.4 Comparison to TEK10

As shown in Figure 9 the biggest saving potential is due to reduction in transmission losses. By reducing the U-values of walls, windows etc. it is possible to reduce the transmission losses significantly. TEK10 requires that the total amount of annual energy delivered to an apartment block should not exceed 115 kWh/m^2 (Kommunal- og regionaldepartementet, 2010). The calculated annual net energy need for space heating after a TEK10-refurbishment for an apartment block built before 1956 is 63.8 kWh/m^2. This gives a net energy need (excluded cooling requirements) of 127 kWh/m^{2}year when standardized values for lighting and electrical equipment are used (NS3031, 2011). The TEK10-requirment for net energy need is not fulfilled even though a TEK10-refurbishment is applied to the building envelope. However, the TEK10-refurbishment package does not include implementation of ventilation heat recovery since a balanced/ mechanical ventilation system is not installed in the original building. To be able to recover heat from the ventilation system a mechanical system has to be installed and this installment can be very expensive (Mathisen et al., 2004). If this kind of ventilation system with 70 % heat recovery is included in the refurbishment package the building's net energy need for space heating gets reduced down to 33.2 kWh/m^{2}year (see Figure 12). This gives a total net energy need of 96.4 kWh/m^{2}year, which fulfills the technical requirement as long as the cooling requirements do not exceed 18.6 kWh/m^{2}year.

For a typical apartment block built between 1956 and 1970 ventilation heat recovery or heat pumps have to be included as well to be able to reach the TEK10-level. For the last period however the TEK10-requirement of a net energy need of 115 kWh/m^{2}year is fulfilled without any extra energy measures as long as there are no cooling requirements.

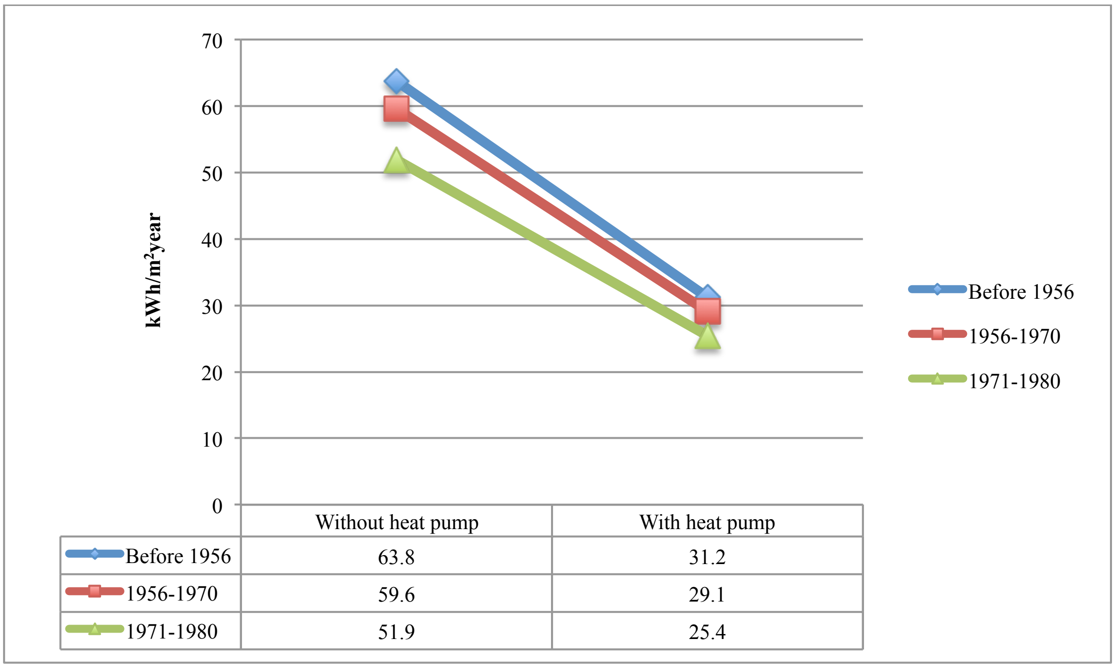


	Without heat recovery	With heat recovery
Before 1956	63.8	33.2
1956-1970	59.6	27.7
1971-1980	51.9	20.2

Figure 12: Energy delivered to space heating after TEK10-refurbishment with and without ventilation heat recovery (70 % efficiency)

Changing to a mechanical ventilation system with heat recovery will though often lead to an increased air exchange rate due to utilization of the building. For apartment blocks the building regulations of 2010 implies that the air exchange rate due to utilization of the building will be as high as 1.7 1/h (Kommunal- og regionaldepartementet, 2010). In this report the air exchange rate due to utilization is set to be 0.4 1/h in all cases due to average value given in TABULA. It can be interesting to see the effect this parameter has on the total energy use, and a sensitivity analysis is therefore performed (see chapter 5.3).

The TEK10-requirement can also be achieved by installing an air-to-air heat pump and only use electricity directly to cover the peak loads. A heat pump is typically dimensioned to cover 60 % of the building's power requirement, which typical corresponds to 80-90 % of the building's energy use (NTNU and SINTEF, 2007). Implementation of heat pumps reduces the building's net energy need for space heating in the same manner as installing ventilation heat recovery (see Figure 13). Then again, how well a heat pump function is dependent on operation, and people tend to increase the level of comfort when using a heat pump. As a consequence of this the savings tends to be smaller than optimal possible (Prognosesenteret AS & Entelligens AS, 2012).



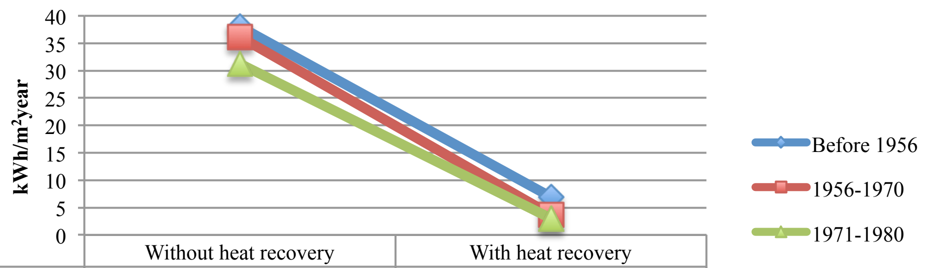
	Without heat pump	With heat pump
Before 1956	63.8	31.2
1956-1970	59.6	29.1
1971-1980	51.9	25.4

Figure 13: Energy delivered to space heating after TEK10-refurbishments with and without heat pumps

4.5 Comparison to the passive house standard

NS3700 requires that the annual energy need for space heating do not exceed 15 kWh/m^2. After passive house refurbishments the building's annual energy need to space heating is estimated to be 38 kWh/m^2 for apartment blocks built before 1956. This does not satisfy the passive house requirement. As for the TEK10-refurbishments, the passive house package does not include changes in the ventilation or heating system. If a mechanical ventilation system with 80 % heat recovery is installed the annual energy need for space heating can be reduced down to 6.9 kWh/m^2 for apartments blocks built before 1956, which satisfies the passive house requirement (NS3700, 2013).

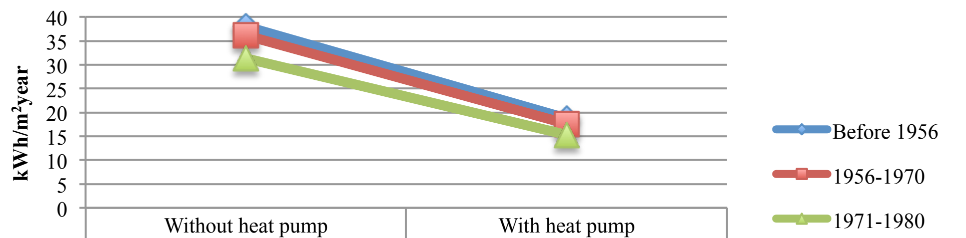
The passive house requirement is not fulfilled either for the two other building typologies by just implementing a passive house refurbishment to the building envelope. The passive house requirement can though be fulfilled when ventilation heat recovery is included as seen in Figure 14.



	Without heat recovery	With heat recovery
Before 1956	38	6.9
1956-1970	36.2	3.7
1971-1980	31.3	3.0

Figure 14: Energy delivered to space heating after passive house refurbishments with and without heat recovery (80 % efficiency)

By installing an air-to-air heat pump the requirement is almost fulfilled as the annual net energy need for space heating is reduced down to 18.7, 17.6 and 15.3 kWh/m^2 for apartment blocks built before 1956, during 1956-1970 and during 1971-1980 respectively (see Figure 15). Even though the requirement is not fulfilled completely, this is probably good enough as the passive house requirement is very difficult to achieve in real life. Achieving a passive house standard is almost impossible without using a heat pump or using heat recovery in the ventilation system. The effect of heat recovery is though dependent on the air exchange that is required in the ventilation system, so the effect of this measure may be less effective than anticipated in this report since the air change rate may not be constant.



	Without heat pump	With heat pump
Before 1956	38	19
1956-1970	36	18
1971-1980	31	15

Figure 15: Energy delivered to space heating after passive house refurbishments with and without heat pumps

4.6 Total energy saving potential

Since the majority of apartment blocks built before 1980 has been refurbished, the total saving potential for these building typologies will typical be from historical refurbished state to TEK10 or passive house state. The total energy savings for the historical refurbished buildings per year are shown in Table 19. For apartment blocks built before 1956, during the period 1956-1970 and during the period 1971-1980 about 84 %, 75 % and 71 % are already refurbished.

Table 19: Saving potential for building stock that has already gone through historical refurbishment

Construction period	Number of blocks	Saving potential TEK10-refurbishment (MWh/year)	Saving potential passive house-refurbishment (MWh/year)
Before 1956	16 963	527	775
1956-1970	4 991	208	332
1971-1980	2 675	94.5	194
Total up until 1980	24 629	829.5	1 301

The rest of these buildings are assumed to be in original state. The total energy saving potential for these buildings per year are given in Table 20

Table 20: Saving potential for building stock in original state (MWh/year)

Construction period	Number of blocks	Saving potential TEK10-refurbishment (MWh/year)	Saving potential passive house-refurbishment (MWh/year)
Before 1956	3 231	250	297
1956-1970	1 663	218	259
1971-1980	1 093	80	121
Total up until 1980	5 987	548	677

If all existing apartment blocks from these three time periods are upgraded to a TEK10-level the total energy savings per year is estimated to be 1.4 TWh, which corresponds to Drammens annual electricity consumption (Energilink, 2006). If a passive house refurbishment is implemented the total energy savings per year is estimated to be 2 TWh.

Implementation of air-to-air heat pumps for space heating gives a further energy reduction, and the total energy savings for TEK10 refurbishments can be increased up to 1.15 TWh/year for apartment blocks built before 1956, 0.64 TWh/year for apartment blocks built between 1956 and 1970, and 0.355 TWh/year for buildings built between 1971 and 1980. The total energy savings for passive house refurbishments to all apartment blocks built before 1980 can therefore be increased from 2 TWh/year without heat pumps to 2.44 TWh/year with heat pumps. Including installation of heat pumps in the TEK10-refurbishment package gives an increase in total saving potential for all three periods of 0.8 TWh/year. This implies that installing a heat pump can increase the energy saving potential with 57 %.

5 Sensitivity analysis of important parameters

Some parameters are more sensitive than others and in this section sensitivity analysis of the most influencing or important parameters are done. The outdoor climate is evaluated first and the sensitivity of this can be seen in chapter 5.1.

Since the choice of U-values for windows in original building state is given with some uncertainty a sensitivity analysis is performed to see how sensitive the building is for changes in window quality. Changing the U-values of the external walls is of great importance, and a sensitivity analysis is therefore performed to see if this measure is more effective than changing windows.

The effect of ventilation heat recovery ($\eta_{ve,rec}$) is also analyzed as this is seen as a potential effective measure, and the sensitivity of this can be seen in chapter 5.4.

The last parameters that are analyzed are air exchange rate due to utilization of the building ($n_{air,use}$) and air exchange rate due to infiltration ($n_{air,infiltr.}$).

5.1 Importance of climate

How much heating a building requires are dependent on the indoor and outdoor climates, and the quality of the building's thermal envelope. Generally buildings with bad thermal envelope have high transmission losses when the outdoor temperature is low due to high difference between indoor and outdoor temperature (NTNU and SINTEF, 2007). However when the outdoor temperature is high it is beneficial to have a thermal envelope with high U-values so that the need for cooling is reduced. Though, in Norway the need for heating is significantly higher than the need for cooling. The length of heating season is normally around 237 days in Oslo (Arnstad, 2004), which implies that the building requires heating approximately 65 % of the days during a year. For Northern Norway the length of heating season can be up to 319 days (Arnstad, 2004). In this chapter four climate zones are evaluated to see the effect of the outdoor climate. Each climate zone has different solar irradiation, different length of heating season and different average temperature during heating season (see chapter 3.2.1). Mid-Norway have the lowest average outdoor temperature during heating season, while Northern Norway (coast) have the longest heating season. The solar irradiation is highest in Northern Norway and lowest in Oslo (reference climate) (Arnstad, 2004).

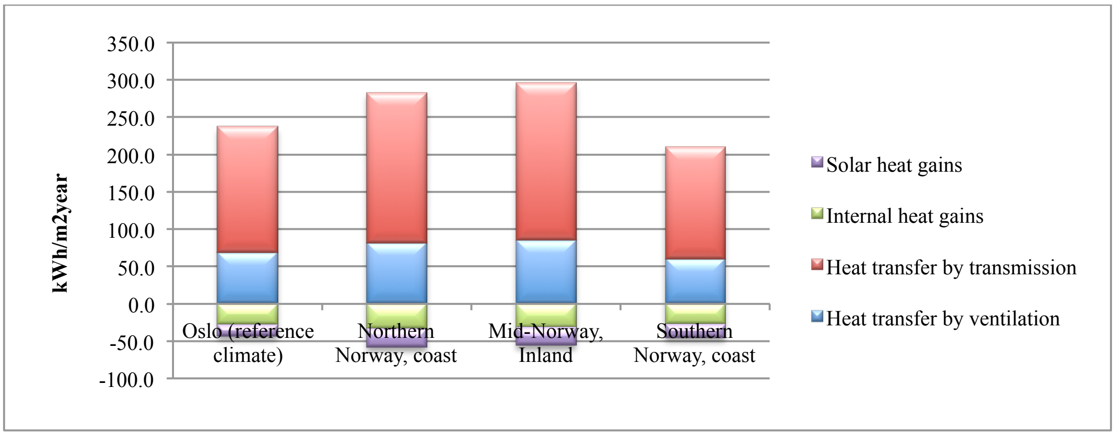


Figure 16: Changes in heat transfer/gain for space heating due to changing of climate zones (Original building built before 1956)

Changing from reference climate, Oslo, to a Mid-Norwegian Inland climate leads to an increase in energy use of approximately 50 kWh/m^{2}year for an apartment block from 1950 in original state (see Figure 16). This is a major difference, and shows the importance of climate when estimating the building's energy use.

The differences between the climate zones decrease when the thermal envelope of the building improves. However, unless the U-values of the building components are equal to zero there will be some differences due to different outdoor climate. After a passive house refurbishment is completed the differences in annual energy need for space heating for the same apartment block built in Oslo and Trondheim (Mid-Norway, inland) will be 10.4 kWh/m^2. This implies that as the building's thermal envelope improves the less sensitive the building is for outdoor climate changes. It also implies that it is more difficult to achieve a low energy need in colder climate than in warmer climate. This is why the passive house standard has different energy requirements for different climates (NS3700, 2013).

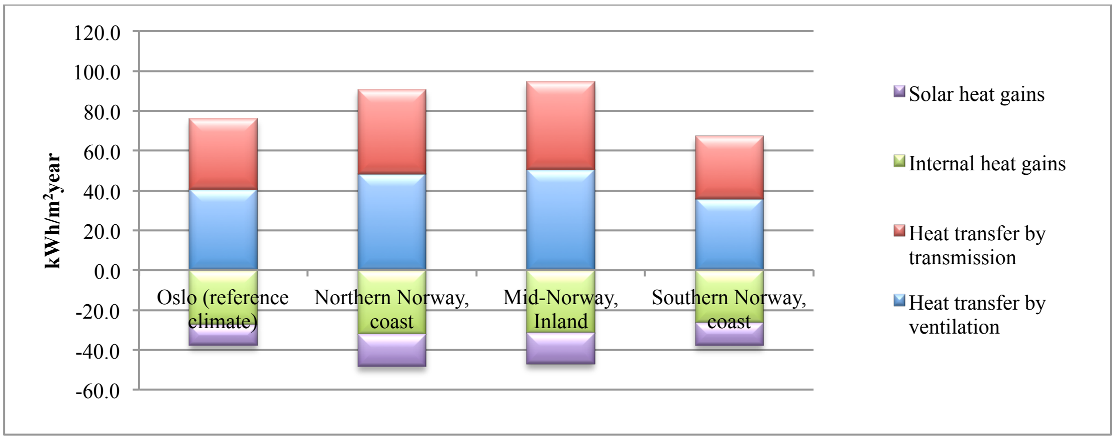


Figure 17: Changes in heat transfer/gain for space heating due to changing of climate zones (After passive house refurbishments)

5.2 Importance of U-values of windows and exterior walls

The two graphs in Figure 18 show how sensitive the net energy need for space heating is for changes in U-values for windows and walls. Per unit change of U-value, the building is most sensitive to changes in the quality of the external wall. This can be explained by the fact that the wall area of an apartment is 4 times bigger than the area of windows. The U-value of the windows in original state is however much higher, which gives a higher reduction potential in U-value. By reducing the U-value of the external walls from 0.82 W/m^{2}K to 0.12 W/m^{2}K the annual energy demand for space heating gets reduced from 209 kWh/m^2 to 155 kWh/m^2, which correspond to a reduction of 21 %. Reducing the U-value of the windows from 2.6 W/m^{2}K to 0.8 W/m^{2}K correspond to a reduction in annual energy need for space heating from 209 kWh/m^2 to 173 kWh/m^2, which correspond to a reduction of 17 %.

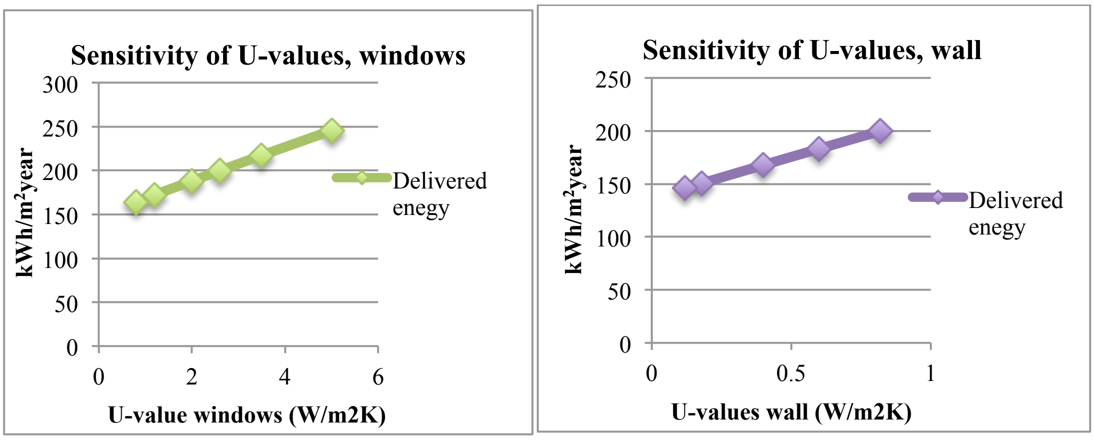


Figure 18: Sensitivity of U-values, windows and walls

The reduction potential is closely related to the reduction potential of U-values. A high U-value corresponds to a high reduction potential for the energy need for space heating. Per unit change of U-value the reduction potential is highest for the external walls as mentioned earlier. Increasing the U-values of the windows from 1 to 2 corresponds to an annual increase in energy demand of 19.6 kWh/m^2. Increasing the U-value of the external walls from 1 to 2 corresponds to an annual increase in energy demand of 77.9 kWh/m^2. This implies that if the U-values of the external walls are high insulating the walls should be the priority refurbishment. However, if the U-value reduction of the windows is high, say from 4 to 0.8 W/m^{2}K this gives more energy reduction than improving the U-value of the wall from 0.5 to 0.18 W/m^{2}K.

5.3 Importance of air exchange rates ($n_{air,use}$) and ($n_{air,infilt.}$)

The building's energy need for space heating is closely dependent on the air exchange rate, both air change due to infiltration ($n_{air,infiltr.}$) and air change due to the ventilation system ($n_{air,use}$). Per unit change both air change rates corresponds to an annual change in energy use of 90 kWh/m^2. This means that the building is more sensitive to changes in air exchange rates than changes in U-values. The infiltration is though closely related to the building envelope, so by improving the building envelope the air change due to infiltration gets reduced. The air change due to the ventilation system is not dependent on the building envelope, but is dependent on the utilization of the building. Old buildings normally have ventilation openings through valves and windows and these are regulated manually. For modern buildings a balanced ventilation system is used. A mechanical ventilation system where fans are used to draw exhaust air out of the building was common in apartment blocks at the 1970s.

As mentioned earlier there are some uncertainties connected to the air change rate due to utilization of the building. As a simplification this air change rate was set constant to 0.4 1/h due to average value given in TABULA (Loga & Diefenbach, 2012). However, if the air change rate due to the ventilation system is higher or lower this will have a major effect on the building's total energy use for space heating. The energy savings related to implementation of heat recovery in the ventilation system can be less if it is assumed that the ventilation air rate is increased from 0.4 1/h to 1.7 1/h which is the standard value used in TEK10 for balanced ventilation systems in apartment blocks.

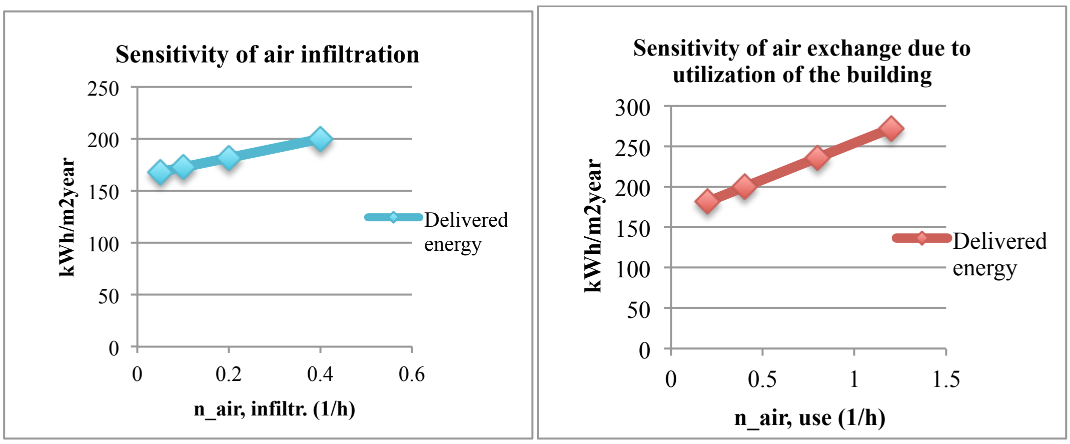


Figure 19: Sensitivity of air infiltration and air exchange due to utilization of building

For buildings built before 1956 the effect of installing heat recovery after a TEK10 refurbishment is applied to the building envelope is calculated to be 30 kWh/m^{2}year. This is when the ventilation air rate is held constant at 0.4 1/h. If the ventilation air rate increases to 1.7 1/h when implementing heat recovery, which is normal when using a balanced ventilation system, the savings are only 5 kWh/m^{2}year. This implies that the building's energy need is closely related to these air change rates. However, a good ventilation system is necessary for a good indoor environment, so reducing the air change rates should not be done if this has negative effect on the indoor environment.

5.4 Importance of ventilation heat recovery

The reduction potential of implementing heat recovery (see Figure 20) is the same as the reduction potential of reducing the U-value of the exterior walls from 0.82 W/m^2K to 0.12 W/m^2K (see Figure 18). Implementing heat recovery in a natural ventilation system is not possible, so a mechanical system has to be installed which can be very costly. A profitability analysis is not done in this report, but is of great interest at a later stage.

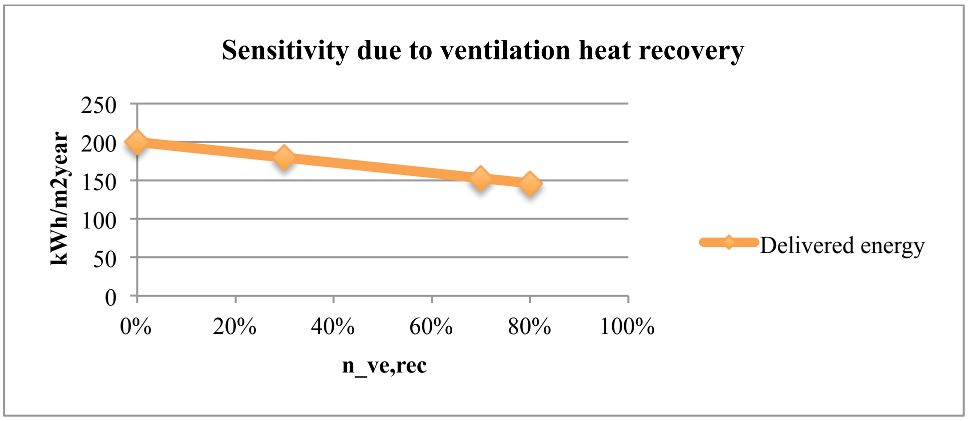


Figure 20: Sensitivity due to ventilation heat recovery

If a mechanical/ balanced ventilation system is installed in the building already, ventilation heat recovery is definitely a measure that should be implemented. If major renovations are planned for a building without a mechanical ventilation system it can also be recommended to install a system with heat recovery, but the consumer must then be aware of the costs related to the installation, as it can be very complex. Implementing heat recovery is efficient as long as the air change rates are constant. If implementing a balanced ventilation system leads to increased air change rates the energy savings by implementing a system like this will be small. However, the air quality in the building will improve when a balanced ventilation system is applied, and that is why a ventilation system like this is used in modern buildings. It can though be discussed if it is necessary to have a complex ventilation system in dwellings, as a natural ventilation system can be good enough for most parts of the year. For passive houses the ventilation need is generally a bit higher due to a more compact building envelope, so a balanced ventilation system may be necessary in these buildings.

Even though it can be discussed whether or not it is beneficial to install a balanced ventilation system with heat recovery if the air flow rates increase as a consequence of the installment, it can be concluded that heat recovery is a good energy measure as it decreases the energy need considerably. If a balanced ventilation system without heat recovery is applied to the building the energy need would be considerably higher than with heat recovery.

6 Recommendations and priority strategies for refurbishments

Based on results given in this report it is recommended to improve the building envelope as much as possible as it can improve the building's net energy need for space heating. A cost-analysis is not performed though, so it may not be efficient to apply passive house refurbishments to the building. A cost-analysis should be done in further work to have a more realistic prospective of the future refurbishments possibilities.

Amount of extra isolation required to upgrade the building envelope to TEK10 or passive house standard varies depending on the quality of the buildings in original state. Generally the quality of the buildings decreases with the age of the buildings as the building regulations have become stricter during the years. A typical building constructed before 1956 needs 200 mm extra mineral wool in walls, and 200 mm extra mineral wool in roof and floors that are connected to an unheated attic or basement to accomplish a U-value that satisfy TEK10 (see chapter 3.3). This is seen as achievable and is therefore recommended as it gives a total energy reduction of 136 kWh/m^{2}year if the building is in original state. If the building is in historical refurbished state it is necessary with 150 mm extra mineral wool in external walls and 100 mm extra mineral wool in roof and floors. The total annual energy reduction from this state to TEK10 state is 54.6 kWh/m^2. Similar energy savings can be seen for apartments built during the period 1956-1970. For apartments built between 1970 and 1980 the quality of the building in original state is considerably better, which implies that upgrading these buildings to a TEK10-level requires less extra insulation thickness. The energy saving potential for upgrading an apartment block in original state from this period to TEK10 level is estimated to be 40.1 kWh/m^{2}year.

Achieving the TEK10-requirement of a total annual energy use lower than 115 kWh/m^2 is seen easier for compact buildings like apartment blocks. As mentioned in chapter 4.6 the total energy saving potential when all existing apartment blocks built before 1980 are upgraded to TEK10-level is 1.4 TWh/year. The energy saving potential when the buildings are upgraded to passive house standard is 2.0 TWh/year. Apartment blocks built before 1956 has the biggest potential for renovation (see chapter 4.6).

Further energy savings can be achieved if ventilation heat recovery is included in the refurbishment packages as mentioned in chapter 4.4 and 4.5. These extra measures are necessary to achieve a TEK10-level or a passive house level. However, to be able to implement heat recovery a balanced ventilation system is required in the dwelling. Since this is seen as a major refurbishment it is not likely that existing buildings will undergo such renovation. It is therefore not a priority strategy. It must though be mentioned that implementing heat recovery can be more effective than improving U-values from TEK10-level to passive house level.

Implementation of air-to-air heat pumps is relatively simple and relatively cheap. Since the building envelope generally is in bad shape in original state, implementation of heat pumps are not seen as an alternative to the other measures. Installing a heat pump after TEK10 refurbishment is however a possibility as it can be cheaper and more efficient than upgrading the building envelope to passive house standard <u>IF</u> the heat pump is operated properly.

7 Further work

Since the literature study and the modeling took more time than anticipated a carbon emission analysis is not included in the report. This should however be included in further work. An analysis of different heating systems should be included as well to see the effect of changing from one heating source to another. This is especially interesting when it comes to carbon emission savings. Changing to renewable energy sources can give major reductions in carbon emissions even though the energy use is the same. Since the heating system remains the same after all refurbishments analyzed in the report the carbon emissions are reduced in the same manner as the energy reduction.

A comparison against "Energimerking.no" should be made to check to what extent the results from the sample buildings are in line with the aggregated results from "Energimerking.no". It should also be discussed how this database can be used as a resource for upgrading of the different building typologies. The database can also be used to give each building typology an energy label before and after different refurbishment packages, and explain which measures that are necessary to achieve an energy label A.

In this project work an average building type from each of the three time periods analyzed was chosen. This was seen as the typical building from the time period and the size of the apartments was estimated based on average values. Using these typical buildings are good when calculating total national energy saving potentials. But it cannot be used as a norm for a real representation of energy saving potential in a real building. In the master thesis several typical buildings from each time period should be included, and an energy and carbon emission analysis should be performed for all typologies to see the real reduction potential in the different building types. A more detailed analysis of the materials used in different building types as well as the materials used in the different refurbishment packages should be included. A comparison between different materials should be made to be able to choose the material that has the best properties when it comes to energy effectiveness, impact on climate and economy.

In the master thesis a cost-analysis should be performed to see which refurbishments that must be prioritized. Also a dynamic representation of the aggregated building stock should be included to define how the quality of the dwellings has improved during the years and to define when dwellings were refurbished.

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Appendix A

Calculation of insulation thickness after TEK10- and passive house refurbishments

Mineral wool, $\lambda = 0.037\ W/mK$

Before 1956						
	Original		TEK10		Passive house	
	U-value	Mineral wool thickness	U-value	Extra insulation thickness	U-value	Extra insulation thickness
External walls	0.82	0	0.18	160	0.12	263
Roof	0.81	0	0.15	201	0.09	365
Floor	0.55	0	0.15	179	0.08	395

1956-1970						
	Original		TEK10		Passive house	
	U-value	Mineral wool thickness	U-value	Extra insulation thickness	U-value	Extra insulation thickness
External walls	0.96	0	0.18	167	0.12	270
Roof	0.33	100	0.15	135	0.09	299
Floor	0.38	50	0.15	149	0.08	365

1971-1980						
	Original		TEK10		Passive house	
	U-value	Mineral wool thickness	U-value	Extra insulation thickness	U-value	Extra insulation thickness
External walls	0.34	100	0.18	97	0.12	200
Roof	0.21	180	0.15	70	0.09	235
Floor	0.24	50	0.15	93	0.08	308

Insulation thickness between 200-250 gives a choice of isolation thickness of 250 mm.
Insulation thickness between 200-250 gives a choice of isolation thickness of 250 mm.
Insulation thickness between 250-300 gives a choice of isolation thickness of 300 mm.
Insulation thickness between 300-350 gives a choice of isolation thickness of 350 mm.
Insulation thickness between 350-400 gives a choice of isolation thickness of 400 mm.

Appendix B

See attached CD. The CD contains an excel-file with the model used for all the calculations.

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