Project thesis

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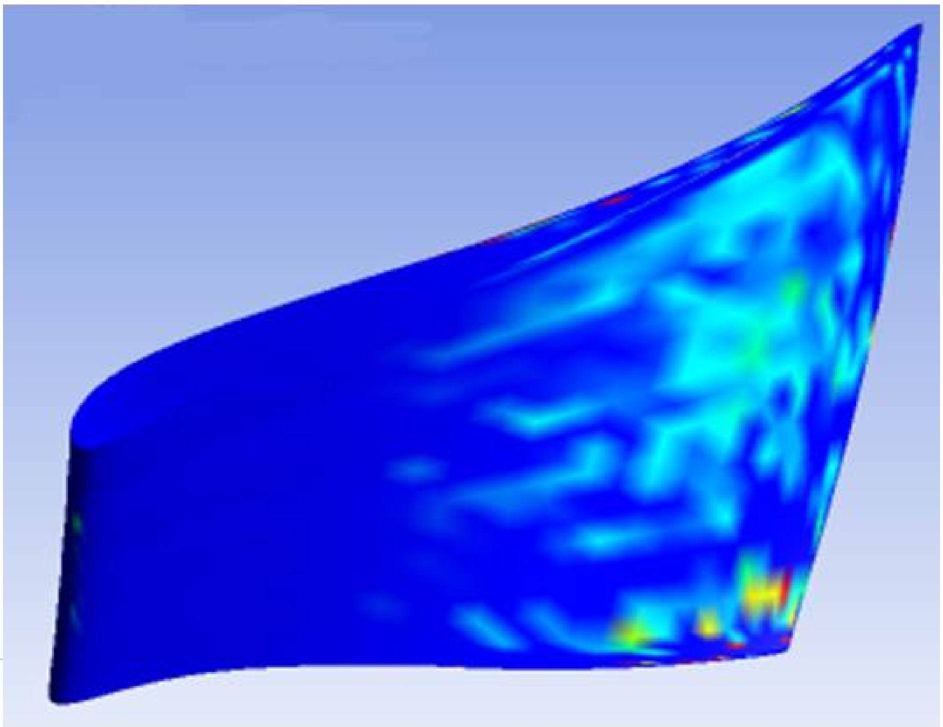
Typologies and energy demand modelling of the Norwegian building stock – Part 3

Single Family dwellings built before 1956

Trondheim, December 20, 2013



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Problem description

The objective of this MSc project is defined as "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 focus in the project has been on the development of standard dwelling types and their energy balance. The research questions of this project has been defined as

What defines the Norwegian dwelling stock in general, and more specific the single-family dwellings? Which energy flows and parameters are most important for the energy balance of the building? Which rehabilitation measures can be classified as standard and extensive rehabilitations and how does these rehabilitations influence the buildings energy balance?

Based on the calculations carried out in the current project the energy saving potential of the Norwegian dwelling stock will be evaluated.

Some alterations compared to the original Project Assignment as displayed on the first pages, have been made in agreement with supervisor Helge Brattebø. Assignment 2e, 5 and 7 have all been removed from the current Project Assignment.

Abstract

Against the backdrop of increasing global energy consumption and the building sector accounting for roughly 40% of total primary energy in many countries, the current MSc project focuses on the energy saving potential in the Norwegian dwelling sector. The project has been carried out in cooperation with three other MSc projects all concentrating on different parts of the Norwegian dwelling stock. The current project focuses on the energy demand in the Norwegian Single-Family buildings originating from before 1980. An Energy Balance Model has been created during this project, based on the methodology developed during the IEE Project TABULA (Intelligent Energy Europe project, Typology Approach for Building Stock Energy Assessment) and has been used to carry out all calculations. Within the given part of the dwelling stock, standard buildings have been defined based on age cohorts, technical state of the original thermal envelope, energy carriers, and space heating systems. For each standard dwelling, energy balance calculations have been carried out for four different thermal envelopes, the original as built, the historically rehabilitated envelope as well as two rehabilitation packages. The first reflecting the current Norwegian level regarding the technical standard of new buildings today defined as a standard rehabilitation for this project. The second reflecting the Passive House standard as defined by the Norwegian Standard NS 3700, and defined as an extensive rehabilitation in the current project. The technical levels for each thermal envelope have been based on literary findings following an extensive literary research. In addition energy calculations with and without heat recovery of ventilation air has been carried out for both the standard and extensive rehabilitations. Heat transmission through the thermal envelope was found to have the biggest influence on the net energy need for space heating, while ventilation heat losses were the second most important factor. Heat loss through the walls and roof was dominating for the original thermal envelopes for the oldest buildings, while heat loss through walls and windows was dominating for newer buildings. The heat loss through the windows was generally high compared to the relative size of the window area. The energy demand for buildings were found to vary across different climate zones, indicating that representing Norway with one climate zone, whether it is the climate of Oslo or an arithmetic average of the climate, will not give good results. A weighted average of the Norwegian climate when it comes to outdoor temperature and solar radiation are recommended. The rehabilitated buildings were found not to manage the energy requirements as set in the Norwegian standard if no heat recovery of ventilation air was applied. This indicates that more research into the economics of installing heat recovery as a part of extensive rehabilitation should be carried out. The extensive rehabilitation did not quite manage the Passive House standard, even with heat recovery, indicating that the space heating system has to be upgraded. The current project has not focused on upgrading the space heating system with measures such as installing a Heat Pump, and this is recommended as further works, especially since this will probably take the buildings to Passive House level. The energy saving potential of the given part of the Norwegian dwelling stock without ventilation heat recovery was found to be 6.9 TWh/year and 9.83 TWh/year with standard and extensive rehabilitation, respectively, compared to the current technical level of the thermal envelope.

Sammendrag

Verdens økende energibehov og bygningers relativt store andel av den totale primærenergien som forbrukes i mange land danner bakgrunnen for dette prosjektarbeidet som fokuserer på energiforbruket og energisparepotensialet i den norske boligsektoren. Arbeidet har blitt gjort i samarbeid med tre andre studenter, hvor alle har fokusert på forskjellige deler av den norske boligmassen. I dette prosjektet har fokuset vært på eneboliger bygget før 1980. Som en del av prosjektarbeidet har en energibalansemodell blitt utviklet basert på en metode utarbeidet gjennom IEE-prosjektet TABULA (et prosjekt utført av Intelligent Energy Europe som går ut på å utvikle typologier for å kunne utføre energivurderinger av bygningsmassen). Denne modellen har blitt benyttet for alle kalkulasjoner i dette prosjektarbeidet. Innenfor denne delen av boligmassen har standard boliger blitt definert basert på alder, bygningskroppens tekniske nivå, energibærer og systemer for oppvarming. For hver standard bolig har energibalanser blitt utført gitt fire forskjellige tekniske nivåer av bygningskroppen, den originale slik bygningen ble bygget, historisk oppgradert og to rehabiliteringspakker. Den første er ment å reflektere norske bygninger slik de bygges i dag ut fra kravene i norsk standard og er definert som en standard rehabilitering. Den andre er Passiv Hus-standard slik den er definert ut fra Norsk Standard NS 3700 og er definert som en omfattende rehabilitering. Det tekniske nivået til hver av standardboligene har blitt basert på informasjon innhentet gjennom en omfattende litteraturstudie. Energibalansene har blitt utført både med og uten varmegjenvinning av ventilasjonslufta for begge rehabiliteringspakkene. Varmetapet gjennom bygningskroppen hadde størst påvirkning på netto energibehov for oppvarming, mens varmetapet gjennom ventilasjonsluft hadde nest størst påvirkning. For eldre bygninger var varmetapet gjennom tak og vegger størst, mens for nyere bygninger dominerte varmetapet gjennom vegger og vinduer. Varmetapet gjennom vinduene var generelt høyt sammenliknet med vindusarealets relative størrelse. Energibehovet varierte for forskjellige klimasoner og resultatene indikerer derfor at å representere Norge med én klimasone, om det er Oslo eller en aritmetisk middelverdi, vil gi feil resultater. Det blir derfor anbefalt å beregne et vektet gjennomsnitt for utetemperatur og solinnstråling hvis én klimasone skal representere hele landet. De rehabiliterte bygningene oppnådde ikke energikravene i standardene uten varmegjenvinning og en grundig undersøkelse av de økonomiske konsekvensene av å installere mekanisk ventilasjon med varmegjenvinner som en del av en omfattende rehabilitering blir anbefalt. Den omfattende rehabiliteringspakken oppnådde ikke Passiv Hus-standard selv med varmegjenvinner noe som indikerer at oppvarmingssystemet må endres. Det nåværende prosjektet har ikke kalkulert energibehovet ved oppgradert varmesystem, som f.eks. ved bruk av varmepumpe. Dette anbefales derfor å se nærmere på ved eventuelle framtidige arbeid, spesielt siden installasjon av varmepumpe trolig vil ta byggene opp til Passiv Hus-nivå. Energisparepotensialet for den gitte delen av den norske boligmassen, uten bruk av varmegjenvinner, vil være 6.9 TWh/år og 9.83 TWh/år hvis henholdsvis standard og omfattende rehabilitering utføres.

TABLE OF CONTENTS

List of Figures

List of Tables

List of abbreviations

IEA	International Energy Agency
SSB	Statistics Norway
IEE	Intelligent Energy Europe
TABULA	Typology Approach for Building Stock Energy Assessment
EPC	Energy Performance Certification
EPBD	Energy Performance of Buildings Directive
TEK	Technical regulations for Norwegian buildings
BTA	Gross Floor Area
BRA	Useful Floor Area
NTA	Net Floor Area
DHW	Domestic Hot Water
EPISCOPE	Energy Performance Indicator Tracking Schemes for the Continuous Optimization of Refurbishment Processes in European Housing Stocks
LECA	Light Expanded Clay Aggregate

1 Introduction

Ever since the Brundtland Commisions Report “Our Common Future”, published in 1987, the environmental impact of the human society and the influence of the industrial revolution has been on the agenda(Brundtland and Khalid, 1987).The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 as the leading international body for the assessment of climate change(IPCC, 2013). Their last Summary for Policymakers states that “It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century.” And “Continued emissions of greenhouse gases will cause further warming (…) Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions.”(Stocker et al., 2013). According to the International Energy Agency (IEA) the world’s total final energy consumption has more than doubled since the 1970’s. The OECD (The Organization for Economic Co-operation and Development) countries still consumes 40% of the total energy, meaning that 34 countries consume an extensive amount of the total energy(IEA, 2013a). With a growing global population, projected to increase by almost one billion people within the next decade (UNFPA, 2012) the rising energy consumption is not likely to decrease. With the rising energy demand and the 2°C target a growing focus is put upon energy efficiency and energy reduction potential. IEA states that buildings account for 40% of primary energy consumption in most countries, as well as being a significant source of CO_2-emissions. The building sector has been identified as one of the most cost-effective sectors for reducing energy consumption. Reduction of overall energy demand by improving energy efficiency in buildings can significantly reduce carbon dioxide emissions from this sector(IEA, 2013b). The increased focus on the building sector has led to better technical regulations and research into more energy efficient buildings giving new concepts such as Nearly Zero Energy Buildings, Passive Houses and Plus Houses.

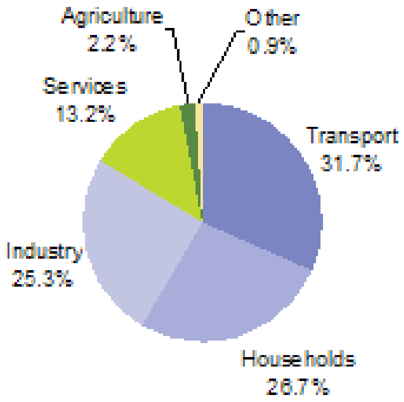
The objective of this MSc project is to carry out a system analysis of a defined part of the Norwegian building stock in order to contribute to the development of a Norwegian building stock typology. Thus three standard dwellings representing the Norwegian Single-Family dwellings built before the 1980’s are defined, and the energy balance for each dwelling examined. In addition rehabilitation packages meant to transform the building envelope from its current technical standard to the current national standard as well as Passive House level is examined. The energy balance is examined based on a methodology developed during the IEE Project TABULA (Intelligent Energy Europe project, Typology Approach for Building Stock Energy Assessment). The results from this project is hoped to give further insight into the Norwegian dwelling stock and its energy saving potential.

2 Background

2.1 Energy consumption

The global final energy consumption increased by 23% during 1990 – 2005. The energy consumption grew most quickly in the service and transport sectors, both had an increase of 37%. In 2005 the three end-use sectors consuming most energy globally was the manufacturing industry with a 33% share, households with 29% and transport with 26%. The trends in CO2-emissions are driven by the amount and type of energy use, as well as the indirect emissions associated with production of electricity. IEA (International Energy Agency) found that the global emissions of CO_2 from final energy use increased with 25% between 1990 and 2005. The most important sectors were as before manufacturing with a share of 38%, transport with 25% and households with 21. Global energy use in the household sector increased with 19% between 1990 and 2005, and electricity and natural gas was found to be the main energy commodities used in OECD countries, providing 72% of total household energy requirements in 2005. The global CO_2 emissions from households increased by 21% between 1990 and 2005, due to both increases in final energy consumption and changes to the energy mix(IEA, 2008).

Eurostat reported the gross inland consumption of primary energy within the EU-27 (countries included in the EU from 2007 – 2013) to be 1 759 tons of oil equivalent (toe) in 2010. The energy consumption had remained relatively unchanged between 2003 and 2008 but had a decrease of 5.4% in 2009. This was attributed to the lower economic activity level as a result of the financial crisis. An analysis over the period 2000 – 2010 revealed that the gross inland consumption of primary energy increased, on average, by 0.2% per year. A study of the share of energy products during the same period indicated a gradual decline of crude oil and petroleum products, solid fuels and nuclear energy. The combined share of crude oil, petroleum products and solid fuels fell from 56.9 % to 51.0 %. The relative importance of renewable energy sources increased as well, their share of the EU-27 inland consumption of primary energy increased by 4.2 percentage points during this decade(Eurostat, 2012). This analysis also showed that the final end use of energy in the EU-27 was dominated by three sectors, transport, households and industry, as seen in Figure 1.



Source: Eurostat (online data code: tsdpc320)

Figure 1 Sector divided energy use in the EU (Eurostat, 2012)

The European Union has set a 20% cut in Europe's annual primary energy consumption as their goal for 2020. Several measures to increase efficiency at all stages of the energy chain have been proposed, and the measures focus on the public transport and building sectors(European Commission, 2013b). Meijer et al., however found that despite the importance given to energy saving on the political agenda, there were serious gaps in the monitoring of the physical residential stock. Apart from a few better sources, as IEA and Eurostat, both the definitions and data-collection methods used in national statistics differed in each country studied. In addition they found that the energy consumption data was not related to the age of the stock, which was considered a key factor in recognizing energy-saving potential(Meijer et al., 2009).

The total end use in main-land Norway amounted to 222 TWh in 2009, an increase of 40% since 1976.There are four main sectors consuming energy on the Norwegian mainland, buildings, industrial processes, production of energy products and energy use for transportation with the distribution as can be seen in Figure 2.The energy use in buildings included lights, space heating and technical appliances for both residential and non-residential buildings, and amounted to 83TWh accounting for 37% of the mainland energy use. 46 TWh were consumed by residential buildings including holiday houses. While the energy use in the transport sector is increasing statistics show that the energy use for so called stationary purposes such as energy use in buildings and industrial processes seems to be flattening since the end of the nineties. For the building sector this can, according to NVE, the Norwegian Water Resources and Energy Directorate, be explained by milder climate, increased energy prices, heat pumps and energy efficiency measures. (NVE, 2011)

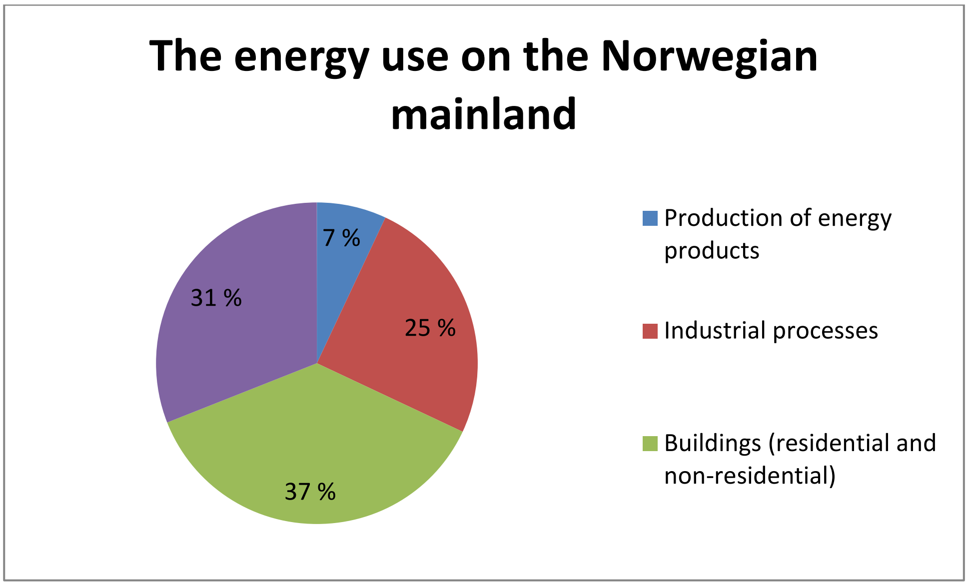


Figure 2: The energy use for the Norwegian mainland in 2009.

The newly retired Norwegian government led by Jens Stoltenberg had a long-term goal of all new buildings being sustainable and having a low impact on the environment over their lifetime. In 2012 they published a goal of 15 TWh reductions in the Norwegian building sector by 2020 by implementations of the measures already set in place(Regjeringen, 2012). The new government has hardly been in place more than three months and as can be expected has not introduced new goals for the building sector.

2.2 Energy use in buildings – determinants and mechanisms

As stated by Bartlett in a report for SSB (Norwegian Statistics) the energy use in the residential sector depends on both physical and behavioral determinants. The physical determinants are described as the size and characteristics of the dwelling stock as well as the state of the energy-using equipment. The characteristics of the dwelling stock that will influence the energy use are such as the composition, i.e. the percentage of single- and multi-family dwellings, the vintage as well as the buildings thermal state. When it comes to the energy using equipment the characteristics that affect the energy use include the types of fuel used for both space- and water heating as well as the respective efficiency of the equipment themselves. The behavioral determinants are such as the household’s selection and utilization of the physical determinants. Both the physical and the behavioral determinants are shaped by socio-demographic characteristics of households, their income, prices, climate and institutional setting(Bartlett, 1993).

Hille et al. examined the direct and indirect drivers for energy use in dwellings and found similar results as Bartlett. The direct drivers where such as floor area, the allocation of the dwellings and the floor area according to age, the technical condition of the thermal envelope, the indoor temperature, the energy use for domestic hot water as well as the electricity demand for lighting and technical equipment, and at last the space heating system. The uncertainties associated with these drivers were also discussed in detail. Statistics are available for the entire post-war period when it comes to new dwellings entering the stock, even if there are some problems with the accuracy. The demolition rates, however, are not yet known. The technical state of the thermal envelope was also difficult to estimate correctly. Even if some regulations have been in place since 1949 these cannot be relied on completely. On one hand faulty design may have left the envelope in a poorer state than suggested by the regulations. On the other hand the regulations themselves were so poor that many went beyond the regulations when it came to insulation of the buildings. There was found to be very limited knowledge when it comes to the indoor temperature. Hille et al. stated that most likely the indoor temperature has increased due to better insulation as well as the introduction of Heat Pumps. According to SSB 25% of those that installed a heat pump increased the indoor temperature and 33% heated additional rooms after the installation. The energy demand for hot water was not found to be well documented by Hille et al. who only had one empirical data source for their choice of 26 kWh/m^2. When it comes to the indirect drivers Hille et al. found six important ones. The changes in outdoor conditions i.e. outdoor temperature, demographic changes such as the number of households and the composition of these, economic conditions, technological improvements, the level of knowledge and peoples attitude as well as political incentives(Hille et al., 2011).

Three main mechanisms can be used to describe changes in the energy use, efficiency, substitution and reduction. By increasing the efficiency of the energy system technological measures are implemented while the function is kept intact. As an example switching from electrical panels to Heat Pump will still provide heat with the same energy carrier, electricity, but more efficiently. Substitution means finding another energy carrier to meet the same need, as substituting the oil burner with electric panels. Reduction means reducing the energy need, such as lowering the indoor temperature (Hille et al., 2011). In addition to these mechanisms a fourth is needed to describe the energy use correctly. The rebound effect describes how not all energy saving measures gives the expected energy reduction. Hille et al describe three such effects, changes in the end use, changes in the energy chain and economical changes. Changing the type of energy use in the dwelling may indirectly affect other forms of energy use. As an example, installing a heat pump will reduce the energy needed for space heating, but also introduces the possibility of cooling during summer. Changes that affect the energy chain are such that changing the energy carrier within the household may affect the energy use in other parts of the energy chain. Economic changes describes how money saved on energy measures within the household can be used on other more energy consuming activities, such as when a family gets more money to spend on holiday trips by air planes(Hille et al., 2011).

2.3 Energy assessment models

2.3.1 Material Flow Analysis

A Material Flow Analysis (MFA) is described as a systematic assessment of the flows and stocks of materials within a system defined in space and time. “It connects the sources, the pathways, and the intermediate and final sinks of a material.”(Brunner and Rechberger, 2003). The law of the conservation of mass ensures that the results of a MFA can be controlled by a material balance comparing all inputs, stocks, and outputs of a process. It delivers a complete and consistent set of information about all flows and stocks of a particular material within the defined system(Brunner and Rechberger, 2003).

2.4 The EPISCOPE and TABULA Projects

The IEE Project TABULA (Intelligent Energy Europe project, Typology Approach for Building Stock Energy Assessment), evaluated the building typologies being used in European countries and based on these developed a common concept. The result of this effort was the creation of national residential building typologies in 13 European countries. The project partners consisted of Germany, Greece, Slovenia, Italy, Ireland, Belgium, Poland, Austria, Czech Republic, Denmark, France, Bulgaria and Sweden. In addition there were two associated partners, Spain and Serbia(TABULA, 2012a). There are large differences in the dwelling stock, both across nations and within each country, when it comes to building characteristics. The TABULA project aimed at laying a basis for models of the building stock by handling this variety and providing a public data source on the building sector. This was achieved by dividing the dwelling stock in different categories and classifying the national building stocks with information on typical building characteristics, both with regard to the thermal quality of the building envelope and the energy systems in use.

“In the past few decades different experiences with building typologies have been made in European countries. The idea of the IEE project TABULA was to examine them and to come to a concerted approach for the field of residential buildings. A focus was placed on the energy consumption for space heating and hot water heaters. The overall objective was to enable an understanding of the structure and of the modernization process of the building sector in different countries and – in the long run – to learn from each other about successful energy saving strategies.” (page 7 (Loga et al., 2012))

The building stock for each country was classified in a typology matrix, where the columns represent four building size classes, single-family houses, terraced houses, multi-family houses and apartment blocks. The rows divide the stock further by defining the construction year classes. The start and end year of each construction class are individually defined for each country. Each of the single cells of the national matrix forms the generic building types. In addition, to each of the generic building types an exemplary building was assigned and represented with both a photo and the data of the thermal envelope. This building is supposed to be a typical representative of the building type, with features which can be commonly found for the respective age and size class. The envelope area and the heat transfer coefficients are not necessarily representative in a statistical sense. Heat supply systems for both space heating and domestic hot water were also defined for each generic building type with focus on both the energy carrier, generator type and energy efficiency level(Loga et al., 2012). In addition to defining the generic building types of each country the focus was placed on refurbishment measures. Therefore three technical stages of the thermal envelope were considered for each building type. First the Existing State, describing the typical state of each building type when no refurbishment has been applied. Then two types of measurements were identified, Standard Measurements, described as "(standard refurbishment): Package of measures for upgrading the thermal envelope and the heat supply system which are commonly realized during refurbishment; typically reflecting the national requirements in case of renovations." The second refurbishment measurement was Advanced Measures, described as "(ambitious refurbishment): Package of measures for upgrading the thermal envelope and the heat supply system which are usually realized in very ambitious renovations or research projects; typically reflecting the level of passive house components."(Loga et al., 2012)

For each country a brochure was made, containing the different elements of a residential building typology, summarized in the list below:

- The classification of the national building stock / display of the building type matrix.
- Frequencies of the building types.
- Typical energy consumption values of exemplary buildings.
- Definition and description of refurbishment measures and the energy saving potential.
- "Building Display Sheets": A double page showing the existing state of the building and the possible energy savings by distinct measures.

A TABULA calculation method was developed and since a comparable energy balance calculation for each exemplary building, in each country was needed, the respective datasets on construction elements, envelope areas and different supply systems were collected in a common database for all countries. As national regulations differ across countries some data transformation had to be done whenever the national regulations differed from the concerted data structure. Thereby two versions of each example building, in each country had to be made, one with data according to the national definitions and one according to the common definitions. The TABULA calculation method will be further elaborated in Chapter 3. Further results from the TABULA project have been a MS Excel workbook "TABULA.xls", containing the example building datasets of all countries, and a building typology webtool. This is an online application intended to "enable an intuitive easy access to the TABULA concept and its possible benefits". (Loga et al., 2012)

The EPISCOPE project (Energy Performance Indicator Tracking Schemes for the Continuous Optimization of Refurbishment Processes in European Housing Stocks) is a continuation of the TABULA work and is an ongoing project lasting from April 2013 to March 2016. The strategic objective has been described as “to make the energy refurbishment processes in the European housing sector more transparent and effective.” The conceptual framework is based on the national residential typologies developed during the TABULA project and the main activity is “to track the energy refurbishment progress of housing stock entireties of different scales.” In addition “the implementation rate of different refurbishment measures will be determined and compared with those activities which are necessary to attain the relevant climate protection targets”. It is also “intended to track the actual measured consumption after refurbishment as far as possible to verify the targeted savings”. The project will complement TABULA with typology schemes from 6 additional countries, and national interpretations of new buildings and Nearly Zero Energy Buildings shall be included. The EPISCOPE pilot actions are done on three levels, National building stock, Regional building stock and Municipalities or housing companies. There are 7 countries contributing to the National building stock level, Austria, England, Germany, Greece, Netherlands, Slovenia and Norway. On the Regional building stock level two countries are in the pilot project, Italy and Spain. At the last level five countries are contributing, Hungary, Ireland, Denmark, Belgium, Czech Republic, Cyprus and France. In Norway the Norwegian University of Science and Technology, NTNU, is involved with the project. (EPISCOPE, 2013)

During the TABULA project the Danish building stock was divided into three main dwelling types, single-family houses, terraced houses and apartment blocks, this due to the fact that these where the dominant building types in the EPC (Energy Performance Certification) database. In addition buildings denoted as trade and service (including offices) was defined as well, because this is a widespread building type and it was seen as crucial to define typologies for it. The dwelling stock was further divided in 9 construction periods, depending on construction techniques and the thermal level of the building envelope. Both space heating and domestic hot water heating were mainly based on non-condensing boilers at varying performance levels and district heating. (Wittchen and Kragh, 2012)

Sweden divided the dwelling stock in two main building categories, single-family houses and multi-family houses, five construction periods and three climate zones. The heating system is based on direct electricity for the older dwellings and central heating based on boilers using either electricity or oil for the newer ones, as well as some district heating(TABULA, 2012b). Table 1 show some results from the Swedish TABULA participation, the net energy needed for space heating for a single-family dwelling in climate zone 3 (South of Sweden). The delivered energy is defined as bought energy minus electricity for lights and electrical appliances. The rehabilitations were only related to the thermal envelope, the heating system has not been taken into account for these numbers, but for the first two age-cohorts the original building used direct electricity for heating, and for the last age cohort oil-burner was used. The Net Energy demand and the U-values for the Swedish project are shown in Table 1 and Table 2. (TABULA, 2012b)

Table 1: Net delivered Energy need for space heating for Swedish Single-Family dwellings

Energy need for thermal envelope at different stages – Swedish Single-Family dwellings				
Age cohort	Heated Floor area [m²]	Original building envelope [kWh/(m²·year)]	Rehabilitated envelope [kWh/(m²·year)]	Rehabilitated to Low Energy building [kWh/(m²·year)]
Before 1960	125	214	139	104
	160	204	132	99
1961 – 1975	125	187	131	87
	160	182	125.5	95.5
1976 - 1985	125	137	106	84.5
	160	134	103	81

Table 2: U-values for Swedish SFH given for three age cohorts

U-values for the thermal envelopes for Swedish Single – Family dwellings				
Age cohort	Envelope Element	Original [W/(m²·K)]	Rehabilitated [W/(m²·K)]	Rehabilitated to Low Energy building [W/(m²·K)]
Before 1960	External Wall	0.6	0.33	0.26
	Roof	0.29	0.11	0.06
	Floor	0.28	0.21	0.21
	Window	2.34	0.9	0.76
	Door	3.0	1.2	0.9
1961 – 1975	External Wall	0.31	0.22	0.19
	Roof	0.21	0.1	0.05
	Floor	0.32	0.24	0.23
	Window	2.3	0.9	0.76
	Door	2.8	1.2	0.9
1976 - 1985	External Wall	0.21	0.16	0.15
	Roof	0.15	0.08	0.05
	Floor	0.27	0.21	0.20
	Window	2.01	0.9	0.76
	Door	2.8	1.2	0.9

2.5 Laws and regulations on energy use in Europe and Norway

2.5.1 Europe

The EU adopted a directive on energy efficiency on the 25 of October 2012, the Directive 2012/27/EU. “This directive establishes a common framework of measures for the promotion of energy efficiency within the Union in order to ensure the achievement of the Union’s 2020 20% headline target on energy efficiency and pave the way for further energy efficiency improvements beyond that date.”(European Commission, 2013c) The directive gives rules to remove barriers in the energy market as well as overcome market failures that impede efficiency in the supply and use of energy. In addition it provides an establishment of indicative national efficiency targets for 2020(European Commission, 2013c). The Energy Performance of Buildings Directive (EPBD) was implemented in the EU in 2002 as Directive 2002/91/EC (European Parliament, 2002). The Directive was adopted in 2010 after experiences and a detailed impact assessment and is now termed Directive 2010/31/EC (European Parliament, 2010). This is the main legislative instrument to reduce the energy consumption of buildings in the EU. Under this directive the Member States must “establish and apply minimum energy performance requirements for new and existing buildings, ensure certification of building energy performance and require regular inspection of boilers and air conditioning systems in buildings.” The Directive also requires the Member States to ensure that all new buildings are so-called ‘nearly zero-energy buildings’ by 2020.
(European Commission, 2013a)

2.5.2 Norwegian building codes, standards and energy labeling

The first national building code for Norway came into act in 1965, until then the building code had only applied to cities and some parts of the country side(Regjeringen, 2003). This building code from 1924 “Lov om bygningsvesenet” had no requirements for U-values of the building elements, but § 104 does insist that the walls should be of such a quality that it provides sufficient protection against the cold climate (DSB, 1924). In 1928 a regulation was added to the building code, with requirements on materials and constructions, with requirements on the dimensions on brick stones, as well as the thickness of wood panels, and some requirements of the amount of cardboard needed for insulation, as described by §2 and §37 (DSB, 1928). In the regulations of 1949 requirements on the U-values of walls, roofs and floors were introduced(DSB, 1949). When the national building code of 1965 came into action many of the technical requirements from the 1924 building code were transferred to the building regulations. These regulations were also changed with more focus on the function of the building elements than the minimum requirements of these(Regjeringen, 2003). The building code of 1965 was supplemented with the building regulations of 1969(DSB, 1969). In 1985 the Planning and building act came in to force, a new legislation focusing on a systematic approach for planning on both the national and the municipality level, to implement the planning of area- and natural resource usage with the sectors other activities(Regjeringen, 1985). With this legislation new building regulations were also implemented, the regulations of 1985, being revised in 1985 and 1987(DSB, 1987). The first Technical Regulation, called TEK 97, was implemented as a regulation of the 1987 act, in 1997(Lovdata, 1997).

The energy requirements in the Norwegian building regulations where revised in 2007 following the implementation of the EPBD in Norway, and was further revised in 2010 when the EPBD was fully implemented (DIBK and NVE, 2012), with the current technical regulation, TEK 10, authorized in the plan and building act of 27 July 2008(Lovdata, 2010). The Norwegian Parliament has agreed that all new buildings should be at passive house level by 2015 and the definition of the coming minimum is currently under development(DIBK 2012).

Technical Regulation, TEK 10

Chapter 14 of TEK 10 is dedicated to energy and energy measurements. §14-1 states that all buildings shall be designed and constructed in such a way that low energy requirement and environmentally energy supply is promoted. There are two ways of achieve the energy efficiency requirements of TEK 10 as stated by §14-2. The building can either achieve the required levels of §14-3, defined as the Energy Measure method, or have a total net energy need, including the energy need for electrical appliances and lightning, lower than those given in §14-4, the Energy Framework method. Either way the building must achieve some minimum requirements as stated in § 14-5. Buildings with an area less than 30 m^2 are exempted from these rules except §14-5 first section. §14-3 gives requirements on building parts as U-values on walls, floors, window etc., as well as the infiltration and ventilation heat losses and temperature efficiency of the ventilation system. §14-3 (2) however states that for dwellings the energy measures concerning U-values and infiltration and ventilation heat losses can be deviated from as long as the heat loss number doesn’t increase. §14-3 also requires a yearly average temperature efficiency of ventilation heat recovery for dwellings at 70%, while §14-7 require all buildings with a heated BRA less than or equal to 500 m^2 to be performed such that at least 40% of the net space heating demand can be covered by other energy carriers than direct electricity or fossil fuel. The requirements of TEK 10 are summarized in Appendix A (TEK10, 2010).

Norwegian Standard NS 3031

The Norwegian Standard NS 3031 describes how to calculate the energy performance of buildings. It has been revised twice, the last time in 2011. This revision was done to complement the European standards on energy performance of buildings, by using the rules of these normative references, but basing the calculations on national values. The standard defines how to calculate total net annual energy demand for a building, including energy needed for space heating, space cooling, domestic hot tap water (DHW), fans, pumps and lighting. The standard also provides standard values for energy need for lights and technical requirements in table A.1. The values have been developed to be used for control calculation against official requirements and thus do not necessarily reflect the real world conditions. The annual energy demand for lighting and technical equipment has been found as the mean power requirement during the time of utilization multiplied with the utilization time. As described in Appendix 1 the net energy need for space heating includes heat recovered from the ventilation air, but does not include heat gains from the domestic hot water system. It should be mentioned that the standard distinguishes between net energy need for space heating and total net energy need, the latter including energy needed for electrical appliances lighting and so on. All the relevant requirements of NS 3031 are summarized in Appendix A. (Norsk Standard, 2011)

Norwegian Standard NS 3700

The Norwegian standard NS 3700 describes the requirements for Passive Houses and two types of Low Energy buildings. It applies both for new buildings and the renovation of buildings to passive house standard. Passive houses are known as environmentally friendly buildings with a good indoor climate and extremely low energy need. This standard defines such passive houses and takes into consideration the Norwegian climate, construction methods and traditions. The standard sets requirements for maximal heat loss, net energy needed for space heating, type of energy supply and constructional elements, as well as annual ventilation heat recovery efficiency. It should be noted that this standard has a requirement on the net energy need for space heating, and this does not include energy needed for electrical appliances and lighting. The standard also set a requirement on the amount of energy delivered that can come from direct electricity or fossil fuel. As stated in the standards chapter 4.4 the total energy delivered from direct electricity or fossil fuels shall be less than the total net energy demand minus 50 % of the net energy need for DHW. NS 3700 is based on NS 3031. The requirements of NS 3700 has been summarized in Appendix A and are all for the category Passive House. In addition to the requirements the building envelope must fulfill the minimum requirements stated in TEK 10. A building that meets the minimum requirements does not necessarily manage the requirements on heat loss and net energy need. Therefore the standard also gives some typical u-values used for Passive Houses, also summarized in Appendix A. (Norsk Standard, 2013)

The Energy Labeling system

As of 1 January 2010 all dwellings and commercial buildings, that are sold or rented out, are obliged to have an energy certificate with an energy label defining the energy related condition of the building (Energimerking, 2013b). The energy calculation is based on NS 3031 and the assessment basis is calculated gross delivered energy, meaning the energy needed to cover the buildings total energy demand, including all system related losses

(Lovdata, 2009). The energy label includes both an energy grade and a heating grade. The energy grade ranges from A to G, A being the best, and is solely based on the gross energy delivered to the building. The energy grade scale has been organized such that grade C corresponds to a building managing the minimum requirements given in TEK 10 and does not use heat pump or solar energy for heating. The heating grade is divided in five colored categories, from green to red, green being the best(Energimerking, 2013a). The Energy labeling system is further elaborated in Appendix A.

Differences in the standards

The standards all have requirements related to the energy demand for the building. However there are some differences here. NS 3031 gives standard calculations for both net energy demand for space heating alone, net energy demand for the building including all energy needed to cover everything beyond space heating, i.e. lights, technical equipment, domestic hot water etc. and finally total delivered energy. The latter is the total net energy demand for the building adjusted for losses in the system, i.e. the system efficiency such as heat loss due to heat generation. TEK 10 has a requirement concerning the total net energy demand, thus including the energy needed for technical appliances, lights etc. The Passive House standard, NS 3700, on the other hand has a requirement related to the net energy demand for space heating only. The Energy Labeling system sets the requirement on gross delivered energy demand, the total energy delivered to the building.

2.6 The Dwelling Stock

2.6.1 The European Dwelling Stock

Meijer et al. found that the pre-war dwelling stock amounted to 20 – 39 % of the total dwelling stock in the countries studied, with one exception. In Finland this dwelling age cohort only accounted for 10%. Dwellings built after the Second World War and before the oil crisis in the seventies were found to account for almost 33% on average. Dwellings built before the Second World War were generally found to be more homogenous in terms of national construction characteristics than those from the second period. A common characteristic was that the buildings were found to generally be poorly insulated at the time of construction, and showed relatively high need for renovation. Dwellings built between 1970 and 1990 account for approximately one-quarter of the total stock, with some exceptions. Both France and the Netherlands had more than 35% allocated to this period, while Finland had as much as 43%. The dwellings built after the oil crisis and the introduction of mandatory thermal regulations were found to be reasonably well insulated, although they already needed some basic renovation. The average share of newly built dwellings from after 1990 was 14% of the total stock, varying from 8% to 22% in the countries studied(Meijer et al., 2009).

District heating was found to be used mainly in multi-family dwellings and had a very large share in Finland and Sweden, while electric heating was used widely in Finland and France with shares up to 30%. The share of households using electricity for domestic hot water varied for the countries studied. Austria, France and Switzerland had a share of 40%, Finland between 39 – 40% and Sweden and Germany between 10 – 20 %. Apart from in Finland and the Netherlands, with 18% and 10%, respectively, mechanical supply and exhaust ventilation was not found to be widely used. Natural ventilation sometimes combined with grilles and kitchen and bathroom fans were far more common(Meijer et al., 2009).

2.6.2 The Norwegian Dwelling Stock

The total area of the Norwegian building stock (BTA) has been estimated to approximately 385 million m^2, with 256 million m^2 in residential buildings and 129 million m^2 in non-residential buildings(Lavenergiprogrammet, 2012). A report by Mjønes et al. divided the Norwegian dwelling stock in three dwelling types, single-family houses, apartment blocks, and divided small houses. Further the stock was divided in the age cohorts, before 1956, 1956 – 1970, 1971 – 1980, 1981 – 1990, 1991 – 2000, and 2001 – 2010. This report was carried out for Enova and all future references to the report will be to the “Enova report” or “Enova”. They found that of the dwelling stock in 2010 as much as 80% of the total dwelling area was built before 1990. 26% of the dwelling area was built before 1956, the cohort with the largest amount of dwelling area built. There was not much focus on energy conserving measures in this period and combined with 58% of the cohorts dwelling type being single-family houses, the dwelling type consuming most energy, thus as stated by the authors, there might be a large energy saving potential in this segment. Single-family houses were defined by Enova to be a collective term for both the normal single-family house, located in every town, as well as farm houses. It is a detached house normally having two floors, and the main construction material is timber. This dwelling type accounted for 65% of the overall dwelling area in 2011. Apartment blocks were defined as detached blocks of apartments, having only one floor per dwelling and therefore the dwellings are relatively small compared to single-family dwellings. A typical apartment block was defined as having an average of 18 apartments over 4 floors, and accounted for 16% of the overall dwelling area of 2011. According to Enova divided small houses typically include two dwellings and have two floors. This building type includes both vertically and horizontally divided houses. The main construction material for the entire stock is timber and represented approximately 19% of the overall dwelling area (BRA) in 2011(Mjønes et al., 2012).

Table 3: The distribution of SFH according to year of construction(Mjønes et al., 2012)

The distribution of Single – Family dwellings in 2010 based on year of construction					
	Total are lived in	% - of area lived in	No. of households	% - of households	Average BRA per household
SFH	169005646	100%	1080955	100%	156
> 1956	39804369	24%	272651	25%	146
1956 – 1970	31139401	18%	212898	20%	146
1971 – 1980	32201810	19%	212545	20%	152
1981 – 1990	35392847	21%	195910	18%	181
1991 – 2001	17162144	10%	107623	10%	159
2001 – 2010	13305075	8%	79367	7%	168

Thyholt et al. described the Norwegian dwelling stock by dividing it in three main groups, Single-family houses (SFH), divided small houses (DSH), including both vertically and horizontally divided houses, and apartment blocks (AB). In addition to five age-bands, buildings constructed before 1945, between 1946 and 1970, between 1971 and 1980, between 1981 and 1990, and finally the buildings constructed between 1991 and 2005. The age-bands of the dwelling stock was mainly divided as such, based on common thermal insulation levels, typically used in the given period. The total number of dwellings in Norway was approximately 2.2 million in 2005 and could be categorized as 57% belonging to the group termed Single-family houses, 21 % were in the group divided small houses, including both vertically and horizontally divided small houses in addition to row houses and smaller terraced houses. The remaining 22 % belonged to the group called apartments, which also included detached blocks of flats and combined buildings. The ownership of the building stock was found to be predominantly private homeowners, amounting to 76% if housing co-operatives were included(Thyholt et al., 2009).

Common features of Norwegian dwellings

The most common construction material for Norwegian buildings is timber. Generally timber has been used for almost all smaller buildings while concrete has been the most common material in apartment blocks as historical fire regulations restricted the use of timber in taller buildings. Even if this is starting to change it is still representative for the Norwegian dwelling stock(Mjønes et al., 2012). The construction practices of buildings have varied over the years as more and more focus has been given to better insulation. Mineral wool was not commercially available in Norway until the early 1950’s. During this decade lighter timber was introduced phasing out the much heavier timber constructions from before. This shift happened mainly because of rationing of timber, the increasing need for new dwellings and the requirements on U-values from the Housing Bank. This bank financed 62% of all new dwellings from 1952 – 1960 and their requirements on U-values, area etc. had to be followed to get the funding(Mjønes et al., 2012).

When it comes to ventilation systems Myhre found that only a very few Norwegian dwellings have balanced mechanical ventilation with heat recovery of the exhaust air(Myhre, 2000).

The indoor temperature in a single-family house is assumed to be lower than for an apartment due to the fact that apartment blocks often have central heating, which often leads to a higher indoor temperature. In addition in larger buildings the ratio of volume and building envelope is smaller than for smaller buildings. The heat conduction through the walls will therefore be lower for larger buildings. A single-family dwelling is smaller than an apartment block and will have a relatively larger heat conduction through the walls and thereby a lower indoor temperature(Mjønes et al., 2012).

Dynamics of the Norwegian dwelling stock

According to Bartlett et al (1993) the share of detached single-family dwellings increased from 25% to 50% of the dwelling stock from 1960 to 1990. The same report stated that because of the rapid expansion of the dwelling stock 76 % of the dwellings were less than 45 years old, and 38 % less than 20 years old in 1990. The rate at which new dwellings have entered the dwelling stock was found to have declined since the early 1970's(Bartlett, 1993). This agrees with data found by Sandberg et al in 2011. They found that the Useful floor are (UFA) was small and the construction activity low during the first half of the 20th century and after the Second World War the construction activity increased due to an increase in the demand for floor area(Sandberg et al., 2011). Bartlett et al found that the composition of new dwellings had also changed. From 1986 to 1991, the share of new single-family dwellings entering the dwelling stock each year declined from 63 to 33%, while at the same time, the shares of semi-attached and attached single-family and multi-family dwellings increased from 25 to 41 % and from 7 to 19 %, respectively(Bartlett, 1993).

Renovations and upgrading of the Norwegian dwelling stock

Enova made some estimation for the renovations of the Norwegian dwellings stock. 52 % of the total dwelling area was found to have undergone energy renovation to varying extent. Just below 50% of all residential buildings have been energy renovated. As may be expected the oldest buildings are the ones where most energy rehabilitation has been done. Most of the energy related rehabilitations have been done in the recent decades. Enova explains this with an increased standard of living with higher incomes, the buildings condition, government requirements as well as increased knowledge. In addition they found that window replacements dominated the energy related rehabilitations. The report states that for single-family dwellings 74% of those built before 1956 had upgraded windows. This amount was at 64% and 35% for those built during 1956-1970 and 1971-1980, respectively. It's mentioned that the reason for this is that windows is subjected to the most visible wear and tear in addition to being the easiest replacements technically. The average age of windows when they were changed was 30 years. Enova also defined measures to rehabilitate dwellings to TEK 10 standards. This was defined based on the Energy Framework requirement as defined by TEK

10 as well as the level of difficulty of rehabilitating the dwellings. Enova pointed out that isolating the floor in dwellings with direct on ground castings will be very difficult as the building had to be “lifted” of the ground before applying the isolation. The model used in the Enova report was been evaluated against the Energy Framework requirements and was found to be satisfactory(Mjønes et al., 2012). Table 4 and Figure 3 describes the energy renovations of the Norwegian dwelling stock as found by Enova.

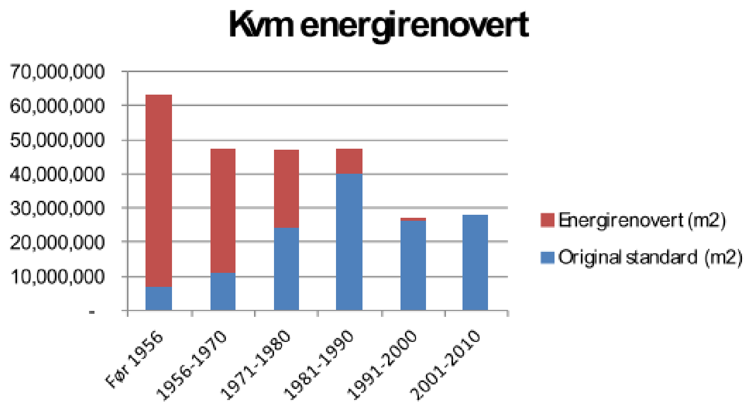


Figure 3: Amount of square meter dwelling area renovated (Kvm = m^2, “Energirenovert” translates to Energy rehabilitated)

Table 4: Amount of renovations on Single-Family dwellings

Single – Family dwellings amount of renovations					
	Original building	Rehabilitated	Windows changed	Extra insulation wall	Extra insulation roof/floor
> 1956	9%	91%	74%	64%	55%
1956 – 1970	24%	76%	64%	32%	44%
1971 – 1980	61%	39%	35%	6%	20%
1981 – 1990	83%	17%	12%	3%	14%
1991 - 2000	95%	5%	4%	3%	2%
2001 - 2010	100%	0%	0%	0%	0%

2.7 Energy use in the dwelling stock

2.7.1 The European dwelling stock

At the European level energy use in the residential sector accounts for 23% of total energy use. The existing housing stock in eight European countries was analyzed in a paper by Meijer et al. in 2009, with the aim of identifying the main needs and trends towards better energy performance in the residential stock in Europe(Meijer et al., 2009). Statistical surveys by the IEA in 2004 show that the residential stock is responsible for 30% of the total final energy consumption in the countries that were studied. There were large differences between the countries, however, the highest share was found in Germany, while the lowest was in Finland(Meijer et al., 2009). Meijer et al. pointed out that “the sustainability of the building stock is strongly related to the energy performance of the stock itself, but also to the sustainability of energy sources”. They also found that despite the increase in the use of renewable energy sources the energy supply still relies largely on fossil fuels, although the energy carriers used in different countries varied. The use of combustible renewables and waste sources are high with 20% in Austria, France and Finland, while District heating, with the waste heat of electricity production as heat source, was used to a large extent in Finland, Sweden and Germany. Electricity had a high share in all countries. Space heating accounted for approximately 60% and domestic hot water for 25% of the energy use in the residential sector in the EU countries(Meijer et al., 2009). Bøeng et al. found that a correlation for all the Nordic countries except Norway was the use of district heating to cover the space heating demand. While this accounted for 20 – 30 % of the energy use in other Nordic countries, in 2003, it only accounted for approximately 1% in Norway. This difference was attributed to the low electricity prices in Norway as well as high investment cost for district heating(Bøeng, 2005).

In a study by Mata et al. the Swedish residential sector was found to account for 21% of the national final energy use, slightly less than the average for the EU-27. This was attributed to the superior building envelopes used in the northern European countries because of colder climates, and more efficient energy supply systems. This study showed that the annual specific net energy demand of an average Single – Family dwelling was 156 kWh/m² for space heating, 16 kWh/m² for hot water and 30 kWh/m² for lighting and appliances for the base-line year 2005. This base-line year represented the current state of the Swedish residential stock in 2005. The total annual energy demand of the sector could be reduced by 53% if all energy saving measures suggested by this study were applied aggregated. The measures that would provide the greatest savings were found to involve heat recovery and reduction of indoor temperature. (Mata et al., 2013)

2.7.2 The Norwegian dwelling stock

A study provided by Vestlandsforsking found the knowledge of the Norwegian energy use in dwellings to be generally poorer than in the neighboring countries, Sweden and Denmark(Hille et al., 2011). This can to some extent be explained by the difference in energy prices in Norway compared to these countries. As Norway generally has had very low electricity prices the consumers have had no incentive to focus on energy use and energy saving measures. This consequentially may have made it less interesting to find information on the energy use and the factors affecting the energy use in households (Hille et al., 2011). The study also allocated the energy use in dwellings to different purposes within the household, as electricity for lightning, space heating or domestic hot water. For all building types, single-family houses, divided small houses and apartment blocks, the energy use for space heating and domestic hot water was found to be the two largest categories. Space heating was the single most influential category for the first two house types, with 70% and 60% of the total energy use for single-family and divided small houses, respectively(Hille et al., 2011). Norway relies heavily on electricity to cover the energy demand, also for space heating. Sartori et al. found electricity to cover about 80% of the energy demand in buildings (Sartori et al., 2009).

Sandberg et al. studied the energy use in the Norwegian dwelling stock and found that the aggregated Norwegian dwelling stock consumed a total of direct and indirect energy increasing from 23 to 45 TWh during 1960 to 2004. This increase happened despite a 39% decrease occurring in the energy consumption per square meter in the use phase, and was found to be due to an increasing stock. The same study showed that the total energy consumption in the dwelling stock was heavily dominated by the use phase, while the upstream and downstream processes were found to have little impact. The long lifetime of buildings in Norway along with the cold climate and high comfort indoor temperature were described as the reasons for this(Sandberg et al., 2011).

Enova estimated the energy use in the dwelling stock and found the annual total energy use in Norway to be 45.2 TWh in 2010. They compared this to SSB and found it to be an overestimation of 3.5% when holiday houses had been subtracted. They found the net energy demand for buildings as described by Table 5. This seems to be the net energy demand in the building stock as it was estimated to be in 2010, and therefore a weighted average between the energy demand in the original thermal envelope and the historically updated one(Mjønes et al., 2012).

Table 5 Net energy demand in Norwegian single-family dwellings(Mjønes et al., 2012)

Age cohort	**Total net energy [kWh/m^2]**	**Net energy need for space heating [kWh/m^2]**	**Net energy need for lighting [kWh/m^2]**	**Net energy need for electrical appliances [kWh/m^2]**	**Net energy need for fans [kWh/m^2]**	**Net energy need for DHW [kWh/m^2]**
> 1956	256.6	197.8	11.4	17.5	-	30.0
1956-1970	180.4	121.5	11.4	17.5	-	30.0
1971-1980	146.6	87.8	11.4	17.5	-	30.0
1981-1990	140.3	80.7	11.4	17.5	0.7	30.0
1991-2000	130.5	70.9	11.4	17.5	0.7	30.0
2001-2010	125.8	62.0	11.4	17.5	0.7	30.0

If the standard dwellings were rehabilitated from their current technical level to TEK 10 standard Enova estimated the energy efficiency potential as 13.4 TWh or 30%. As a mean value each household could save 6300 kWh/year with this rehabilitation. Single – Family dwellings from before 1956 could save as much as 20.548 kWh/year by rehabilitating from so called historically upgraded envelope to TEK 10 standard. The same values were 8.381 and 3.584 for buildings built during 1956 – 1970 and 1971 – 1980, respectively. The energy demand for the Single-Family dwelling stock as well as the energy saving potential when upgrading to TEK 10 level are displayed in Table 6(Mjønes et al., 2012).

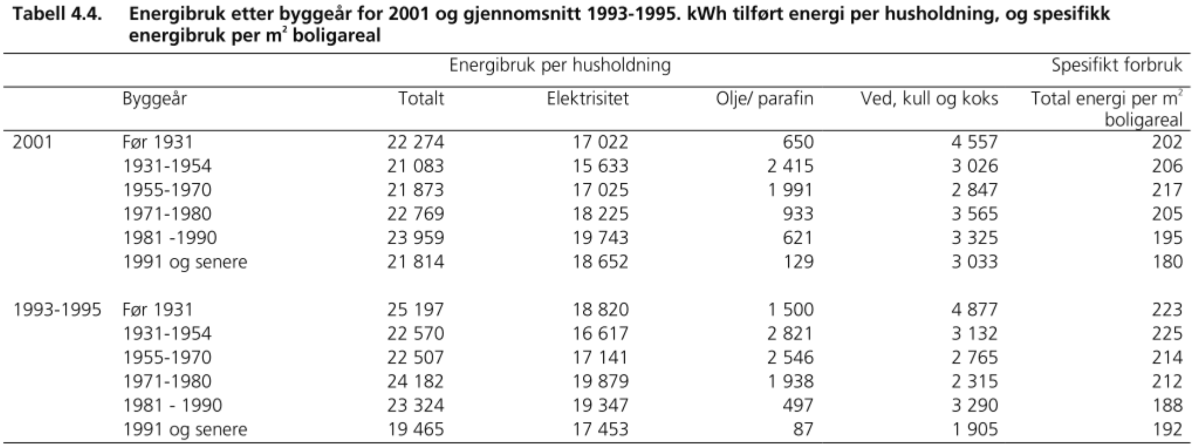
Table 6: Total delivered energy for SFH and Energy Saving Potential in the dwelling stock according to Enova.

The total delivered energy demand for the Single-Family dwelling stock			
	Standard dwellings delivered energy [TWh/year]	TEK 10 upgraded buildings delivered energy [TWh/year]	Energy Saving potential [TWh/year]
Before 1956	10.5	4.9	5.6
1956 – 1970	5.6	3.9	1.78
1971 - 1980	4.8	4.0	0.76

The energy savings from each of the rehabilitation measures applied in the TEK 10 rehabilitation, such as insulating the roof or changing the windows, were compared to installing a Heat Pump. In this evaluation the Heat Pump was found to give the largest reduction in the energy demand.(Mjønes et al., 2012). This result is not very surprising considering that with the right heat pump system the Heat pump can reduce the energy demand for heating with as much as 75%(Stene, 1997).

Bøeng et al. found the specific average energy use in dwellings, in 2001, to be 214kWh/(m^2·year) and 174 kWh/(m^2·year) for single-family dwellings and apartments respectively. In Table 7 the energy use as found by Bøeng et al. has been summarized. The calculations were based on data from SSB and the energy use has not been divided into categories depending on levels of rehabilitation. The average specific energy use during 1993 – 1995 was generally higher than for 2001, especially for older dwellings. As remarked by the authors the 2001 survey did reveal that 85% of the dwellings had undergone some rehabilitation measures, although this was not asked for in the 1993 to 1995 surveys. Higher specific energy use from earlier years may indicate that a larger share of dwellings had been subjected to rehabilitation(Bøeng, 2005). (“Byggeår” translates to Construction year, “Total energy per m² boligareal” to total energy per m² living area)

Table 7: Energy use according to construction year 2001 and the average for 1993 - 1995, given as kWh delivered energy per dwelling and specific energy use per floor area.



Tabell 4.4. Energibruk etter byggeår for 2001 og gjennomsnitt 1993-1995. kWh tilført energi per husholdning, og spesifikk energibruk per m² boligareal

		Energibruk per husholdning				Spesifikt forbruk
	Byggeår	Totalt	Elektrisitet	Olje/ parafin	Ved, kull og koks	Total energi per m² boligareal
2001	Før 1931	22 274	17 022	650	4 557	202
	1931-1954	21 083	15 633	2 415	3 026	206
	1955-1970	21 873	17 025	1 991	2 847	217
	1971-1980	22 769	18 225	933	3 565	205
	1981 -1990	23 959	19 743	621	3 325	195
	1991 og senere	21 814	18 652	129	3 033	180
1993-1995	Før 1931	25 197	18 820	1 500	4 877	223
	1931-1954	22 570	16 617	2 821	3 132	225
	1955-1970	22 507	17 141	2 546	2 765	214
	1971-1980	24 182	19 879	1 938	2 315	212
	1981 - 1990	23 324	19 347	497	3 290	188
	1991 og senere	19 465	17 453	87	1 905	192

Energy carriers and systems for space heating

The energy survey from 1983 classified different buildings age cohorts and energy carriers used for space heating (Ljones, 1983). For Single-Family dwellings built before 1955, 47% used solid fuels in burners, such as a woodstove, 28% used electricity and 19% used liquid fuels in a burner, as their main source of space heating. In addition 7% used central heating (Ljones, 1983). Numbers from Statistics Norway made in 2001 also suggest the same trend. 42% of buildings from before 1920 had two systems for space heating, electricity and woodstove. For dwellings built during 1920-1940 slightly less had the same space heating systems, only 36%, but these were still the most common space heating systems. For dwellings from 1921-1940 the percentage was the same as for those from before 1920. The statistics doesn’t differentiate between Single-Family or apartment dwellings but still give a suggestion of the type of space heating system used in Single-Family dwellings(SSB, 2001). During 1956 – 1970 the share of solid fuels decreased form 47 % to 30 %, while both the share of liquid fuel and direct electricity increased, from 19 % to 21 % and from 28 % to 39 %, respectively. In addition central heating had a small increase from 7 % to 10%(Ljones, 1983). The share of liquid fuels dropped from 21 % to 15 % during the next decade, 1971-1980. This can to a large extent be explained by the oil crisis of 1973 and the consequential increase in oil prices. The share of solid fuels stayed constant at 30 % while the share of electricity increased further to 47 %. The share of central heating decreased to 8%. This agrees well with information from an interview with Associate Professor Rolf Ulseth and Per Olaf Tjelflaat. According to them the most common energy carrier was wood or coke and electricity in dwellings before the 1950’s. During the 1950 – 1970 oil and electricity were at the same price range and thereby competitors, but after the oil crisis in the early 1970s electricity was dominating(Ulseth and Tjelflaat, 2013).

Bøeng et al. studied the energy use in dwellings and found it to have changed over the decades. In 1930 the electricity consumption in Norwegian dwellings was only ca. 2000 kWh/year on average. This however was probably a small share of the dwellings total energy consumption as most of the energy use was based on solid fuels, as wood and coal. In the 1960s the electricity use had increased to approximately 7000 kWh/year on average and from the mid-eighties the electricity consumption has been ca. 18000 kWh/year. The total average energy consumption per dwelling has increased less than the electricity use per dwelling, indicating that the electricity share has increased. The electricity share increased from approximately 35% in 1960 to more than 70% from the mid-eighties. Until 1960 solid fuels were the most important source for space heating. The use of oil and kerosene increased from the start of the sixties until the oil crack in 1973-1974 where it started to decrease. The use of solid fuels slightly decreased from 1960 to 1973 but started to increase after 1973. As stated by the authors this was most likely due to increasing oil prices. The study also presented the energy use for different dwelling types, and found that approximately 77% of the energy use in single-family dwellings was covered by electricity, and that the second most used energy carrier for these buildings was solid fuels as wood or coal. The numbers were for the total dwelling stock as a whole and not for a standard dwelling, but still indicates to which extent electricity is used to cover the energy need for space heating in Norway(Bøeng, 2005).

That the main energy carrier in Norwegian dwellings is electricity seems to be of literary consensus. As stated by Novakovic et al. “While the development in most countries moved from stoves to central heating (…) Norway has, especially after the Second World War moved towards having direct electric heating appliances in each room.” The stoves have not been abandoned, however, as stated by the authors, the most common Norwegian solution for space heating in dwellings is the combination of direct electric heating and wood stoves. The stoves are typically used only on cold days to cover peak load. (Novakovic et al., 2007)

3 Methodology and assumptions

The conceptual framework of the EPISCOPE project will be based on the building typologies developed during the TABULA project(Loga & Villatoro 2013). The energy calculations carried out in this thesis are therefore based on the methodology used in the TABULA project. This chapter provides an overview of the TABULA calculation methods as well as the model for energy calculation of residential buildings developed for this project, along with all assumptions for the modelling.

3.1 The TABULA Method

The method developed in the TABULA project consists of

- A harmonized data structure which is the foundation of a building data base;
- A standard reference calculation procedure for determining the heat need and the delivered energy demand;
- A scheme for assessing the calculated energy wares in terms of primary energy, carbon dioxide emissions and heating costs;
- A scheme for adapting the calculated energy use to the level of energy consumption which is typical for the respective building types and energy performance levels of the different countries;

(Loga & Villatoro 2013)

The method focuses on the energy use for space heating and domestic hot water of residential buildings, while cooling, air conditioning, lighting and electrical appliances have been left out. As TABULA aims to show the relevant parameters determining the energy consumption of a building in a realistic way yet at the same time keeping the method as simple as possible, averages are used when applicable.

The energy needed for space heating is calculated by applying the seasonal method according to EN ISO 13790 on the basis of a one-zone model. The external boundary conditions are defined for each country for a standard base temperature. In the case of significant climatic differences between regions of a country as for Norway, several climate datasets are supposed to be provided. For the utilization conditions as room temperature, air exchange rate etc. standard values are used. The envelope area is calculated based on the buildings external dimensions as established in the Intelligent Energy Europe project DATAMINE(Loga and Diefenbach, 2013). According to EN 15316, level B the energy performance of the supply system is calculated by use of tabled values for the different subsystems(Loga and Diefenbach, 2013). All the parameters used in the TABULA method are summarized in Appendix B.

3.2 Model for calculation of the energy balance of buildings

This section provides an overview of the model used for this project along with all its assumptions.

3.2.1 Energy Balance Model

An Energy Balance model has been developed based on the equations and information given in the TABULA method(Loga and Diefenbach, 2013). It is based on the methodological framework of MFA, using a well defined system boundary, prosesses and flows. However the flows are based on energy per floor area and are all given as kWh/m^2, and not the flow of a material as defiend by the MFA methodology(Brunner and Rechberger, 2003). The energy balance is displayed in Figure 4.

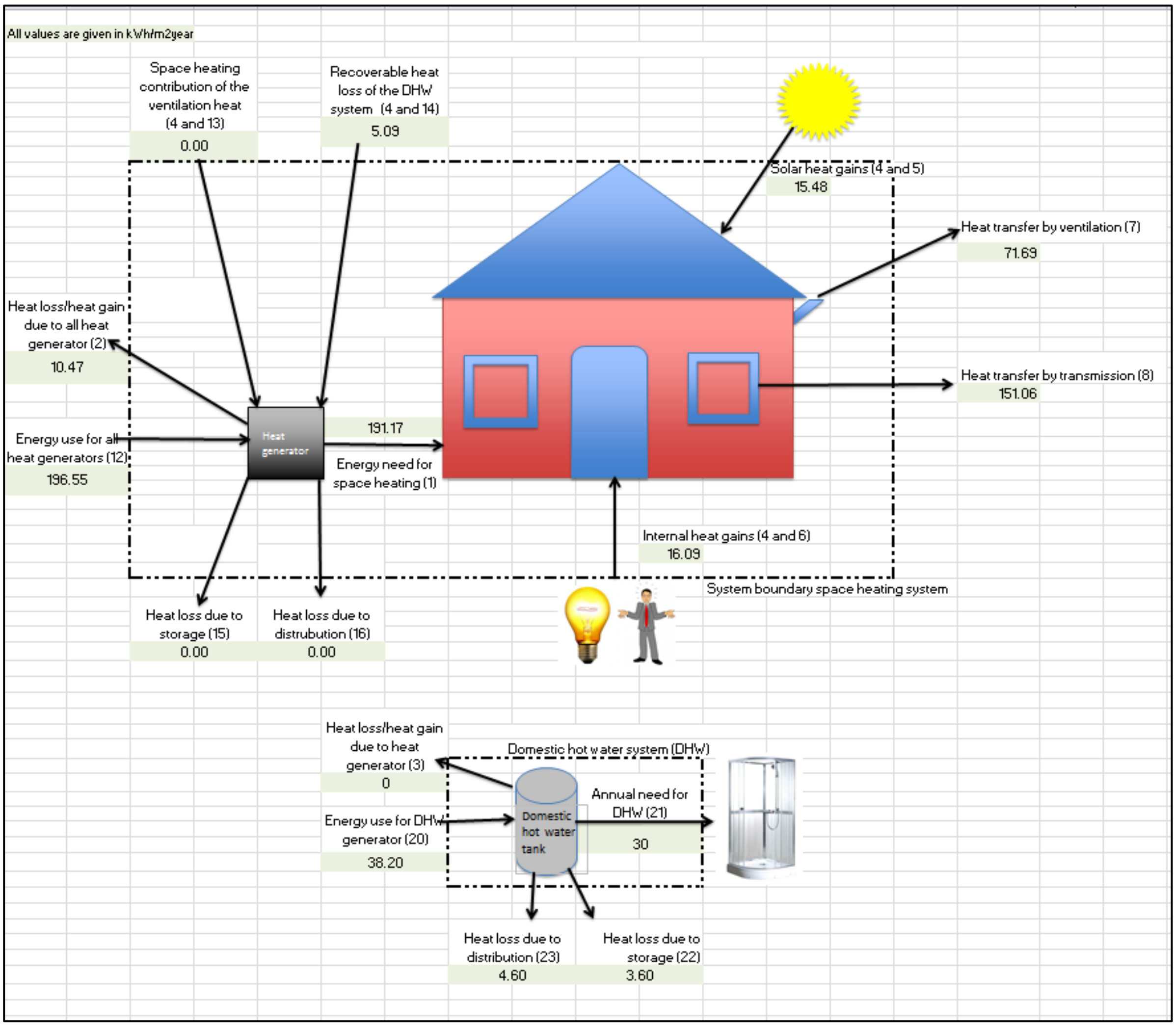


Figure 4: The energy balance model.

As can be seen from Figure 4 two energy balances are carried out, one for the domestic hot water (DHW) system, and one for the building with all heat generation and losses, respectively. These are linked as some of the heat loss from the DHW is recovered as an input to the building. All flows with the corresponding equations are given in Appendix C in addition to all the parameters that had to be based on literary research along with their respective sources. In addition the full energy balance model has been provided electronically attached to Appendix D. The model only takes into account the energy use for space heating and domestic hot water. Electricity needed for lighting and appliances are not included, only the indirect heat gains from these. In addition no behavioral determinants are taken into account, but the vintage as well as the thermal state of the building envelope are accounted for.

Assumptions for the model

The Norwegian dwelling stock is divided in three main dwelling types as well as six age cohorts, depending on the year the dwelling was ready for use. The input data for the model has to a large extent been based on a study performed by Enova, aiming at revealing the potential and the barriers of energy savings in the Norwegian dwelling stock(Mjønes et al., 2012). All further references to the Enova report or the results from Enova refer to this report. The dwelling types and age cohorts have been chosen in accordance with this study and are as follows:

Dwelling types

- Single – Family dwellings
- Divided small houses, including terraced houses and multi-family houses divided vertically or horizontally
- Apartment blocks

Age cohorts for:

- Dwellings built before 1956
- Dwellings built during 1956-1970
- Dwellings built during 1971-1980
- Dwellings built during 1981-1990
- Dwellings built during 1991-2000
- Dwellings built during 2000-2010

(Mjønes et al., 2012)

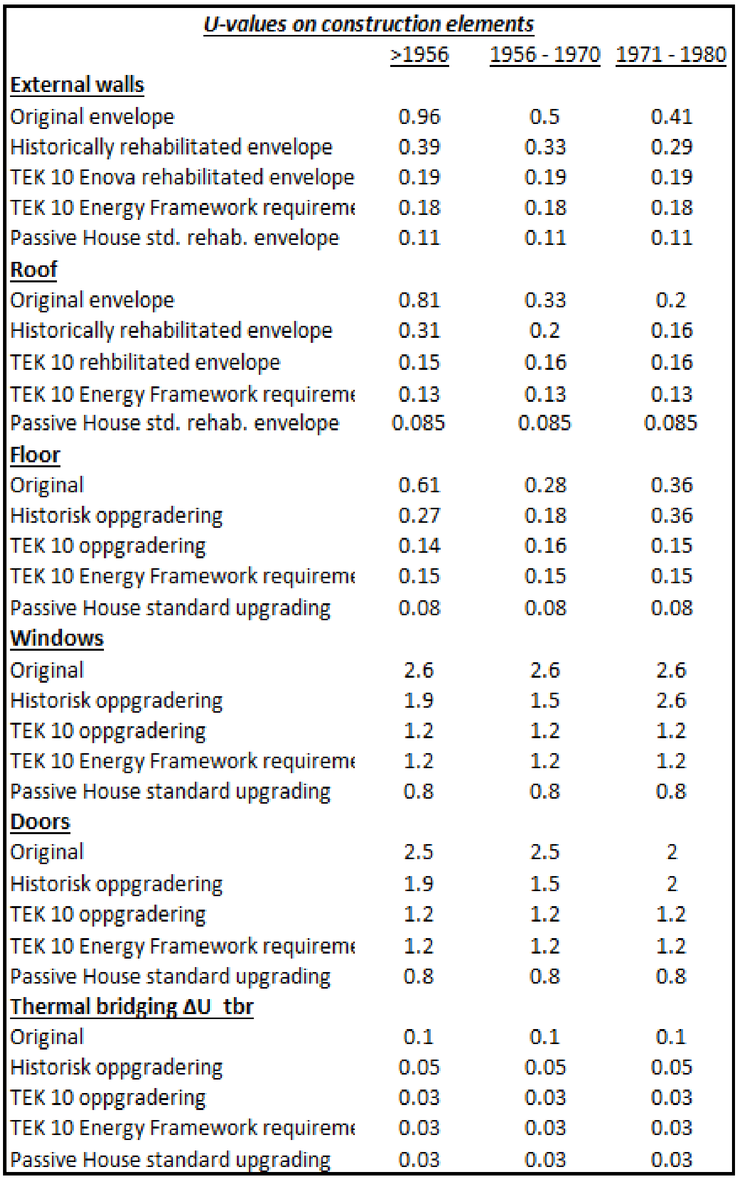
This specific classification of the Norwegian dwelling stock is based on the different age cohorts' respective building traditions as well as the technical characteristics for buildings within these time periods. The dwellings has been classified as such based on their differences considering size, design and living patterns(Mjønes et al., 2012).

This master project focuses on one building type and three age cohorts, as there are other master projects handling the rest of the dwelling stock. The building type in focus is single-family dwellings, and the age cohorts are the three first ones, “before 1956”, “1956-1970” and “1971-1980”.

<u>Standard building types</u>

The study performed by Enova defined the standard dwellings in Norway beyond just the type and age cohort. Each building standard has been defined with parameters such as area, U-values, temperatures and air change rates. The dwellings have been defined for three states, the original building as it was when the first family could move in, a historical upgrading of the buildings envelope and an upgrade to TEK 10 level. The historical upgrading has been defined based on both a survey, conversations with building assessors and construction workers, and data sheets from Sintef Byggforsk, and are defined as renovations done either on the entire building or only some parts of it (Mjønes et al., 2012). The upgrading to TEK 10 standard was defined as future energy measures that would give the building the requirements of TEK 10 and are described to replace the historical upgrading(Mjønes et al., 2012). Therefore it is assumed for this project that the TEK 10 improvements are not in addition to the historical measures, but an upgrading done relative to the original building envelope. The current project work defines four technical stages for the building envelope in each age cohort, the original as it was built, the historically upgraded and TEK 10 upgraded as defined by Enova, and a rehabilitation to Passive House standard. The current Norwegian dwelling stock is defined as a weighted average between the original thermal envelopes and the historically rehabilitated one, based on information given in Table 4. TEK 10 rehabilitation is defined as a standard rehabilitation as it will take the buildings envelope to the standard corresponding to new buildings today, while the Passive House standard rehabilitation is seen as an extensive rehabilitation measure. This is in accordance with the TABULA methodology described in 2.4. The values used for the thermal envelope of each thermal state is summarized in Table 8 and further elaborated in chapter 3.2.2. There are some differences in the U-values for TEK 10 rehabilitation as defined by Enova and the Energy Framework requirements of TEK 10, as seen in Table 8. In order to evaluate the implications of these differences the energy balance for both TEK 10 rehabilitations is calculated.

Table 8: The U-values of construction elements



U-values on construction elements	>1956	1956 - 1970	1971 - 1980
External walls			
Original envelope	0.96	0.5	0.41
Historically rehabilitated envelope	0.39	0.33	0.29
TEK 10 Enova rehabilitated envelope	0.19	0.19	0.19
TEK 10 Energy Framework requireme	0.18	0.18	0.18
Passive House std. rehab. envelope	0.11	0.11	0.11
Roof			
Original envelope	0.81	0.33	0.2
Historically rehabilitated envelope	0.31	0.2	0.16
TEK 10 rehbilitated envelope	0.15	0.16	0.16
TEK 10 Energy Framework requireme	0.13	0.13	0.13
Passive House std. rehab. envelope	0.085	0.085	0.085
Floor			
Original	0.61	0.28	0.36
Historisk oppgradering	0.27	0.18	0.36
TEK 10 oppgradering	0.14	0.16	0.15
TEK 10 Energy Framework requireme	0.15	0.15	0.15
Passive House standard upgrading	0.08	0.08	0.08
Windows			
Original	2.6	2.6	2.6
Historisk oppgradering	1.9	1.5	2.6
TEK 10 oppgradering	1.2	1.2	1.2
TEK 10 Energy Framework requireme	1.2	1.2	1.2
Passive House standard upgrading	0.8	0.8	0.8
Doors			
Original	2.5	2.5	2
Historisk oppgradering	1.9	1.5	2
TEK 10 oppgradering	1.2	1.2	1.2
TEK 10 Energy Framework requireme	1.2	1.2	1.2
Passive House standard upgrading	0.8	0.8	0.8
Thermal bridging ΔU_tbr			
Original	0.1	0.1	0.1
Historisk oppgradering	0.05	0.05	0.05
TEK 10 oppgradering	0.03	0.03	0.03
TEK 10 Energy Framework requireme	0.03	0.03	0.03
Passive House standard upgrading	0.03	0.03	0.03

Floor Area and Roof Area

The floor are of a dwelling can be defined in three different ways according to the Norwegian standards. Gross area(BTA), useful area (BRA), and net area (NTA), where gross area is defined as the area inside of the thermal envelope, including the enclosing thermal envelope, useful area as only the area inside of the thermal envelope and net area as the area inside of the thermal envelope but subtracting all of the walls inside the dwelling(Norsk Standard, 2012). The most common definition of floor area used in Norway for energy calculations is useful area or the term BRA(Norsk Standard, 2012). This is also the area provided in the Enova report(Mjønes et al., 2012), and is therefore used in this project. The roof area is set equal to the floor area because the U-values used for the roof is calculated as effective U-values accounting for cold attics by Enova(Mjønes et al., 2012). Therefore the roof area is seen as the area of the ceiling and the slope of the roof is not taken into account when the roof area is calculated.

Windows and doors

The window area has been has been based on the Enova report and is 20% of BRA for buildings form before 1956 and 15% of BRA for buildings from the remaining age cohorts.

The original U-values for the windows are set to the values given by Enova(Mjønes et al., 2012). This can be debated as information given by Multiconsult indicates that older windows have much higher U-values(Bøhn Trond Ivar et al., 2006). However as most of the information for the model in this project has been based on the Enova report it is seen as most correctly to use their values also for the windows.

When it comes to the upgrading of windows in each rehabilitation package the assumptions are made considering the information from Enova summarized in chapter 2.6.2. It is assumed that dwellings from before 1956 will have historically upgraded windows from the 1980s, dwellings built during 1956-1970 will have windows from the 1990s and dwellings built during 1971-1980 will have windows from 2001. However, as only 35% of the dwellings from 1971-1980 have upgraded the windows it's assumed that a standard dwelling of this period still has its original windows. The U-values for the doors are assumed equal to those of the windows when no information was provided in the Enova report(Mjønes et al., 2012).

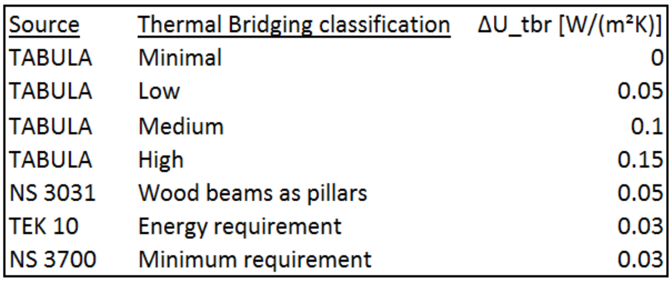
Indoor temperature

The indoor temperature used for each age cohort is an average of the temperature in the heated area and the unheated area for each building type(Mjønes et al., 2012).

Thermal Bridges

The TABULA project classified thermal bridges in four categories with corresponding ΔU_{tbr}, "High", "Medium", "Low" and "Minimal", referring to the effect of constructional thermal bridging(Loga and Diefenbach, 2013). As seen in Table 9 the Norwegian Standard recommends a thermal bridging value equal to the TABULA classification "Low" for buildings constructed of wood beams(Norsk Standard, 2011). Since this number is primarily for newer buildings the original standard dwelling from before 1956, as well as for the period 1956-1970 are assumed to have a thermal bridging surcharge ΔU_{tbr} equal to the class "Medium". Historically upgraded buildings are assumed to have the Norwegian Standard and the TEK 10 and Passive House upgraded buildings are assumed to have the minimum requirements of their respective standards as presented in the chapter 2.5.2. The values for the thermal bridges are summarized in Table 9.

Table 9: Thermal bridging surcharge



Source	Thermal Bridging classification	ΔU_tbr [W/(m²K)]
TABULA	Minimal	0
TABULA	Low	0.05
TABULA	Medium	0.1
TABULA	High	0.15
NS 3031	Wood beams as pillars	0.05
TEK 10	Energy requirement	0.03
NS 3700	Minimum requirement	0.03

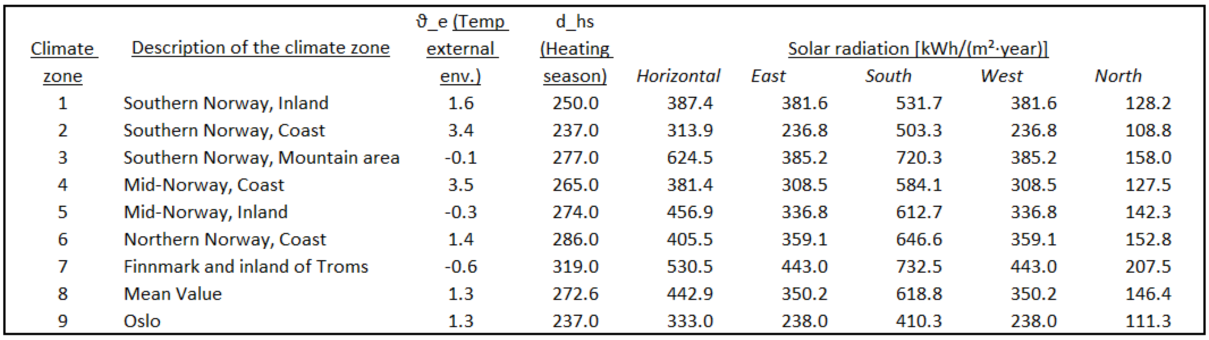
Air use and air infiltration

The air use for each building is based on the numbers given by Enova for each age cohort(Mjønes et al., 2012). The TABULA methodology provides numbers for air infiltration classified depending on the air tightness of the building envelope. There are four categories, “Minimal”, “Low”, “Medium” and “High”(Loga and Diefenbach, 2013). The original dwellings are all assumed to have the classification “High”, thus having a high effect of air infiltration. The air infiltration values in TABULA are all based on the indication blower door result n_{50}. This number indicates the amount of airflow through the building envelope at 50 Pa pressure difference (Byggforsk, 2012). The Norwegian standards and Technical regulations all gives minimal values for this leakage rate. For the original buildings the leakage rate is set equal to the worst category in TABULA, “High”, all historically upgraded buildings are assumed to have the category “Medium”, as it gives a leakage rate above the TEK 10 requirement. The TEK 10 requirement doesn’t fit perfectly with the TABULA values for air infiltration and is somewhere between the categories “Medium” and “Low”. However the requirement in TEK 10 is a minimum one, and therefore the TEK 10 upgraded houses are assumed to have the category “Low”. The Passive House requirement, however, fits the category “Minimal” perfectly. The value for air usage is not updated when the thermal envelope is improved, and the air infiltration is decreased. It can be argued that this should be done to ensure a good indoor air quality, however this is seen as beyond the scope of the current project.

Climate zones

To account for the fact that Norway is a long and narrow country stretching over 13 latitudes, and thereby does not have a homogenous climate, the country is divided in seven climatic zones as they are defined by Enova (Enova, 2004b). Two extra climate zones are used as well, one for Oslo climate and one describing the mean of the Norwegian climate. The values for the Oslo climate are calculated based on information in table M.1 and M.2 in NS 3031(Norsk Standard, 2011) and are calculated based on the length of the heating season, not the entire year. The respective solar radiation is calculated based on information from Olset and Skartveit and Enova for climate zone 1 - 7(Olseth and Skartveit, 1987, Enova, 2004a), and according to NS 3031 for the Oslo climate (Norsk Standard, 2011). The climate zones are summarized in Table 10.

Table 10: Norwegian climate zones

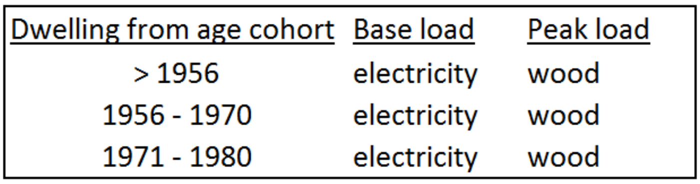


Climate zone	Description of the climate zone	ϑ_e (Temp external env.)	d_hs (Heating season)	Solar radiation [kWh/(m²·year)]				
				Horizontal	*East*	*South*	*West*	*North*
1	Southern Norway, Inland	1.6	250.0	387.4	381.6	531.7	381.6	128.2
2	Southern Norway, Coast	3.4	237.0	313.9	236.8	503.3	236.8	108.8
3	Southern Norway, Mountain area	-0.1	277.0	624.5	385.2	720.3	385.2	158.0
4	Mid-Norway, Coast	3.5	265.0	381.4	308.5	584.1	308.5	127.5
5	Mid-Norway, Inland	-0.3	274.0	456.9	336.8	612.7	336.8	142.3
6	Northern Norway, Coast	1.4	286.0	405.5	359.1	646.6	359.1	152.8
7	Finnmark and inland of Troms	-0.6	319.0	530.5	443.0	732.5	443.0	207.5
8	Mean Value	1.3	272.6	442.9	350.2	618.8	350.2	146.4
9	Oslo	1.3	237.0	333.0	238.0	410.3	238.0	111.3

Energy carriers for space heating and domestic hot water

For the original building, the original thermal envelope is assumed intact, the system for space heating is not assumed to have undergone any major changes but it is assumed that the space heating system is according to what is normal today. Meaning that the space heating system is assumed to be as close to the original as possible but that most likely no standard dwelling cover space heating only based on wood or coal, and no domestic hot water system is fueled by wood but by electricity. Therefore the assumption for old dwellings not having been rehabilitated is that they cover base load with electricity and peak load with wood or to some extent oil burners, while the entire domestic hot water need is covered by electricity. The assumptions for energy carriers for each age cohort are based on the information given in chapter 2.7.2, and summarized in Table 11. In the model the base load is assumed to cover 90% of the energy demand for space heating. This is based on information from Somamiljø indicating that a base load source covering 40% of the maximum load will cover about 90% of the net energy need(somamiljo, 2013). This assumption can vary for different climate zones, especially if a boiler or a Heat Pump is used to cover base load. The efficiency of direct electricity does not, however, vary with the external temperature. Since direct electricity can be used to cover the entire heat load, even if it is more common to use electricity combined with a peak load source, the assumption of base load coverage of 90% of the energy need is seen as well-founded and the parameter $\alpha_{nd,h,1}$ is set equal to 0.9.

Table 11: The chosen energy carriers



Dwelling from age cohort	Base load	Peak load
> 1956	electricity	wood
1956 - 1970	electricity	wood
1971 - 1980	electricity	wood

The TABULA method accounts for the possibility of heat storage in relation with the space heating as well as losses due to storage and distribution of heat. If district heating were used for space heating or Heat Pump for water heating, it could be possible to store hot water in a tank which would be used to even out the peak heat loads. However as none of the standard dwellings in this project are simulated with district heating, and instead are using either electricity or wood for space heating there will be no heat loss due to heat storage or due to heat distribution. Consequentially the parameters $q_{s,h}$ and $q_{d,h}$ are always set to 0.

As described in chapter 2.7.2 very few single-family dwellings use district heating. Therefore it is assumed that the standard dwellings use electricity for heating of tap water, and that each dwelling has its own tap water tank for storage and separate pipes for distribution. It has been quite difficult to obtain values for the parameters describing the energy need for DHW in Norwegian literature. Therefore some of the values had to be obtain from the values given by other countries in the TABULA model (TABULA, 2013). The values used are based on German values as they seemed to have the best values for the given system for storage and distribution of DHW. The values used are for the so called decentralized electric hot water storage and distribution. All values and assumptions, as well as the respective sources, are been summarized in Table 12.

Table 12 Parameters for DHW

Parameter			Assumptions	Source
Description	Symbol	Denomination		
Annual energy need for DHW	q_nd,w	[kWh/m^2·year]	The Norwegian standards	Appendix 1 (Norsk Standard, 2011)
Annual heat loss of the DHW storage	q_s,w	[kWh/m^2·year]	German value for decentralized hot water storage	(TABULA, 2013)
Annual heat loss of the DHW distribution	q_d,w	[kWh/m^2·year]	German value for decentralized hot water distribution	
Recoverable heat loss from the DHW storage	q_s,w,h	[kWh/m^2·year]	German value for decentralized hot water storage	
Recoverable heat loss from the DHW distribution	q_d,w,h	[kWh/m^2·year]	German value for decentralized hot water distribution	

These values will vary with the rehabilitation measures explained fully in chapter 3.2.2, as they have been given depending on the water system being implemented before or after 1994(TABULA, 2013). It can be argued that the water distribution probably is the same for all rehabilitation measures, as changing the water heater does not necessarily imply changing all the water distribution pipes in the building. However as these numbers are seen as uncertain it has been decided to update the whole system without regard to the difficulty of changing pipes. It may also be argued that most pipes installed before 1956 probably will have been changed at some point in the buildings history. As stated, these are very uncertain values. The choices done for these parameters are found in Table 13.

Table 13: Choices for DHW parameters

Description	Parameter [kWh/(m²·year)]	Original thermal envelope	Historical rehab.	TEK 10 rehab.	Passive House rehab.
Annual heat loss of the DHW storage	$q_{s,w}$	3.6	3.6	2.9	2.9
Annual heat loss of the DHW distribution	$q_{d,w}$	4.6	4.6	1.4	1.4
Recoverable heat loss from the DHW storage	$q_{s,w,h}$	2.4	2.4	1.9	1.9
Recoverable heat loss from the DHW distribution	$q_{d,w,h}$	3.0	3.0	0.8	0.8

3.2.2 Rehabilitation measures

The standard buildings are simulated for each age cohort with the original building envelope as well as three rehabilitation packages. The packages are related to the building envelope and are summarized in Table 14 to Table 18, as well as the DHW system as defined in Table 12 and Table 13. All references used for the building envelopes are summarized in Table 19. As there are some differences between the U-values given in the Enova TEK 10 rehabilitation and the Energy Framework requirements of TEK 10, two different TEK 10 rehabilitations are considered briefly.

Even if both TEK 10 and NS 3700 have requirements for ventilation heat recovery, the rehabilitation packages presented here does not take this into account. As described in chapter 2.6.2 very few Norwegian single-family dwellings have mechanical ventilation. However the energy balance is also calculated with mechanical ventilation and heat recovery, just to provide an overview of how this influences the energy demand.

The U-values and insulation measures applied to manage these U-values are taken directly from Enova for the original envelope, the historically rehabilitated envelope and the TEK 10 rehabilitated envelope as displayed in Table 14, Table 15 and Table 16Table 18. For the TEK 10 rehabilitation package meeting the Energy Measure requirements of TEK 10 in Table 17, and the Passive House rehabilitation package, Table 18, the insulation measures needed are calculated based on the wanted U-values according to Equation 1.

$$d_m = (R_n - R_o) \times \lambda_m \tag{1}$$

Where

$$R_n = \frac{1}{U_n} \tag{1.1}$$

$$R_o = \frac{1}{U_o} \tag{1.2}$$

R_n	The thermal resistance of the new thermal envelope element after rehabilitation is done
R_o	The thermal resistance of the original thermal envelope element
λ_m[1]	The thermal conductivity of the insulation applied (Byggforsk, 2003)
d_m	The insulation thickness needed to reach the wanted $R_{n.}$

It is not taken into account whether or not the calculated insulation thickness, d_m, is a standard thickness that can be bought or not. The thickness is only found as the one needed to achieve the wanted R_n. In real life cases the calculated d_m would only be a guidance of the lower limit of thickness needed, and one would apply insulation with the standard thickness closest to this value.

In addition it should be noted that both TEK 10 and NS 3700 require a large part of the buildings energy demand to be supplied by another energy carrier than direct electricity or fossil fuel. This can only be achieved by changing the direct electricity with another heating system such as a Heat pump. As this is a requirement of the standards the buildings are evaluated against it could be argued that this is a crucial point. Especially since changing to a heat pump was found to be of major importance by Enova(Mjønes et al., 2012). However, to limit the work load in this project work it was decided together with the supervisor not to have this as a main focus, thus calculations including Heat Pump are defined as beyond the scope of this project.

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[1] The thickness of insulation in Passive house rehabilitation measure has been found by applying the same type of insulation, with $\lambda = 0.40$ [W/(mK)] for all envelope elements

Table 14: Original building envelope

Original building envelope									
Envelope element	>1956			1956 – 1970			1971 – 1980		
	Description	U_{eff}-value [W/m^{2}K]	Ref.	Description	U_{eff}-value [W/m^{2}K]	Ref.	Description	U_{eff}-value [W/m^{2}K]	Ref.
Wall	Heavy timber frame, 100 mm beams , non-isolated	0.96	1)	Light timber frame, 48×98 mm beams, 100 mm mineral wool	0.5	1)	Light timber frame, 48×98 mm beams, 100 mm mineral wool	0.41	1)
Roof	150×200 mm rafters with sheeting clay	0.81	1)	48×198 mm rafters with 100 mm mineral wool	0.33	1)	48×198 mm rafters with 200 mm mineral wool	0.2	1)
Floor	150×200 mm joists with sheeting clay	0.61	1)	48×198 mm joists with 100 mm mineral wool	0.28	1)	100 mm reinforced concrete, 50 mm ground plate, 250 mm sole foundation of LECA concrete.	0.36[2]	1)
Windows	Double layer	2.6	1) and 2)	Double layer	2.6	1) and 2)	Double layer	2.6	1)
Doors	Wooden door with isolation	2.5	1) and 3)	Wooden door with isolation	2.5	1)	Thermally enhanced wooden door	2	1)

Table 15 Historical rehabilitation package

Historical upgrading of building envelope									
Envelope element	>1956			1956 – 1970			1971 – 1980		
	Description	U_{eff}-value [W/m^{2}K]	Ref.	Description	U_{eff}-value [W/m^{2}K]	Ref.	Description	U_{eff}-value [W/m^{2}K]	Ref.
Wall	Isolation with 100 mm (foam isolation blown onto wall)	0.39	1)	Lining with 50 mm extra mineral wool	0.33	1)	Lining with 50 mm extra mineral wool	0.29	1)
Roof	Sheeting clay replaced with 100 mm mineral wool	0.31	1)	100 mm extra mineral wool on cold attic	0.2	1)	50 mm extra mineral wool on cold attic	0.16	1)
Floor	Sheeting clay replaced with 100 mm mineral wool	0.27	1)	100 mm extra mineral wool	0.18	1)	Has typically not been upgraded. Same value as for the original building	0.36	1)
Windows	Double-layer isolated with air	1.9	3)	Three-layered. Energy glazing, argon gas.	1.5	3)	Assumed not upgraded. Same value as for original building	2.6	1)
Doors	Assumed same value as for window	1.9		Assumed same value as for window	1.5		Assumed not upgraded. Same value as for original building	2	1)

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[2] Dwellings from before 1956 and 1956-1970 typically had basements and therefore the U_{eff} takes this into account. For dwellings from 1971-1980 however basement was not typical and the u-value is not given as an effective U-value.

Table 16: TEK 10 rehabilitation package

TEK 10 upgrading of building envelope as given by Enova (Mjønes et al., 2012)									
Envelope element	>1956			1956 – 1970			1971 – 1980		
	Description	U_{eff}-value [W/m^{2}K]	Ref.	Description	U_{eff}-value [W/m^{2}K]	Ref.	Description	U_{eff}-value [W/m^{2}K]	Ref.
Wall	100 mm + 150 mm mineral wool	0.19	1)	Lining with 150 mm extra mineral wool	0.19	1)	Lining with 150 mm extra mineral wool	0.19	1)
Roof	Sheeting clay replaced with 100 mm mineral wool + 150 mm min wool on cold attic	0.15	1)	150 mm extra mineral wool on cold attic	0.16	1)	50 mm extra mineral wool on cold attic	0.16	1)
Floor	Sheeting clay replaced with 100 mm mineral wool + lining with additional 100 mm mineral wool	0.14	1)	Lining with 150 mm additional mineral wool	0.16	1)	155 mm of extra insulation calculated with a $\lambda = 0.04$ [W/(mK)]	0.15	5)
Windows	Energy requirement	1.2	4)	Energy requirement	1.2	4)	Energy requirement	1.2	4)
Doors	Energy requirement	1.2	4)	Energy requirement	1.2	4)	Energy requirement	1.2	4)

Table 17 Rehabilitation to TEK 10 Energy Framework requirements

TEK 10 upgrading of building envelope as given by the Energy Measure requirements in Appendix 1									
Envelope element	>1956			1956 – 1970			1971 – 1980		
	Description	U_{eff}-value [W/m^{2}K]	Ref.	Description	U_{eff}-value [W/m^{2}K]	Ref.	Description	U_{eff}-value [W/m^{2}K]	Ref.
Wall	Isolation with 181 mm extra mineral wool	0.18	1)	Isolation with 142 mm extra mineral wool	0.18	1)	Isolation with 125 mm extra mineral wool	0.18	1)
Roof	Isolation with 258 mm extra mineral wool	0.13	1)	Isolation with 186 mm extra mineral wool	0.13	1)	Isolation with 108 mm extra mineral wool	0.13	1)
Floor	Isolation with 201 mm extra mineral wool	0.15	1)	Isolation with 124 mm extra mineral wool	0.15	1)	Isolation with 156 mm extra mineral wool	0.15	5)
Windows	Energy requirement	1.2	4)	Energy requirement	1.2	4)	Energy requirement	1.2	4)
Doors	Energy requirement	1.2	4)	Energy requirement	1.2	4)	Energy requirement	1.2	4)

Table 18: Passive House rehabilitation package

Passive House standard upgrading of thermal envelope									
Envelope element	>1956			1956 – 1970			1971 – 1980		
	Description	U_{eff}-value [W/m^{2}K]	Ref.	Description	U_{eff}-value [W/m^{2}K]	Ref.	Description	U_{eff}-value [W/m^{2}K]	Ref.
Wall	Extra 322 mm insulation, mineral wool	0.11	7)	Extra 284 mm insulation, mineral wool	0.11	7)	Extra 266 mm insulation, mineral wool	0.11	7)
Roof	Extra 421 mm insulation, mineral wool	0.085	7)	Extra 349 mm insulation, mineral wool	0.085	7)	Extra 271 mm insulation, mineral wool	0.085	7)
Floor	Extra 434 mm insulation, mineral wool	0.08	7)	Extra 357 mm insulation, mineral wool	0.08	7)	Extra 389 mm insulation, mineral wool	0.08	7)
Windows	Three layered isolation window	0.8	6) and 8)	Three layered isolation window	0.8	6) and 8)	Three layered isolation window	0.8	6) and 8)
Doors	Required door	0.8	6)	Required door	0.8	6)	Required door	0.8	6)

The U-values used for the Passive House rehabilitation package are based on the typical U-values for Passive Houses given in Appendix A. Using these U-values doesn’t guarantee that the total delivered energy demand for the building will fulfill the Passive House rehabilitation, but is seen as an extensive rehabilitation none the less.

Table 19: References for the rehabilitation packages

Reference number	Description
1)	(Mjønes et al., 2012)
2)	(Bøhn Trond Ivar et al., 2006)
1) and 2) combined	U-value from (Mjønes et al., 2012), description from (Bøhn Trond Ivar et al., 2006)
3)	(TABULA, 2013)
1) and 3)	U-value from (Mjønes et al., 2012), description from (TABULA, 2013)
4)	(Lovdata, 2010)
5)	Appendix 4
6)	(Norsk Standard, 2013)
7)	Appendix 4, calc. based on (Norsk Standard, 2013) according to (Byggforsk, 2003)
8)	Typical U-values for windows(Enova, 2013)

Along with upgrading the windows U-value the parameter $g_{gl,n}$, the solar energy transmittance for radiation perpendicular to the glazing will change. The upgraded values for this parameter is found based on the U-values and information from the TABULA project provided by Brattebø (TABULA, 2013).

3.3 Summary of calculations for the project

3.3.1 Gross and net energy need for space heating

As can be seen from Figure 4 the gross energy need for space heating (delivered energy) is determined as an energy balance depending on six flows. As the heat loss due to storage and distribution, flow 15 and 16, are always zero, as explained in chapter 3.2.1, and the space heating contribution of the ventilation heat will be zero as long as no heat recovery is applied, in reality the delivered energy is dependent on three flows. These flows are as follows; the net energy need for space heating, the heat loss from the heat generators, both increasing the delivered energy need, and the recoverable heat from the DHW-losses, which decreases the delivered energy need.

For each age cohort the delivered and net energy need for space heating is calculated for all four stages of the thermal envelope, original, historically rehabilitation, TEK 10 rehabilitation, and Passive House rehabilitation. The net energy need for space heating is also calculated with the Energy Measure requirements of TEK 10 for each age cohort to examine the difference between the Enova TEK 10 rehabilitation and the Energy Measure requirements on U-values.

Comparison to the Enova results

As most of the values used for determining the delivered and net energy demand for buildings are based on the Enova report it is interesting to compare the results to the estimated net energy demand presented by Enova as displayed in Table 5. As described in chapter 2.7.2 the report seems to present the net energy need for a weighted average of original dwellings and historical updated ones. It must be emphasized that this is an assumption by the author based on information at page 48 in this report stating that “The standard dwellings have a constructional condition being the average of the original building construction and the historically updated construction”. In order to compare the Enova values for specific net energy demand for space heating with the results from the current project, a weighted average between the net energy demand when considering the original and the historically rehabilitated thermal envelope is found based on the information given in Table 4.

Comparison to the standards and the Energy Labeling System

The maximum total net energy demand for the buildings is calculated according to TEK 10 as described in Appendix A and compared to the total energy demand for the building, including energy for electric appliances and lights, also calculated based on information given in Appendix A.

The maximum net energy demand allowed for space heating in a Passive House is determined for each standard building based on information in Appendix A and compared to the results from the current project to see if the building will achieve Passive House standard when the Passive House rehabilitation package is applied.

As described in chapter 3.2.2 neither the rehabilitation package for TEK 10 nor for Passive House standard includes heat recovery of ventilation. To examine the implications of this simplification, the energy need for space heating is calculated with ventilation heat recovery, and the same comparisons with the standards are done. As seen by Figure 4 the heat recovery from ventilation air will not influence the energy need for space heating, Flow 1 directly. Thus the net energy need for space heating when heat recovery is applied, is calculated based on the flows in Figure 4 according to equation 2, and this value is evaluated against the standards.

$$Q_{H,h,rec} = Q_{H.nd} - \eta_{h,gn} Q_{ve,h,rec} \qquad (2)$$

$Q_{H,h,rec}$	The net energy need for space heating when heat recovery is applied
$Q_{H.nd}$	The energy need for space heating, Flow 1 in Figure 4.
$\eta_{h,gn} Q_{ve,h,rec}$	Heat recovered from the ventilation, the Flow “Space heating contribution of the ventilation heat” in Figure 4.

Total delivered energy

As most literature sources gives information about the total energy delivered to the building the delivered energy calculated in the current project is increased to account for energy needed for lighting, technical appliances and DHW. This is for simplicity done as described in chapter 2.5.2 and Appendix A using standard values from NS 3031.

3.3.2 Flows influencing the net energy need for space heating

In accordance with Figure 4 the different flows influencing the net energy need for space heating is further examined in order to give some insights into which flows are the most important for the net energy demand for space heating.

3.3.3 Parameters and flows influencing the heat transfer by transmission

The flows and parameters influencing the heat transfer by transmission is further examined in order to give some insights in which rehabilitation measures that induce the most significant energy reduction.

3.3.4 Differences across climate zones

In order to account for the differences in climate across the Norwegian continent the thermal envelopes are examined in each climate zone and the result compared to the Oslo climate and the arithmetic average climate.

3.3.5 The energy saving potential in the Norwegian dwelling stock

Based on the specific net energy demand and the information given in Table 3 the total net energy demand for this part of the dwelling stock is examined. The energy demand for the current stock is found as the weighted average between the energy demand for original and historically rehabilitated buildings based on the information given in Table 4. This value is compared to the energy demand when applying TEK 10 and Passive House rehabilitation packages in order to evaluate the energy saving potential of the Norwegian dwelling stock. The energy saving potential is also compared to the energy saving potential calculated by Enova as given in Table 6.

4 Results and discussion

All references made to the “Enova report” or simply “Enova” are in reference to the report by (Mjønes et al., 2012).

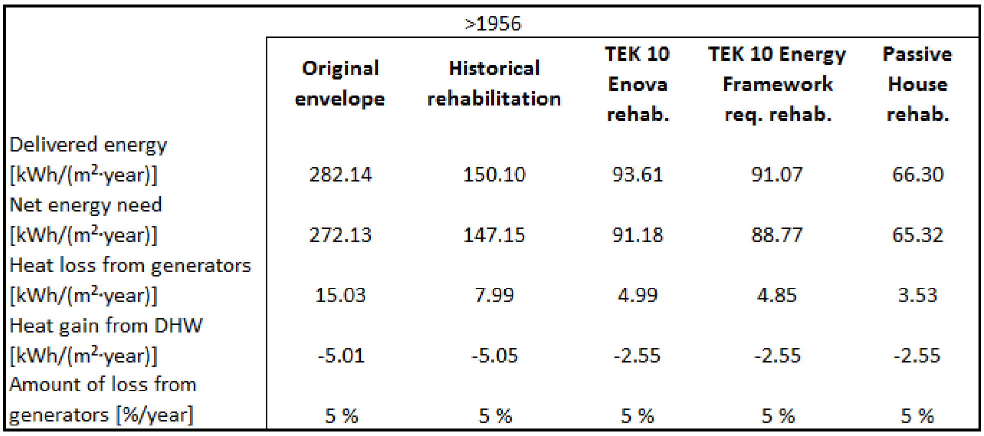
4.1 Gross and net energy need for space heating

4.1.1 Results

In the next sections the energy need for the buildings in each age cohort and with all rehabilitation packages are presented. Gross and delivered energy need is the same flow, $Q_{del,h}$, and net energy need is $Q_{H,nd}$. All energy flows are given as the annual specific energy.

Buildings from before 1956

Table 20: Delivered and net energy need as well as losses



	>1956				
	Original envelope	**Historical rehabilitation**	**TEK 10 Enova rehab.**	**TEK 10 Energy Framework req. rehab.**	**Passive House rehab.**
Delivered energy [kWh/(m²·year)]	282.14	150.10	93.61	91.07	66.30
Net energy need [kWh/(m²·year)]	272.13	147.15	91.18	88.77	65.32
Heat loss from generators [kWh/(m²·year)]	15.03	7.99	4.99	4.85	3.53
Heat gain from DHW [kWh/(m²·year)]	-5.01	-5.05	-2.55	-2.55	-2.55
Amount of loss from generators [%/year]	5 %	5 %	5 %	5 %	5 %

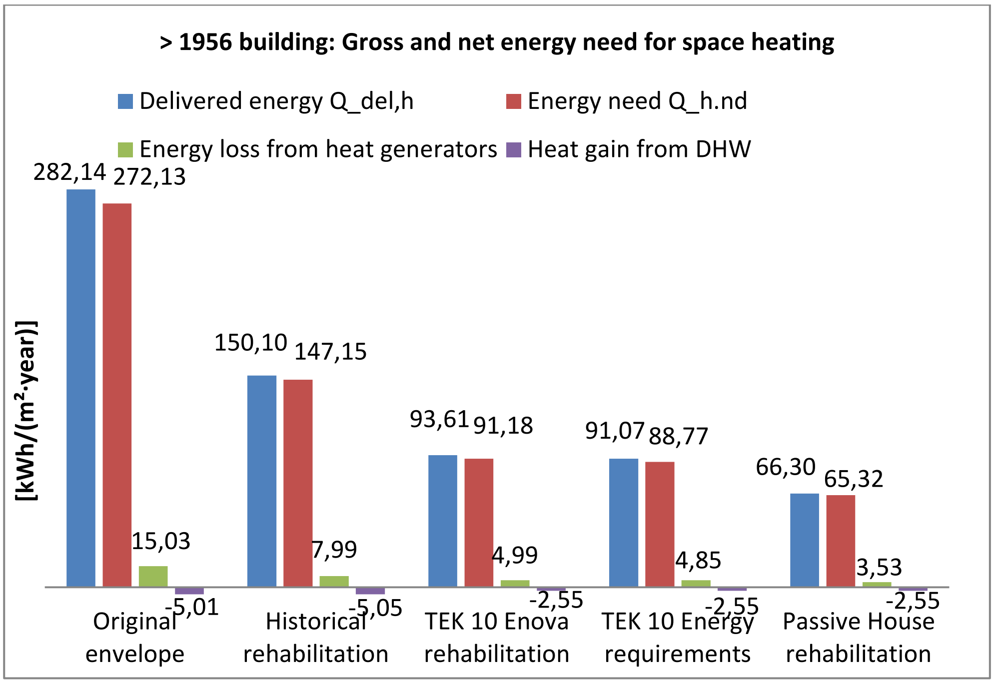


Figure 5: Gross and net energy need for space heating for buildings built before 1956

Buildings from 1956 – 1970

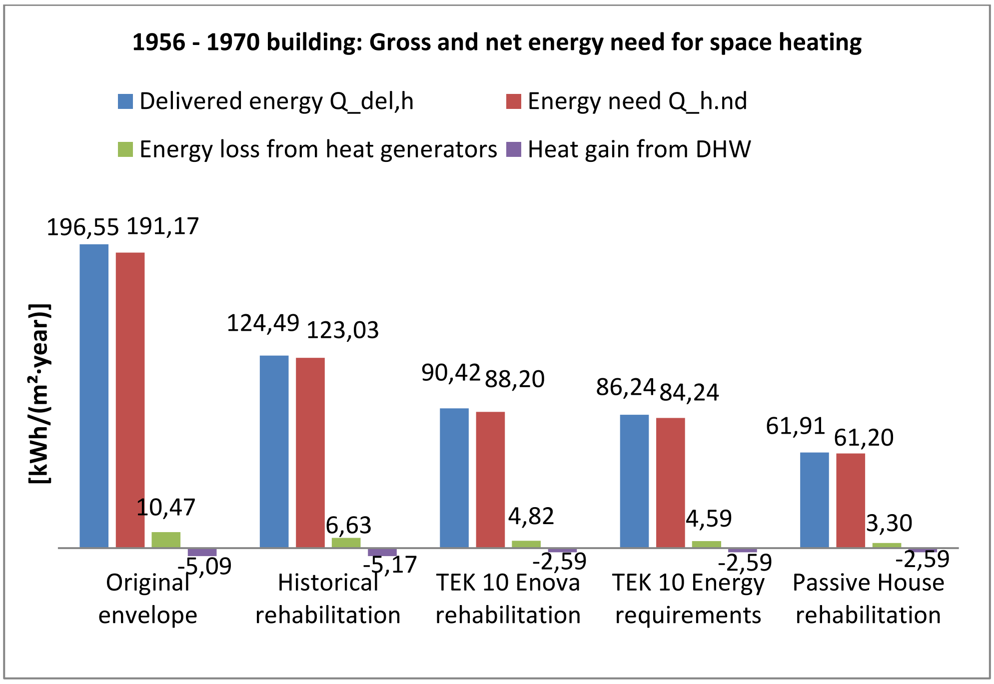


Figure 6: Gross and net energy need for space heating for buildings built during 1956 - 1970

Buildings from 1971 – 1980

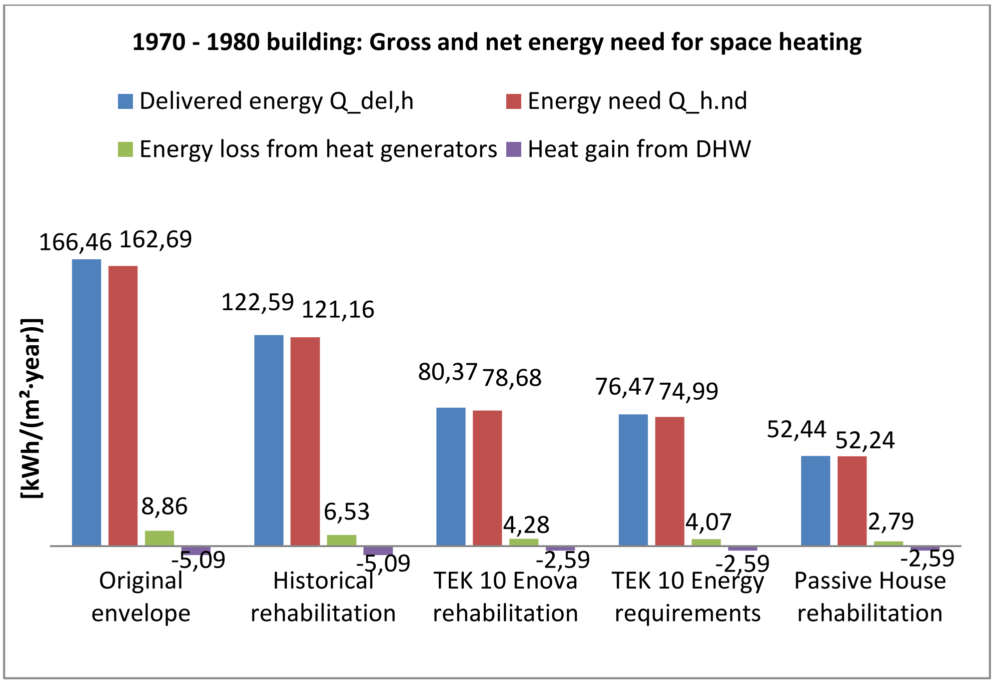


Figure 7: Gross and net energy need for space heating for buildings built during 1971 – 1980

Comparison to Enova results

Table 21: Comparison with Enova values on net energy demand for space heating

Comparison with Enova values on net energy demand for space heating [kWh/(m²·year)]

	>1956	1956 - 1970	1971 - 1980
Net energy demnad for space heating according to Enov	197.8	121.5	87.8
Net energy demand for space heating as found in project			
For original thermal Envelope	272.13	191.17	162.69
For historically rehabilitated thermal envelope	147.15	123.03	121.16
Weighted average for project	158.4	139.4	146.5
Deviation from Enova results	-19.9 %	14.7 %	66.8 %

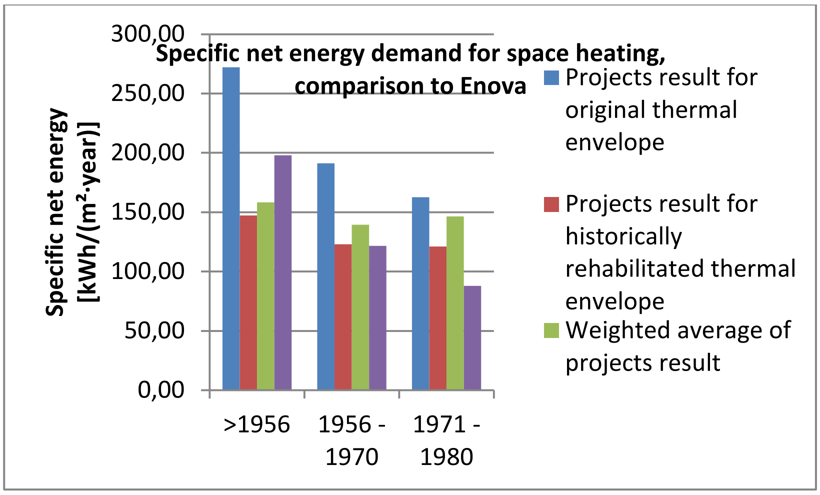


Figure 8: Comparison with Enova values on specific net energy demand for space heating

Total delivered energy to the building, including energy for technical appliances, lighting and DHW

Table 22: Total delivered energy demand for original and historically rehabilitated envelopes

	> 1956		1956 - 1970		1971 - 1980	
	Original envelope	Historical rehabilitation	Original envelope	Historical rehabilitation	Original envelope	Historical rehabilitatio
Delivered energy for space heating [kWh/(m^2·year)]	282.1	150.1	196.5	124.5	166.5	122.6
Net energy needed for technical aplliances [kWh/(m^2·ye	17.5	17.5	17.5	17.5	17.5	17.5
Net energy needed for lighting [kWh/(m^2·year)]	11.4	11.4	11.4	11.4	11.4	11.4
Net energy needed for DHW	29.8	29.8	29.8	29.8	29.8	29.8
Total delivered energy demand [kWh/(m^2·year)]	340.8	208.8	255.2	183.2	225.2	181.3

Table 23: Total delivered energy demand for TEK 10 and Passive House rehabilitated envelopes

	> 1956		1956 - 1970		1971 - 1980	
	TEK 10 Enova rehab.	Passive House rehab.	TEK 10 Enova rehab.	Passive House rehab.	TEK 10 Enova rehab.	Passive House rehab
Delivered energy for space heating [kWh/(m^2·year)]	93.6	66.3	90.4	61.9	80.4	52.4
Net energy needed for technical aplliances [kWh/(m^2·ye	17.5	17.5	17.5	17.5	17.5	17.5
Net energy needed for lighting [kWh/(m^2·year)]	11.4	11.4	11.4	11.4	11.4	11.4
Net energy needed for DHW	29.8	29.8	29.8	29.8	29.8	29.8
Total delivered energy demand [kWh/(m^2·year)]	152.3	125.0	149.1	120.6	139.1	111.1

Energy Labeling and TEK 10 and Passive House standards

The delivered energy limit for each building related to each grade is displayed in Table 24, and the calculated Energy labels for each standard building for each age cohort and thermal envelope level can be seen in Table 25.

Table 24: Delivered energy limit for each grade

Maximum total delivered energy demand for each grade [kWh/m^2·year)]			
	> 1956	1956 - 1970	1971 - 1980
A	90.5	90.5	90.3
B	126.0	126.0	125.5
C	162.1	162.1	161.4
D	203.1	203.1	202.0
E	244.7	244.7	243.2
F	304.8	304.8	302.6
G	> F	> F	> F

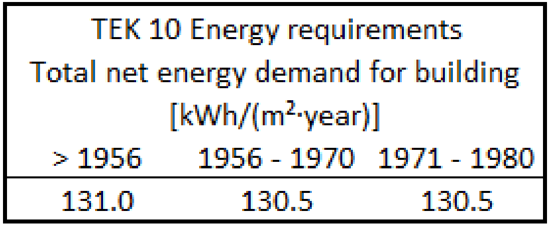
Table 25: Energy labels

		>1956		
Original envelope	Historical rehab.	TEK 10 Enova rehab.	TEK 10 Energy req.	Passive House rehab.
G	E	C	C	C
		1956 - 1970		
Original envelope	Historical rehab.	TEK 10 Enova rehab.	TEK 10 Energy req.	Passive House rehab.
F	D	C	C	B
		1971 - 1980		
Original envelope	Historical rehab.	TEK 10 Enova rehab.	TEK 10 Energy req.	Passive House rehab.
E	D	C	C	B

Energy requirements

The TEK 10 and Passive House energy Framework requirements are displayed in Table 26 Table 27.

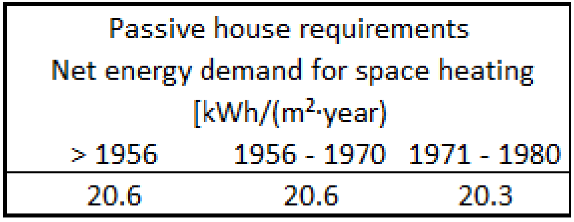
Table 26: TEK 10 energy requirements



TEK 10 Energy requirements
Total net energy demand for building
[kWh/(m^{2}·year)]

> 1956	1956 - 1970	1971 - 1980
131.0	130.5	130.5

Table 27: Passive House energy requirements



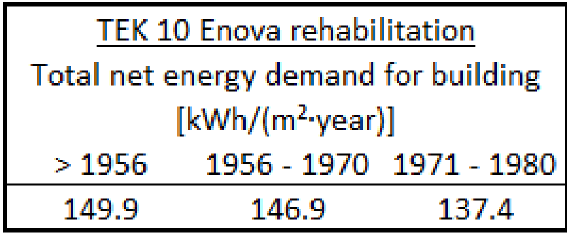
Passive house requirements
Net energy demand for space heating
[kWh/(m^{2}·year)

> 1956	1956 - 1970	1971 - 1980
20.6	20.6	20.3

Energy demand without heat recovery

This section presents the results for the total net energy demand, including energy needed for technical appliances and DHW for the two TEK 10 rehabilitation packages, as well as the net energy demand for space heating after Passive House rehabilitation. No heat recovery has been applied for these results.

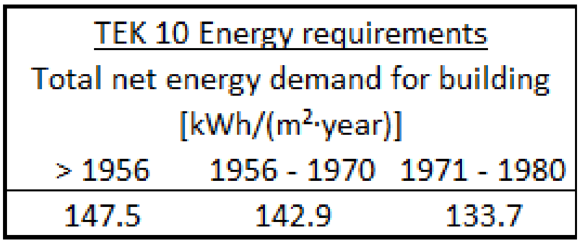
Table 28: TEK 10 Enova rehab. total net energy demand, no heat recovery



TEK 10 Enova rehabilitation
Total net energy demand for building
[kWh/(m^{2}·year)]

> 1956	1956 - 1970	1971 - 1980
149.9	146.9	137.4

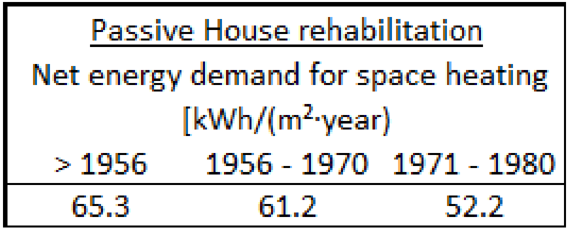
Table 29: TEK 10 Energy Framework req. rehab. total net energy demand, no heat recovery



TEK 10 Energy requirements
Total net energy demand for building
[kWh/(m^{2}·year)]

> 1956	1956 - 1970	1971 - 1980
147.5	142.9	133.7

Table 30: Passive House rehab. net energy demand for space heating, no heat recovery



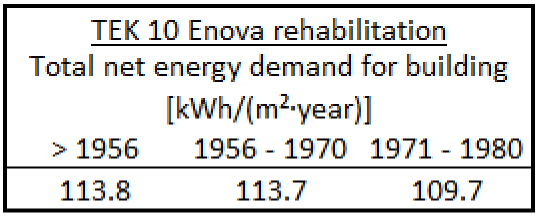
Passive House rehabilitation
Net energy demand for space heating
[kWh/(m^{2}·year)

> 1956	1956 - 1970	1971 - 1980
65.3	61.2	52.2

Energy demand with heat recovery

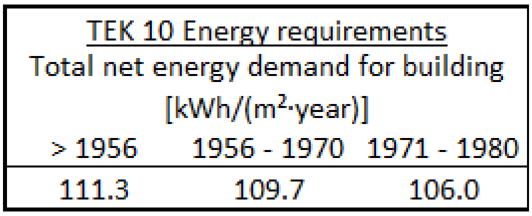
This section displays the same results as the previous section with the only difference that heat recovery has been applied.

Table 31: TEK 10 Enova rehab. total net energy demand with heat recovery



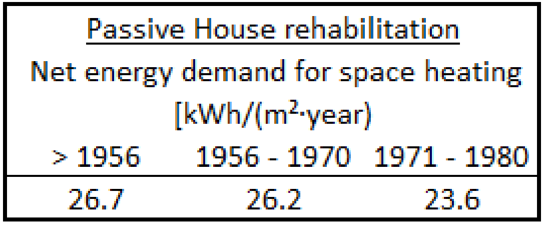
TEK 10 Enova rehabilitation Total net energy demand for building [kWh/(m^2·year)]		
> 1956	1956 - 1970	1971 - 1980
113.8	113.7	109.7

Table 32: TEK 10 Energy Measure req. rehab. total net energy demand with heat recovery



TEK 10 Energy requirements Total net energy demand for building [kWh/(m^2·year)]		
> 1956	1956 - 1970	1971 - 1980
111.3	109.7	106.0

Table 33: Passive House rehab. Net energy demand for space heating with heat recovery



Passive House rehabilitation Net energy demand for space heating [kWh/(m^2·year)		
> 1956	1956 - 1970	1971 - 1980
26.7	26.2	23.6

4.1.2 Discussion of results

The flow determining the delivered energy demand is clearly the net energy demand for space heating $Q_{H,nd}$ as might be expected. The energy loss related to the heat generators is small compared to the delivered energy need, constant at 5%, as shown in Table 20. As the energy need for space heating is covered by electricity and wood for all age cohorts as well as all rehabilitation measures, in this section, the loss from the heat generation should be constant. There are no losses from the electricity, and even if there are some losses associated with the use of wood this source is only used to cover peak loads, thus not contributing much to the overall energy need. The heat gain from the DHW remains fairly the same for the original and the historically rehabilitated thermal envelope, as well as for the TEK 10 and Passive house rehabilitation. The small variations between the first two are due to the fact that the gain utilization factor has a tiny variation. As the TEK 10 and Passive House rehabilitations includes better DHW tanks, simulated as smaller losses from the DHW, these results agrees well with the model. As seen by Figure 5, Figure 6 and Figure 7 the difference in calculated energy demand is not very large for the two TEK 10 rehabilitation measures. The Enova simplifications for the TEK 10 rehabilitation seem therefore to have little impact on the energy demand. Therefore the results in the next sections will focus on the Enova TEK 10 rehabilitation package instead of both.

Compared to Enova results

Table 21 and Figure 8 show the results from the evaluation against the Enova values; weighing has been done based on the information given in Table 4. The results do not agree that well with the Enova results. For the first age cohort the weighted average is lower than that from Enova. Knowing that the weighing of $Q_{H,nd}$ for the first age cohort is 0.09 and 0.91 for the original envelope and the rehabilitated envelope, respectively, the energy need for the historically rehabilitated envelope will have the most effect on the results and seems too low in the calculations in the current project. In this project the U-value for both windows and doors were decreased for the historical rehabilitation, this was not done in the Enova report. For the age cohort 1956 – 1970 the weighted average from Enova is very close to the $Q_{H,nd}$ for the rehabilitated envelope. With a weighing for $Q_{H,nd}$ of 0.24 and 0.76 for the original envelope and the rehabilitated envelope, respectively, it could seem like both of the calculated specific energy needs are too high. The largest deviation from Enova is found in the last age cohort, where the weighted average from Enova is extremely low, 87 kWh/(m²·year) compared to 146.5 kWh/(m²·year) in the current project . Here the energy need for both building envelopes must be too high. There are many factors influencing the energy need for space heating in the Tabula model, and it is hard to say with certainty why the energy need for space heating calculated in the current project deviates from Enova’s results. The thermal bridge surcharge is different in the two models. Enova used normalized thermal bridge surcharge from the standards and seems to use the same both for the original and the rehabilitated thermal envelope. In this project the thermal bridge surcharge has been decreased for the rehabilitated envelope for the first two age cohorts, and held constant in the last. Assuming that the standardized thermal bridge factor referred to by Enova is the one in TEK 10 this would imply a higher heating demand for both the original and the historically rehabilitated buildings in the present project, compared to that in Enova’s report. The windows are another uncertainty. Enova does not update the windows, but seems to give them a constant u-value which is an average of the U-values for older and newer windows. In this project, however, the windows have been updated, probably reducing the energy need for space heating. In addition Enova does not mention the solar energy transmittance at all, but does seem to take solar radiation in to account. This factor is reduced for the first two age cohort when rehabilitating the windows in the current project. A reduction of this factor will increase the energy demand slightly, as less heat from the sun is let through the window. However, no sensitivity analysis has been done to estimate the importance of this reduction. The air use and infiltration losses are other factors that will give differences in the results. In general the deviations in these results should have been further explored, preferably by a sensitivity analysis of each parameter. Unfortunately this had to be left out due to limited time.

Compared to literature

The delivered energy need calculated as shown in Table 22 and Table 23 was calculated using net energy need for DHW, lighting and appliances. For the results to be correct the gross energy need for these should have been used. However as electricity is used for heating of DHW and for lights and appliances there will be no losses related to the generation. There will be a loss related to DHW storage and distribution as shown in Figure 4 but it is quite small. In addition it is not normal to account for this heat loss when comparing to Norwegian standards and it is therefore assumed that this loss can be seen as irrelevant when comparing to Norwegian literature. As the literature in question does not say anything about the energy use for DHW it is also hard to know how relevant this loss is. Comparing Table 22 with the numbers from Bøeng et al. summarized in Table 7 reveals that the total energy demand for the original building envelope is not too far off for the two last age cohorts, with 255kWh/(m^2·year) compared to 214 kWh/(m^2·year), and 225 kWh/(m^2·year) compared to 212kWh/(m^2·year). As the numbers from Bøeng et al. does not consider to which extent the building stock has been rehabilitated the numbers can never match perfectly. The largest deviation for the delivered energy demand for the original building is for the 1956 age cohort. This is probably because the energy use given by Bøeng et al. includes energy rehabilitations, although it is not known to which extent. The value from Bøeng et al. should therefore be between the value for the original and the historically rehabilitated building. This holds for all age cohorts and gives more credit to the results of the current project. However, the energy use in the original buildings is generally too high compared to Bøeng et al.

Compared to the net energy demand for a SFH in Sweden found by Mata et al. the net energy demand for the historically rehabilitated envelopes seems very possible. Where Mata et al. found it to be 156 kWh/m² the net energy demand for the current project range between 147kWh/m² and 121kWh/m² for historically rehabilitated dwellings. As the Swedish value was calculated for a standard building representing the current state of the dwelling stock this indicates that the historically rehabilitated envelope, as defined by Enova, may be a good measure on the current technical state of the Norwegian dwelling stock.

Compared to the Swedish TABULA project

It may be more relevant to compare the results to those found by other projects using the TABULA methodology, such as the values from Sweden summarized in Table 1 and Table 2. For the first age cohort and the original envelope the net energy demand calculated in the current project is too high with 272 kWh/(m²·year) compared to 204 - 214 kWh/(m²·year). As seen by Table 2 this can be explained by higher U-values for the Norwegian thermal envelope. In addition the age cohorts have been divided slightly different in Norway compared to Sweden. The Norwegian dwellings are generally older in the first category since Sweden includes dwellings until 1960. The first rehabilitation given by the Swedish values seems to lie somewhere between the historical upgrade and the TEK 10 rehabilitation when comparing the U-values of Table 2 to the ones used in this project, as seen in Table 8. By comparing the energy demands for these rehabilitation measures with the first rehabilitation it can be seen that the Swedish rehabilitation lies more or less in between the historically and TEK 10 rehabilitations, with the exception of the period 1956 – 1970 where it is quite similar to the historical rehabilitation. Again there are differences in floor area and in addition not all the variables used in the Swedish calculations are known. Therefore the differences may be explained by parameter differences. For the last rehabilitation to Low Energy building as calculated for Sweden the energy demand is generally higher than that calculated for Passive House rehabilitation in Norway. This bodes well for the results for this project, as a Passive House has stricter requirements on U-values than a Low Energy house. Overall the results from the current project seem to agree with the results from the Swedish TABULA project.

Achieving the standards energy requirements

Achieving TEK 10 Energy requirements or Passive House requirements is clearly not possible without applying heat recovery to the ventilation system as seen by comparing Table 26 with Table 28 and Table 29, as well as Table 27 with Table 30. As both TEK 10 and NS 3700 do require the buildings to have heat recovery it should not be possible to achieve the energy requirements of the standards without. When heat recovery is applied both the Enova rehabilitation and the TEK 10 Energy Measure rehabilitation will meet the Energy Framework requirements of TEK 10. The Energy Measure requirements should meet the energy requirement since the choice of TEK 10 standard is to meet either the Measure or the Energy Framework requirements. This result also shows that even if the Enova rehabilitation measure doesn’t meet the Energy Measure requirements it will meet the Energy Framework requirement as long as heat recovery is applied, meaning the Enova rehabilitation gives a good result. Achieving Passive House standard is difficult even with heat recovery. None of the building envelopes in the current project can be classified as a Passive House after the Passive House rehabilitation. However, the U-values used for this rehabilitation measure was chosen as the mean of the U-values that from experience will achieve Passive House standard. Thus these U-values were not strict enough, and if Passive House standard is to be achieved for Single-Family dwellings, especially the older ones, stricter U-values must be used. It would be interesting to find out how strict U-values are needed to meet the Passive House standard, unfortunately this has not been done in the current project due to limited time. As mentioned in 3.2.2 the rehabilitation package for Passive House standard does not take into account the requirement on energy supply set in NS 3700. This means that even if the building envelopes could achieve the Passive House standard when it comes to the energy requirement per floor area, they cannot as simulated in this project be classified as Passive Houses. This could be achieved by using a Heat Pump to cover most of the space heating, but this was defined as beyond the scope of this project, due to limited time. However, on general terms, given information from Stene, introducing a heat pump for the Passive Houses in this project would make it possible to achieve Passive House standard, even without further upgrading of the thermal envelope.

Compared to the Norwegian Energy Labeling system

The original building envelopes will achieve a bad energy label, G, F and E for the three age cohorts respectively. This result seems reasonable as they all have very poor U-values and no heat recovery is applied. Both TEK 10 rehabilitation measures for all age cohorts resulted in the label C even if no heat recovery was applied. This suggests that the label C might be too wide. The energy labeling system is constructed so that a building fulfilling the minimum requirements of TEK 10 will get the label C. The TEK 10 rehabilitated buildings does not fulfill the Energy Framework requirements in TEK 10 if no heat recovery is applied and it could be argued that they should therefore have less than C. The energy labeling system will encourage more energy efficient buildings if the label C was based on fulfilment of the Energy Framework requirement. The total delivered energy demand for the building is based on the TABULA methodology which includes heat recovery from the DHW system, some German values for the DHW system and NS 3031. In addition the energy labeling system does not take into account heat gain from the DHW system. As the results are calculated based on information from different systems and then compared to a labeling system not using the same method to calculate the energy label requirements, the results may not be very resilient. However, in general the results do not look completely off, as the original dwelling envelopes all gets a bad grading.

4.2 Flows influencing the net energy need for space heating

As Figure 5 to Figure 7 presented in chapter 4.1 shows the flow influencing the delivered energy needed for space heating the most is, as can be expected, the net energy need for space heating. In order to understand what drives the delivered energy need, the net energy need has to be examined.

4.2.1 Results

Figure 9 shows the net energy need for space heating for all rehabilitation packages for one age cohort. The two other age cohorts have a lower net energy demand, while the contribution of the different flows to this demand is quite similar.

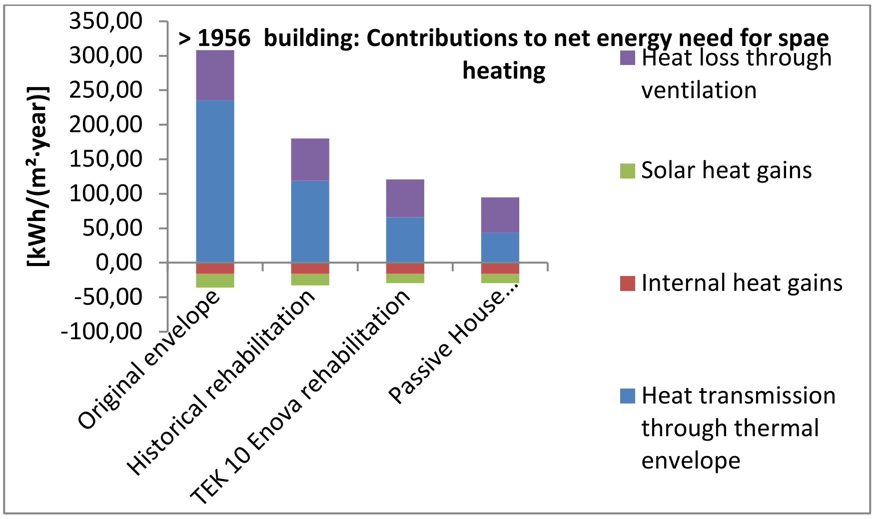
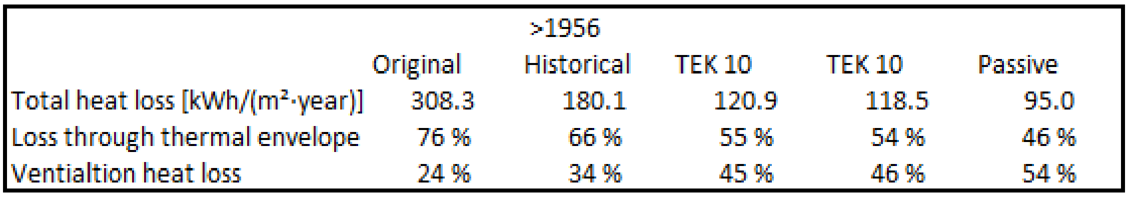


Figure 9: Contributions to net energy need for space heating for buildings built before 1956

Table 34: The influence of ventilation and transmission heat losses on the total heat loss



		>1956			
	Original	Historical	TEK 10	TEK 10	Passive
Total heat loss [kWh/(m²·year)]	308.3	180.1	120.9	118.5	95.0
Loss through thermal envelope	76 %	66 %	55 %	54 %	46 %
Ventialtion heat loss	24 %	34 %	45 %	46 %	54 %

4.2.2 Discussion of the results

Figure 9 gives two key insights into the net energy need for space heating. First, the largest contribution to the net energy demand for space heating is the heat transmission through the thermal envelope. The better insulated the envelope gets the less energy is needed to account for heat loss. Any other result would have meant there had to be something wrong with the model. Second, the ventilation heat loss is the second contributor to the heating demand and becomes more influential the better the thermal envelope gets. This phenomenon can be seen in Table 34. For the other age cohorts the results where similar and can be found in Appendix D, sheet “Results, tables and charts”. As seen from this table the ventilation heat loss only accounts for 24% of the total heat loss for the original building. As the level of the thermal envelope is improved, while nothing is done to the ventilation system, the influence of the ventilation heat loss increases to more than 50% for a Passive House rehabilitated building. This gives an incentive to explore the possibility of heat recovery in ventilation systems in the buildings, and explains why mechanical ventilation with heat recovery is a recommendation in Passive House buildings.

4.3 Parameters and flows influencing the heat transfer by transmission

The heat transfer by transmission during the heating season has been calculated as given by the equation for $Q_{ht,tr}$ in Appendix B. To evaluate the importance of the heat transfer through each envelope element, $Q_{ht,tr,i}$ has been calculated for all the elements and the ones that had the most influence on the total heat transmission has been further evaluated. The evaluation has been done for each age cohort and for every rehabilitation package, except the TEK 10 Energy Framework package, as the results of chapter 4.1 show it doesn’t deviate largely from the Enova TEK 10 rehabilitation package.

4.3.1 Results

Buildings from before 1956

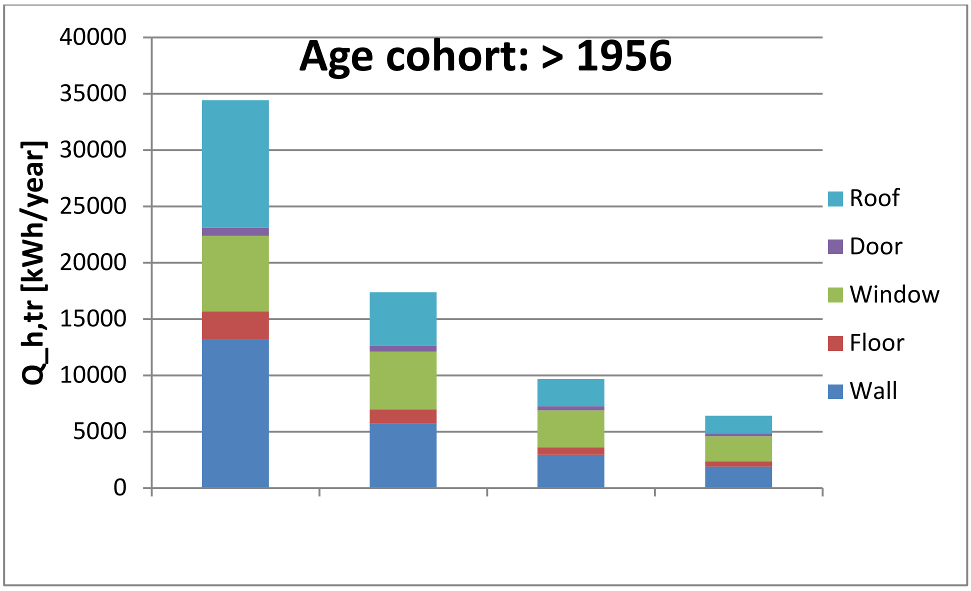


Figure 10: Before 1956, Heat transmission through building envelope elements

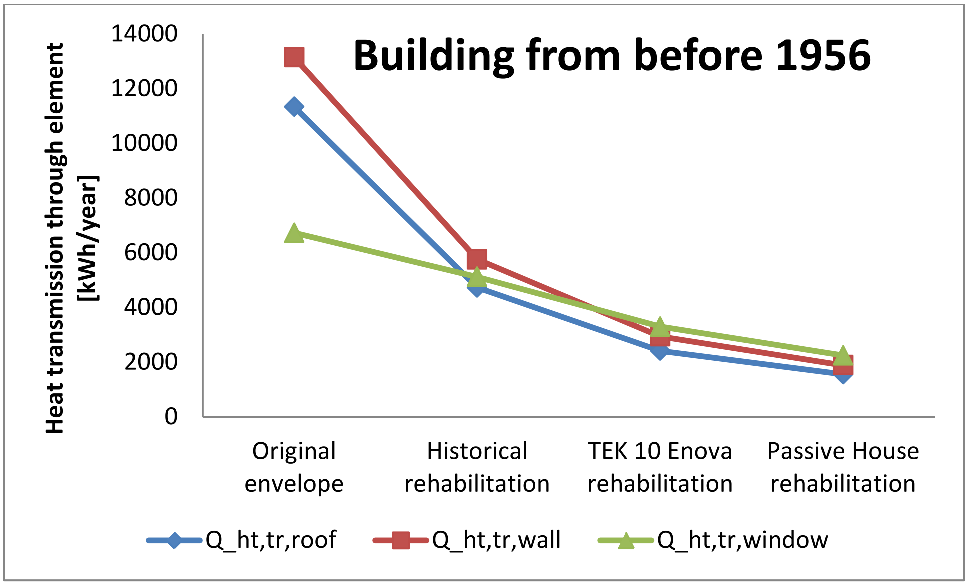


Figure 11: >1956 Heat transmission through walls, windows and roof

Buildings from 1956 - 1970

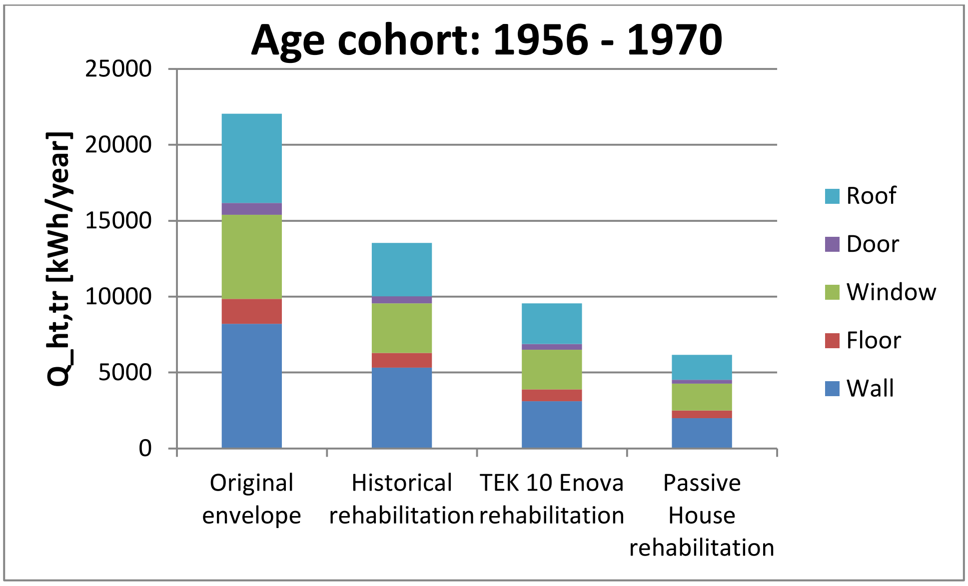


Figure 12: 1956 - 1970 Heat transmission through building envelope elements

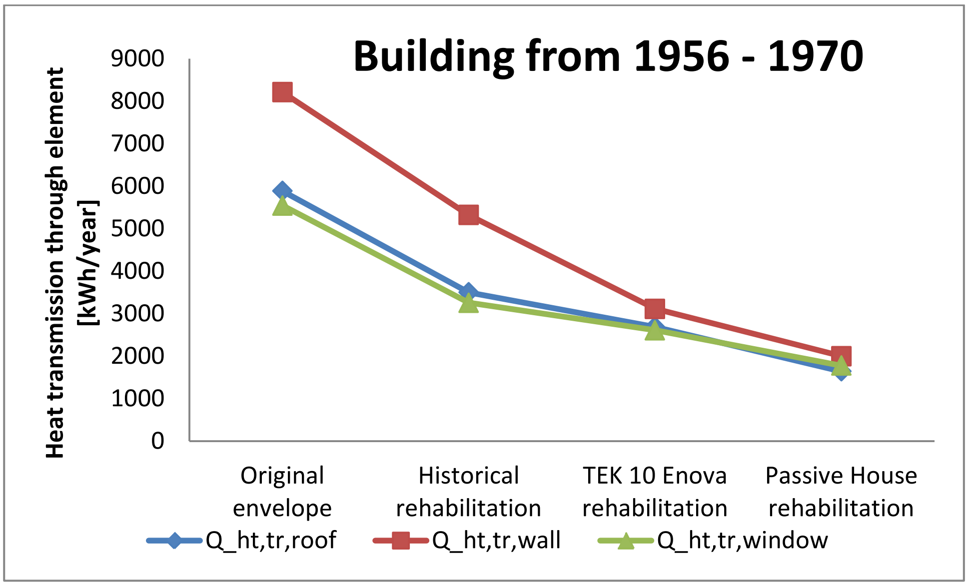


Figure 13: 1956 - 1970 Heat transmission through walls, windows and roof

Buildings from 1971 - 1980

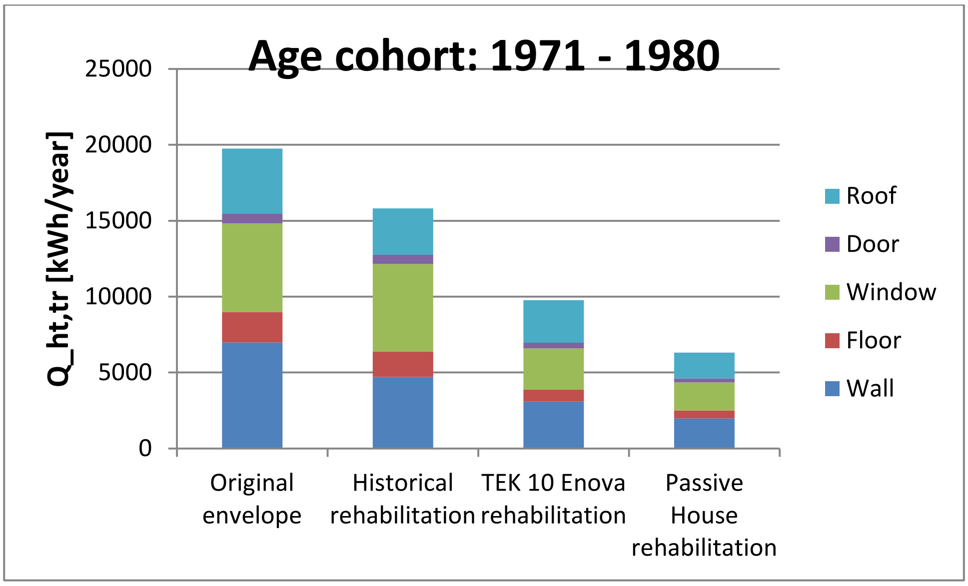


Figure 14: 1971 - 1980 Heat transmission through building envelope elements

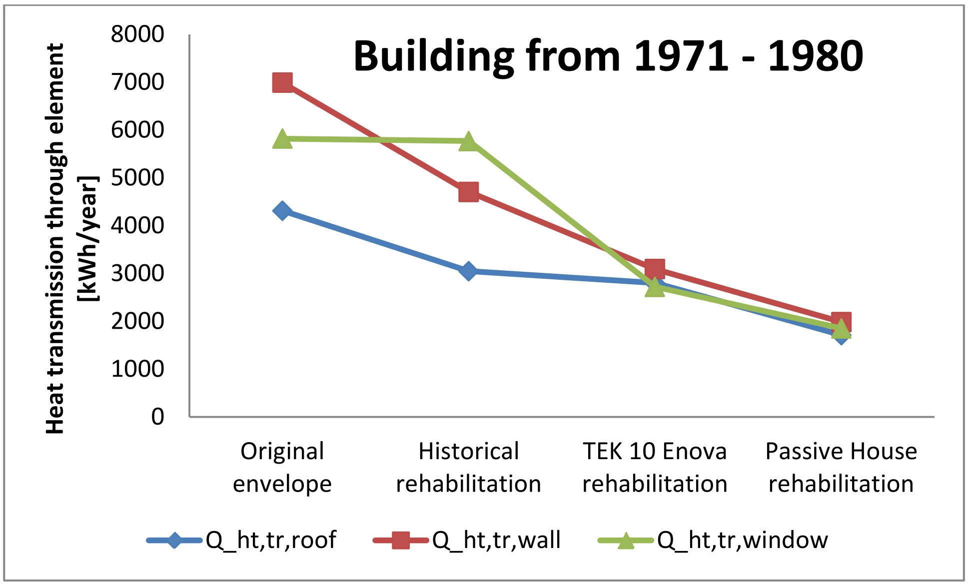


Figure 15: 1970 - 1980 Heat transmission through walls, windows and roof

4.3.2 Discussion of results

The most prominent heat transmission for every original building envelope happens through the walls. As the walls are the elements that constitute most of the thermal envelope this result seems plausible. As Figure 11 shows the heat transfer through both the walls and roof can be more than halved by the historical rehabilitation and further reduced with roughly 50% if TEK 10 rehabilitation is applied for a building originally from before 1956. If a building built before 1956 were to be rehabilitated insulation of walls and roof would induce the largest energy saving as seen in Figure 11. For an original building from this age cohort the walls and roof are clearly in a very bad technical state, as the heat transmission through the elements can be reduced this much just by applying a 100 mm of extra insulation. As seen from Figure 13 both the heat transmission through the walls and roof have been reduced significantly for the original envelope in the next age cohort. The results also show that even if the windows constitute a small amount of the total envelope area they are responsible for a large amount of the heat transmission. As long as the walls and roof of the original dwelling was in such a bad state as for the oldest dwellings the heat transfer through the windows only accounted for approximately 20% of the total heat transfer. For an original building envelope from the period 1970 – 1981 the windows account for 30% of the heat transmission. In a Passive House rehabilitated dwelling from before 1956 the windows will account for as much as 35% of the total heat transmission. For the last age cohort changing the windows would induce a larger reduction in the heat transmission through the building than insulating the roof when upgrading to TEK 10 standard. It should be mentioned that this is because the windows are assumed not to be historically upgraded in this last time period. Even so, the heat transmission through the windows is larger than that through the roof for the original envelope in this period. This clearly shows that the windows are a weak link in the building envelope, and that changing the windows alone can give a large reduction in the heat loss. Especially for buildings with a higher technical standard on the walls and roof, changing the windows will be an easy way of reducing the heat loss through the envelope. However as long as the heat loss through the walls and the roof are as large as for the first age cohort it would probably be better to rehabilitate these at first. Even if the economic perspective has not been taken into account in the current project work, it can be argued that rehabilitating both walls and roof will probably be very expensive compared to changing the windows. Therefore if such large rehabilitation work were to be carried out the results show that changing the windows would induce such reduction in the heat loss that it would probably be profitable to change them as well.

4.4 Differences across climate zones

4.4.1 Results

Table 35: Differences across climate zones for a building from before 1956

	Original building from before 1956									
	Historically rehabilitation					TEK 10 Enova rehabilitation				
Climate zone	Net energy need for space heating [kWh/(m^2·yr)]	Solar heat gains [kWh/(m^2·yr)]	Internal heat gains [kWh/(m^2·yr)]	Heat transfer by ventilation [kWh/(m^2·yr)]	Heat transfer by transmission [kWh/(m^2·yr)]	Net energy need for space heating [kWh/(m^2·yr)]	Solar heat gains [kWh/(m^2·yr)]	Internal heat gains [kWh/(m^2·yr)]	Heat transfer by ventilation [kWh/(m^2·yr)]	Heat transfer by transmission [kWh/(m^2·yr)]
1	146.2	23.8	16.5	63.3	123.2	89.4	19.1	16.7	56.6	68.6
2	122.8	18.5	15.6	53.2	103.6	74.7	14.8	15.8	47.6	57.7
3	181.5	28.1	18.4	77.4	150.7	111.9	22.6	18.6	69.2	84.0
4	135.4	22.4	17.4	59.4	115.7	82.1	17.9	17.5	53.1	64.5
5	184.3	24.5	18.4	77.1	150.1	114.3	19.7	18.6	68.9	83.6
6	170.6	25.7	19.0	73.0	142.2	104.7	20.6	19.2	65.3	79.2
7	216.8	30.7	21.3	91.3	177.6	134.3	24.7	21.6	81.6	99.0
8	164.0	24.8	18.1	70.2	136.6	100.7	19.9	18.3	62.7	76.1
9	147.2	17.0	16.0	61.1	118.9	91.2	13.6	16.1	54.6	66.3

Table 36: Deviations from Oslo climate

	Differences compared to climate zone 9			
	Historically rehabilitation		TEK 10 Enova rehabilitation	
Climate zone	Net energy need for space heating [kWh/(m^2·yr)]	Heat transfer by transmission [kWh/(m^2·yr)]	Net energy need for space heating [kWh/(m^2·yr)]	Heat transfer by transmission [kWh/(m^2·yr)]
1	-1.0	4.2	-1.8	1.9
2	-24.4	-15.3	-16.4	-7.0
3	34.4	31.7	20.7	14.6
4	-11.8	-3.3	-9.1	-1.5
5	37.2	31.1	23.1	14.3
6	23.4	23.2	13.5	10.7
7	69.7	58.7	43.1	26.9
8	16.8	17.7	9.5	8.1

Table 37: Deviations from the mean climate

	Differences compared to climate zone 8			
	Historically rehabilitation		TEK 10 Enova rehabilitation	
Climate zone	Net energy need for space heating [kWh/(m^2·yr)]	Heat transfer by transmission [kWh/(m^2·yr)]	Net energy need for space heating [kWh/(m^2·yr)]	Heat transfer by transmission [kWh/(m^2·yr)]
1	-17.8	-13.5	-11.3	-7.5
2	-41.2	-33.0	-25.9	-18.4
3	17.6	14.0	11.2	7.8
4	-28.6	-21.0	-18.6	-11.7
5	20.4	13.4	13.6	7.5
6	6.6	5.5	4.0	3.1
7	52.9	41.0	33.6	22.8
9	-16.8	-17.7	-9.5	-9.9

Table 38: TEK 10 rehab. compared to Historically rehab across climate zones

	TEK 10 rehab. compared to Historically rehab. across climate zones	
Climate zone	Energy saving, net energy for space heating [kWh/m^2·yr)]	Heat transfer losses [kWh/m^2·yr)]
1	56.8	54.5
2	48.0	45.9
3	69.6	66.7
4	53.3	51.2
5	70.0	66.4
6	65.9	63.0
7	82.6	78.6
8	63.3	60.5
9	56.0	52.7

4.4.2 Discussion of results

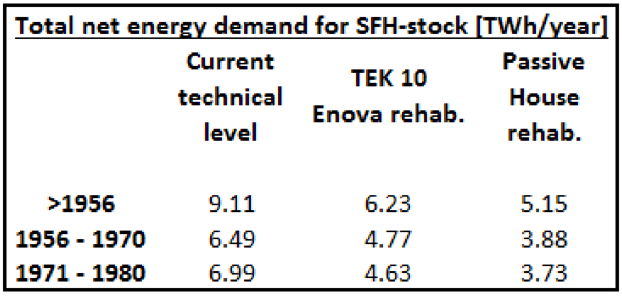
There are large differences across the country when it comes to specific net energy demand for space heating as displayed in Table 35, Table 36, and Table 37. The net energy demand for climate zone 8, representing the national mean deviates from the Oslo climate, zone 9 with approximately 17 kWh/(m^{2}year). The largest deviation from climate zone 9 is found in Finnmark and the inland of Troms. This result comes as no surprise as this is the climate zone located in the most northern part of the country. The internal heat gains and the solar heat gain is also largest for this climate zone, this however, is because the heating season is longest here. As the internal and solar heat gains are calculated based on the length of the heating season, the longer the heating season the more heat gain. This rather large difference in solar heat gains can be attributed to the heating season being so long that 15 days had to be allocated to the month of June, where one might expect the solar radiation, and thus the heat gain to be quite large, especially since the daylight lasts for almost the entire day and night during the summer in the north. Table 37 and Table 37 also show the difficulties of using one standard climate zone when calculating the energy demand and energy saving potential in the Norwegian dwelling stock. Climate zone 8 represents the climate better for those zones that are located in areas where it is generally colder than in Oslo, as the northern parts of Norway as well as mountain areas in the inland of the southern part, which could be expected. However, for the rest of the country the Oslo climate will be better. Neither the Oslo climate nor the arithmetic mean climate of zone 8 is a good description of the Norwegian climate as a whole. A better representation of the Norwegian climate might be a weighted average. It can however be argued that as long as most of the Norwegian dwelling stock is located in the southern part of Norway, Oslo may very well be a good enough representation of the climate whenever the energy saving potential for the dwelling stock is to be calculated.

4.5 The energy saving potential in the Norwegian dwelling stock

4.5.1 Results

Table 39 displays the total energy demand in the dwelling stock both for the current technical level, TEK 10 and Passive House rehabilitation, respectively. The energy saving potential in the dwelling stock when applying each of the rehabilitation packages can be seen in Table 40.

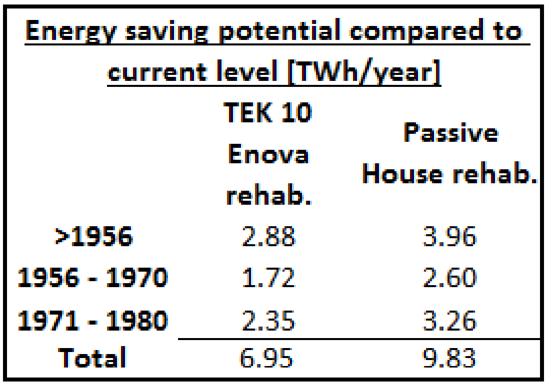
Table 39: Total net energy demand for space heating in the dwelling stock



Total net energy demand for SFH-stock [TWh/year]

	Current technical level	TEK 10 Enova rehab.	Passive House rehab.
>1956	9.11	6.23	5.15
1956 - 1970	6.49	4.77	3.88
1971 - 1980	6.99	4.63	3.73

Table 40: Energy Saving Potential in this part of the dwelling stock



Energy saving potential compared to current level [TWh/year]

	TEK 10 Enova rehab.	Passive House rehab.
>1956	2.88	3.96
1956 - 1970	1.72	2.60
1971 - 1980	2.35	3.26
Total	6.95	9.83

4.5.2 Discussion of the results

Comparing the net energy demand for space heating when TEK 10 and Passive House rehabilitations have been carried out, to the net energy demand for space heating as found for the current dwelling stock reveals an energy saving potential of approximately 6.9 an 9.8 TWh/year, respectively. There are some deviations from the results calculated by Enova, as shown in Table 6, however as described in Chapter 4.1.2 the results in the current project deviates from the Enova results and this can be due to many reasons. Therefore the energy demand for the total stock was expected to deviate as well. It should be noticed that the Enova report is quite difficult to use as a good comparison, as they fail to give a decent explanation of many of their tables. Assuming that the information provided in Table 6 is based on a weighted average between the original thermal envelope and the historical rehabilitation the results of the current project seems plausible. Compared to the government goal of 15 TWh reductions in the building sector the possible reductions in this part of the dwelling stock are quite extensive. However, it is not likely that every dwelling in this segment will be rehabilitated to the levels presented here. The energy use, and thus the rehabilitation to achieve energy saving potential, does as stated in Chapter 2.2 depend on the socio-economics of the country as well. Even if Norway generally is a very rich country compared to the world it is not likely that every homeowner will prioritize such a comprehensive upgrading of the thermal envelope. In addition the rebound effect will probably ensure that the energy saving in the Norwegian dwelling stock never can reach the estimated level. If all such social, and economic obstacles are neglected the result shows a remarkable energy saving potential in this part of the Norwegian dwelling stock. Compared to the 46 TWh annual consumption in the residential sector these results indicates a 15% and 21% reduction in annual energy consumption in the dwelling stock, if carrying out the TEK 10 and Passive House rehabilitations, respectively. This result is only for this part of the dwelling stock alone, and is quite remarkable. Introducing heat recovery of the ventilation air as well as Heat Pump to cover space heating would increase the energy saving potential significantly. No calculations for this scenario have been carried out in the current project due to two main reasons, first limited time has made it necessary to stop the calculations somewhere, second, even if the economics of these rehabilitations have not been considered in the current work, installing mechanical ventilation with heat recovery is assumed such an extensive cost that it has not been focused on in this project. Installing a heat pump would not be such an expensive rehabilitation and is suggested for further works.

4.6 The impact of assumptions and uncertainties

The results indicated that windows account for a large part of the heat transmission through the building envelope and thus increases the net energy demand for space heating. As the calculations in this project have been related to the oldest dwelling segment the technical state of the windows may have been overestimated. As described earlier the U-values for the original windows were based on the choices Enova made. In retrospect it seems possible that they have simply found an average of the U-values for the windows and that especially for the oldest age cohort this may not be correct. Based on values from Multiconsult the U-values used for the windows are probably underestimated. Therefore the net energy need for space heating for the original building for before 1956 should probably be higher. For the historically rehabilitated building, however the values are seen as good and thus the result as well. This indicates that Enova may have underestimated the energy demand in the original part of the dwelling stock, and thus the energy saving potential.

The air use and infiltration rates are other parameters with related uncertainties. Although the values in themselves are seen as sound and well based, the choice of not increasing the air use when decreasing the infiltration rate may have influenced the results. In a real life case reducing the infiltration will probably lead to increased ventilation of the building, thus higher air use and as long as mechanical ventilation is not used this would increase the heat loss and thus increase the specific net energy need for space heating. Without having done a sensitivity analysis on this parameter, however, it is hard to estimate the implication of this choice.

As described in the Background chapter the chosen space heating system and the related system losses will influence the net energy demand for space heating. The choices made in the current project for the space heating system seem to be well documented in the literature. The system efficiency on the other hand has been harder to obtain. The efficiency of direct electric heating is normally assumed to be 100% and this assumption should not have influenced the energy need for space heating. The efficiency for wood stoves on the other hand is not as well documented. However as wood is assumed to only cover 10% of the energy demand for space heating the uncertainty in this parameter should be of little importance.

The indoor temperature has not been increased as a result of better insulation. This assumption is probably wrong. As documented in the Background chapter better insulation of dwellings often results in higher indoor temperature and thus increased energy use. The saving potential when upgrading the thermal envelopes may therefore have been overestimated.

The floor area used in these calculations is based on the estimations by Enova and is given as BRA. When comparing to literature it has sometimes been difficult to reveal which area definition has been used, especially when comparing to literature beyond Norway. This will not influence the results of the current project, but makes it difficult to make sound comparisons to literature.

In the model the thermal bridge surcharge has been upgraded to the standard requirements. It will, however be quite difficult to verify that an upgraded thermal envelope manage the given thermal bridge factor in real life. Therefore the heat transmission through the envelope may be larger in the real life cases.

The economic perspective has been disregarded completely in this project work. When defining rehabilitation measures with the aim of calculating the energy saving potential it will be crucial to make the calculations based on real life assumptions. Thus the economics of the rehabilitation measures will be an important part of establishing these measures.

4.7 Summary of discussions and future works

The historical rehablitiation of the Norwegian dwelling stock as estimated by Enova seems to be a good representation of the current Norwegian dwelling stock when comparing to the values given by Mata et al. As long as Enova also provides percentages for the amount of the dwelling stock that has been rehabilitated a weighted average between the energy demand for the original and the histirically upgraded thermal envelope is seen as the best basis when calculating the potential energy savings of rehabiliation.

The TABULA method seems to give reasonable results for the Norwegian dwelling stock, although the energy demand for the original dwellings are a bit overestimated compared to calcuations done by Enova. Compared to calculations from the Swedish TABULA project the calculations of the current project seems reasonable. Every country can define the age cohorts making it difficult to directly compare the results. However the results from neighbouring countries works as guideline on energy use and can also tell something about political measures to decrease the energy use. Literary sources have pointed out that higher electricity prices in Sweden compared to Norway may have contributed to lower energy use in Sweden. As the energy use in these calculations generally where higher than for Swedish calculations the results support the literature.

The net energy demand for the building depends largely on the heat loss through transmission and ventilation. The results shows that with very old buildings the heat transmission through walls and roof are of greatest significance. Heat transmission through the windows account for a significant share of the total heat transmission thorugh the envelope, despite the relatively small amount of area they constitute. The amount of heat transfer thorugh the window will increase when increasing the technical standard of the buildings envelope. This result indicates that newer buildings can benefit from just changing the windows. The original buildings as simulated in the current project, seems to be of such a poor technical standard that the entire envelope should be rehabilitated. The results also show that with a better insulated thermal envelope the relative heat loss through ventialtion increases, and thus when extensive rehabilitations are done heat recovery should be applied to the ventilation system. Extensive rehabilitation to the Passive House level will not achieve the Passive House standard without mechanical ventilation including heat recovery. The heating system also have to be changed to account for the standards requirement on energy carriers, and calculations including a Heat Pump is suggested for further works.

Comparing the results to the energy labeling system revealed that the building would get an energy grade of C, despite not achieving TEK 10 standard. This indicates that the grade C might be too easy to achieve and should be revised. In stead of C being for buildings achieving the minimum requirements of TEK 10 , it might be better if it was reflecting buildings achieving the TEK 10 Energy Framework requirements, and Low-Energy buildings could achive B, while Passive Houses would achieve A. This would encourage more eneregy efficient buildings.

Having one standard climate zone in a country with such varying climate as in Norway can be problematic. The results showed large deviations in energy need for different climate zones compared to the Oslo climate as well as the arithmetic average. If one zone is to be use to describe the entire country the calculations of aggregated energy use in the dwelling stock would probably benefit from finding a weighted average for the climate.

Assuming the weighted average for the technical standard of the current dwelling stock, is a valid representation of the Norwegian dwelling stock, rehabiliations to TEK 10 and Passive House level for this part of the dwelling stock can induce a decrease of 15% and 21% in total energy demand in the dwelling sector, respectively.

The parameters for this project work have been based both on national standards and findings from other countries making the results less representative for Norway. Better Paramterers might be a suggestion for further works.

As the economic perspective has not been taken into account for this project more research should be done to reveal the economics of the rehabilitation measures proposed in this project. As stated socio-economics play a vital role when it comes to energy rehabilitation. If the energy saving potential revealed in the current project were to be realized the work and costs would have to be carried by the homeowner. With extensive rehabilitations the energy saving and thus the cost savings may not be enough of an incentive for the homeowners. More research into the different governmental fundings might be a good idea for future work. An economic assessment of installing mechanical ventialtion with heat recovery in dwellings where the ventialtion originally has been based on natural ventilation as well as installation of a Heat Pump will be crucial points for further works.

If the goal of 15TWh reductions in the energy demand in the Norwegian building sector is to be achieved much stricter technical regulations than those of TEK 10 has to be created. The fact that the new technical regulations currently in the making are supposed to reflect Passive House level bodes well for the energy demand in the future dwellings. However, as most of the dwelling stock won’t be new buildings better incentives for rehabilitation of the current stock is needed.

4.8 Critiques of the method

As the energy balance calculations of the current work have been based on the TABULA methodology the following critique is for both the TABULA methodology and the method used in this project.

When it comes to the TABULA method there are some shortcomings. For instance the method does not provide an opportunity for calculating the energy demand for space cooling. This is not of major importance when calculating the net energy demand for buildings located in such cold climate as in Norway. However, as this method is used in other, much warmer countries it’s peculiar that cooling has been deliberately kept outside the scope of the method. Especially when calculating the energy demand for buildings achieving Passive House level cooling should be accounted for. Most Passive Houses may increase the need for space cooling as the heat transmission through the walls is so limited. If the goal is to get more energy efficient buildings the total energy demand for the buildings should be accounted for. The fact that the energy demand for lights and appliances are kept outside the scope as well can also be subjected to critiques. When calculating total delivered energy demand in the current project energy demand for lights and equipment was based on the Norwegian standards. These values may be too high for Passive House level. When upgrading to Passive

House level the equipment inside the thermal envelope should also be upgraded to low energy equipment such as energy saving light bulbs. The method doesn’t take this into account. This will not influence the results when comparing to Passive House level, however, as the energy requirement of Passive Houses relate only to net energy demand for space heating. In addition it is seen as a bit odd that het recovery of ventilation air does not influence the net energy demand for space heating. Heat recovery only influences the delivered energy demand for the building, Flow 12 in Figure 4. This has no real implications for the results as it is still easy to find the net energy demand for space heating when heat recovery is applied. However, the net energy demand for space heating should reflect the energy demand when losses in the system are not accounted for, and the current model does not show this. In addition the TABULA method does not take into account the indoor environment, except for the air usage rate. This becomes especially important when applying Passive House rehabilitation. When the walls get as insulated as they are at Passive House level the indoor temperature is likely to increase. This has been totally disregarded in the current project. When the walls are as well insulated as they are at Passive House level the indoor temperature may be very high during the summer and cooling may be needed. This will increase the total energy demand for the building and should be accounted for in the model.

5 Conclusion

The net energy demand for space heating is mainly influenced by two flows, the heat transmission through the thermal envelope and the ventilation heat losses. With the aim of reducing the energy demand of a building reducing the heat loss through the thermal envelope should be the main priority. For old and poorly insulated buildings the roof and walls are the most critical to rehabilitate. In addition the results show that changing the windows will induce a large reduction of the total heat transmission compared to the relative size of the window area. For newer buildings with a thermal envelope in a better technical state changing the windows should have priority. Representing Norway by one climate will not reflect the energy demand correctly. The result show large differences in net energy demand for space hating across the country. Rehabilitating this part of the dwelling stock has an energy saving potential of 6.95 TWh/year if rehabilitated form historical rehabilitation to TEK 10 standard. If the dwellings where rehabilitated to Passive House level the energy saving potential would be 9.83 TWh. These numbers are both for rehabilitation without mechanical ventilation using heat recovery. The results show that the buildings cannot achieve TEK 10 or Passive House energy requirements without heat recovery of the ventilation air. In addition the energy supply system for the dwellings has to be changed to meet the requirement on energy carriers in the TEK 10 and Passive House standards. If heat recovery of ventilation air and Heat Pumps were part of the rehabilitation packages the energy saving potential is assumed to significantly increase.

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Appendix A

Norwegian building standards and Technical Regulations

The Technical Building code TEK 10 (TEK10, 2010)

Table 41

§14-3 Energy requirements	
a) 1. Total area of windows and doors	≤ 20% of heated part of BRA
a) 2. U-value envelope wall	≤ 0.18 [W/(m²K)]
a) 3. U-value roof	≤ 0.13 [W/(m²K)]
a) 4. U-value floor	≤ 0.15 [W/(m²K)]
a) 5. U-value windows/doors	≤ 1.2 [W/(m²K)]
a) 6. Normalized thermal bridging value for detached dwellings	≤ 0.03 [W/(m²K)]
b) 1. Infiltration at 50 Pa pressure difference for detached dwellings	≤ 2.5 [1/h]
b) 2. Yearly average temperature efficiency of ventilation heat recovery for detached dwellings	≥ 70 %
c) 1. Specific Fan Power for ventilation system in detached dwellings	≤ 2.5 [kW/(m^3/s)]
c) Further requirements	2. A possibility for night- and week-end set back of indoor temperature. 3. Measures to reduce the buildings need for local cooling.

Table 42

§ 14-4 Energy framework requirement for detached dwelling	
Total net energy need (based on NS 3031)	120 + 1600/(Floor area) [kWh/m^2 heated BRA per year]

Table 43

§14-5 Minimum Requirements for detached dwellings	
U-value envelope wall	≤ 0.22 [W/(m²K)]
U-value roof	≤ 0.18 [W/(m²K)]
U-value floor against ground or air	≤ 0.18 [W/(m²K)]
U-value window/door	≤ 1.6 [W/(m²K)]
Infiltration at 50 Pa pressure difference	≤ 3.0 [1/h]

The Norwegian Standard NS 3031(Norsk Standard, 2011)

- BRA – utility floor space
    - Defined as the gross floor space minus the area of the walls
    - Heated area, A_{fl} is defined as the part of BRA that receives heat from the buildings heating system and which is enclosed by the buildings thermal envelope.
    - For areas that are unheated or only partly heated the heated area is determined as follows:
        - If the area is included in BRA the room is calculated as if it has the same temperature as the adjacent room
        - If the area is not included in BRA the rooms thermal resistance can be included when calculated the heat loss through building elements bordering on the unheated space.[3]
- There are three calculation methods that can be chosen for calculating the heating- and cooling need, where only the two first ones are relevant for dwellings[4].
    - Stationary monthly calculations
    - Simplified time based calculation, dynamic method
    - Detailed validated calculation method, dynamic method
- The standard gives definitions on how to calculate energy need for space heating, energy need for space cooling, total net energy need, total delivered energy demand as well as primary energy need and CO_2-emissions.

Table 44:Energy demand for lights, technical appliances and hot water.

Building type	Lighting appliances		Technical equipment		Domestic hot water		Min. specific airflow
	W/m^2	$kWh/(m^2 \cdot year)$	W/m^2	$kWh/(m^2 \cdot year)$	W/m^2	$kWh/(m^2 \cdot year)$	$m^3/(h \cdot m^2)$
Detached dwellings[5]	1.95	11.4	3.00	17.5	5.1	29.8	1.2

Calculation of energy need for the building:

Net energy need for space heating is found as the heat loss through transmission – the heat gain from ventilation. See NS 3031, chapter 6.1 for more information.

$$Q_{H,nd,i} = Q_{H,Is} - \eta_{H,i} Q_{gn,i}$$

Where

$Q_{H,nd,i}$	is the net energy need for space heating
$Q_{H,Is,i}$	is the heat loss both due to ventilation and heat transmission
$\eta_{H,i}$	is the gain utilisation factor

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[3] 4.2 NS 3031

[4] 4.4 NS 3031

[5] Detached dwellings are defined as single-family dwellings, multi-family dwellings and row-houses.

$Q_{gn,i}$ is the solar and internal heat gain

When calculating $Q_{H,Is,I}$ the heat recovery of ventilation air is accounted for if heat recovery is used as described in chapter 6.1.1.1 and 6.1.1.1.4 in NS 3031. Heat recivered from the DHW-system is assumed to be zero as described in Tabell A.2 "MERKNAD 3" in NS 3031.

The total net energy need is calculated as the sum of energy need for space heating and cooling, energy need for DHW, energy need for pumps and fans, technical appliances and lighting, in addition to the heat needed to protect the heat recovery from freezing over. This is described in chapter 6.2 in NS 3031

The total delivered energy takes the system efficiency into account and is described in chapter 7.2 in NS 3031.

The Norwegian Standard NS 3700(Norsk Standard, 2013)

- Maximum heat loss by transmission and infiltration[6]
  - Dwelling with $A_{fl} < 100$ m^2, $H''_{tr,inf} \leq 0.53$ [W/m^{2}K]
  - Dwelling with 100 m^2 < $A_{fl} < 250$ m^2, $H''_{tr,inf} \leq 0.48$ [W/m^{2}K]
  - Dwelling with $A_{fl} \geq 250$ m^2, $H''_{tr,inf} \leq 0.43$ [W/m^{2}K]

Maximum net energy need for space heating, depending on climatic conditions

Table 45

Average external temperature during the year θ_{ym}	Maximum calculated net energy need for space heating kWh/(m^2·year)	
	Dwelling where $A_{fl} < 250$ m^2	Dwelling where $A_{fl} \geq 250$ m^2
≥ 6.3 °C	$15 + 5.4 \times \frac{(250 - A_{fl})}{100}$	15
< 6.3 °C	$15 + 5.4 \times \frac{(250 - A_{fl})}{100} + \left(2.1 + 0.59 \times \frac{(250 - A_{fl})}{100}\right) \times (6.3 - \theta_{ym})$	$15 + 2.1 \times (6.3 - \theta_{ym})$

θ_{ym} shall be calculated in Accordance with NS-EN ISO 15927 – 1:2003 as the mean temperature over the year, based on mean temperatures calculated for each day. Calculation of the net energy demand for building before evaluation against the standard shall be based on NS 3031. Internal heat gains and air usage should be found in NS 3031 Table A.6.

- The building shall be constructed in such a way that thermal comfort can be achieved without cooling.

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[6] A_{fl} is the heated part of the BRA

- The heating demand should be covered to a large extent by other energy carriers than electricity or fossil fuels. Calculated delivered electricity and fossil energy shall be less than total net energy need minus 50 % of net energy demand for hot water.

Table 46 Minimum requirement of NS 3700, for Passive House

Attribute	Passive House
U-value windows and doors	≤ 0.80 [W/m^{2}K]
Normalized thermal bridging value Ψ”	≤ 0.03 [W/m^{2}K]
Average temperature efficiency for heat recover system	≥ 80%
SFP for the ventilation	≤ 1.5 [kW/(m^3/s)]
Leakage rate at 50 Pa, n_{50}	≤ 0.60 h^{-1}

Table 47 Typical u-values for Passive Houses

Building element	U-value Passive House [W/(m^{2}K)]
Wall	0.10 – 0.12
Roof	0.08 – 0.09
Floor	0.08

Table 48:Energy demand for lights, technical appliances and hot water.

Building type	Lighting appliances		Technical equipment		Domestic hot water		Min. specific airflow
	W/m^2	kWh/(m^2·year)	W/m^2	kWh/(m^2·year)	W/m^2	kWh/(m^2·year)	m^3/(h·m^2)
Detached dwellings[7]	1.95	11.4	3.00	17.5	5.1	29.8	1.2

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[7] Detached dwellings are defined as single-family dwellings, multi-family dwellings and row-houses.

The Norwegian Energy Labeling System(Energimerking, 2013a)

Energimerkeordningen for bygninger / Energy grading for buildings

New enery scale from 01.07.13

01.07.2013

Building category	Delivered energy per m^2 heated BRA (kWh/m^2)						
	A	B	C	D	E	F	G
	Less or equal to	Less or equal to	Less or equal to	Less or equal to	Less or equal to	Less or equal to	No limit
Small house	85,00+ 800/A	115,00+ 1600/A	145,00+ 2500/A	175,00+ 4100/A	205,00+ 5800/A	250,00+ 8000/A	> F
Apartment block	75,00+ 600/A	95,00+ 1000/A	110,00+ 1500/A	135,00+ 2200/A	160,00+ 3000/A	200,00+ 4000/A	> F
Nursery	80.00	110.00	145.00	180.00	220.00	275.00	> F
Office building	85.00	115.00	145.00	180.00	220.00	275.00	> F
School	70.00	100.00	135.00	175.00	220.00	280.00	> F
University and college of higher education	85.00	125.00	160.00	200.00	240.00	300.00	> F
Hospital	165.00	235.00	305.00	360.00	415.00	505.00	> F
Nursing home	140.00	190.00	240.00	295.00	355.00	440.00	> F
Hotel	125.00	185.00	240.00	290.00	340.00	415.00	> F
Sporting facility	115.00	160.00	205.00	275.00	345.00	440.00	> F
Commercial building	105.00	155.00	210.00	255.00	300.00	375.00	> F
Cultural building	85.00	130.00	175.00	215.00	255.00	320.00	> F
Light industrial building, workshop	100.00	140.00	185.00	250.00	315.00	405.00	> F

A = heated area of BRA [m^2]

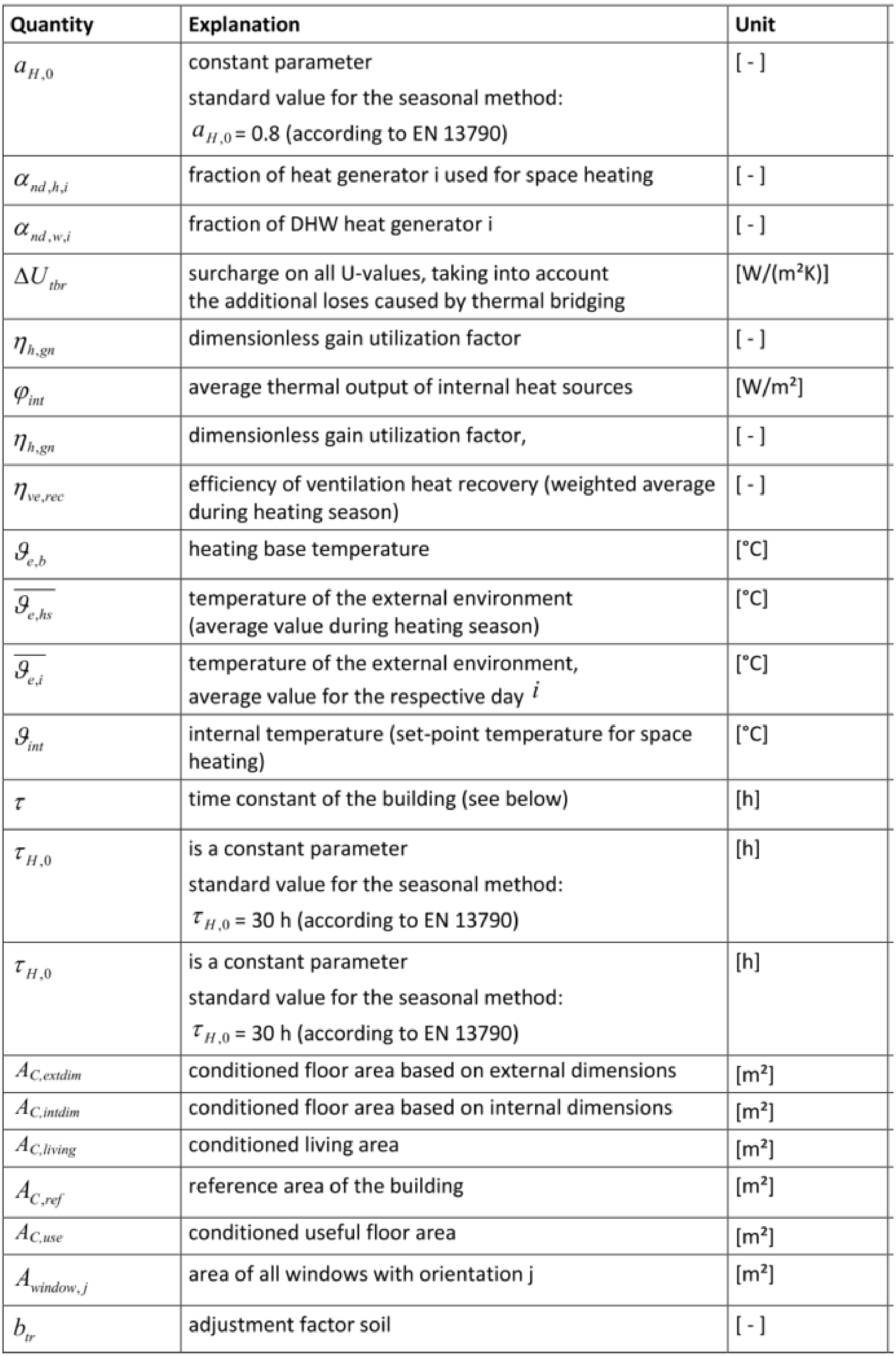
Upper limit for grade C is based on level for TEK 2010.

Limits for scaling depends onheated BRA, and is calculated within two decimals.

EMS	Version 6.73
Valid from	01.07.2013
Changes	See assumptions underneath

Appendix B

The TABULA Abbreviations for all parameters used (Loga and Diefenbach, 2013)

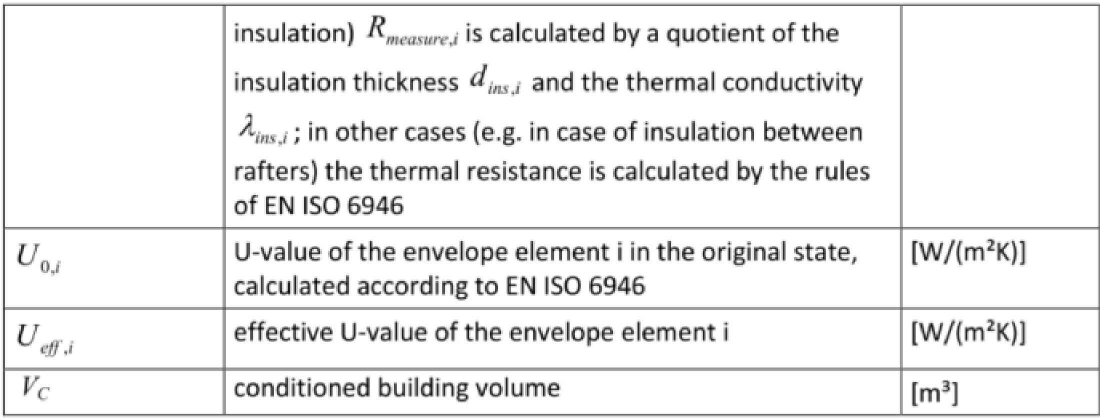


Quantity	Explanation	Unit
$a_{H,0}$	constant parameter standard value for the seasonal method: $a_{H,0}$ = 0.8 (according to EN 13790)	[-]
$\alpha_{nd,h,i}$	fraction of heat generator i used for space heating	[-]
$\alpha_{nd,w,i}$	fraction of DHW heat generator i	[-]
ΔU_{tbr}	surcharge on all U-values, taking into account the additional loses caused by thermal bridging	[W/(m²K)]
$\eta_{h,gn}$	dimensionless gain utilization factor	[-]
φ_{int}	average thermal output of internal heat sources	[W/m²]
$\eta_{h,gn}$	dimensionless gain utilization factor,	[-]
$\eta_{ve,rec}$	efficiency of ventilation heat recovery (weighted average during heating season)	[-]
$\vartheta_{e,b}$	heating base temperature	[°C]
$\overline{\vartheta_{e,hs}}$	temperature of the external environment (average value during heating season)	[°C]
$\overline{\vartheta_{e,i}}$	temperature of the external environment, average value for the respective day i	[°C]
ϑ_{int}	internal temperature (set-point temperature for space heating)	[°C]
τ	time constant of the building (see below)	[h]
$\tau_{H,0}$	is a constant parameter standard value for the seasonal method: $\tau_{H,0}$ = 30 h (according to EN 13790)	[h]
$\tau_{H,0}$	is a constant parameter standard value for the seasonal method: $\tau_{H,0}$ = 30 h (according to EN 13790)	[h]
$A_{C,extdim}$	conditioned floor area based on external dimensions	[m²]
$A_{C,intdim}$	conditioned floor area based on internal dimensions	[m²]
$A_{C,living}$	conditioned living area	[m²]
$A_{C,ref}$	reference area of the building	[m²]
$A_{C,use}$	conditioned useful floor area	[m²]
$A_{window,j}$	area of all windows with orientation j	[m²]
b_{tr}	adjustment factor soil	[-]

c_h c_w	annual energy costs for space heating and domestic hot water	[€/(m^{2}a)]
c_m	internal heat capacity per m^2 reference area	[Wh/m^{2}K]
$c_{p,air}$	volume-specific heat capacity of air	[Wh/(m^{3}K)]
d_{hs}	length of the heating season expressed in days	[d/a]
d_i	duration of day i = 1 d i index of the days of a year	[d]
$e_{g,h,i}$	heat generation expenditure factor of heat generator i used for space heating	[-]
$e_{g,w,i}$	heat generation expenditure factor of DHW heat generator i	[-]
$A_{env,i}$	area of envelope element i	[m^2]
$f_{adapt,k}(q_{del})$	adaptation factor of type k, as a function of the delivered energy q_{del} (sum of energywares without auxiliary electricity) determined by standard calculation method	[-]
$f_{co2,aux}$	carbon dioxide emission factor of electricity used for auxiliary devices	[g/kWh]
$f_{co2,h,i}$ $f_{co2,w,j}$	carbon dioxide emission factors of the energyware used by heat generator i of the heating system and by heat generator j of the hot water system	[g/kWh]
F_F	frame are fraction of the windows	[-]
F_{nu}	dimensionless correction factor for non-uniform heating, taking into account systematic deviations of the set-point temperature and the actual average temperature (time average over night and day as well as space average over living areas and reduced or indirectly heated spaces)	[-]
$f_{p,nonren,aux}$	non-renewable primary energy factor of electricity used for auxiliary devices	[-]
$f_{p,nonren,h,i}$ $f_{p,nonren,w,j}$	non-renewable primary energy factors of the energyware used by heat generator i of the heating system and by heat generator j of the hot water system	[-]
$f_{p,total,aux}$	total primary energy factor of electricity used for auxiliary devices	[-]
$f_{p,total,h,i}$ $f_{p,total,w,j}$	total primary energy factors of the energyware used by heat generator i of the heating system and by heat generator j of the hot water system	[-]
F_{sh}	reduction factor external shading	[-]
F_W	is a reduction factor, considering radiation non-perpendicular to the glazing	[-]
$g_{gl,n}$	total solar energy transmittance for radiation perpendicular to the glazing	[-]

$h_{room,ve\ ref}$	ventilation reference room height	[m]
H_{tr}	overall heat transfer coefficient by transmission	[W/K]
h_{tr}	heat transfer coefficient by transmission per m^2 reference floor area	[W/(m^2K)]
h_A , h_B	are constants, depending on the building type	[W/(m^2K)]
H_{ve}	total heat transfer by ventilation	[W/K]
$I_{Sol,j}$	average global irradiation on surfaces with orientation j during the heating season	[m^2]
$I_{sol,k,hs}$	global solar radiation on 1 m^2 surface of orientation k during the heating season	[kWh/(m^2a)]
$I_{sol,k,i}$	global solar radiation on 1 m^2 surface of orientation k during day i	[kWh/(m^2d)]
k	orientation of a transparent surface	[-]
$m_{co2,h}$ $m_{co2,w}$	annual carbon dioxide emissions for space heating and domestic hot water	[kg/a]
$n_{air,infiltr}$	air change rate by infiltration	[1/h]
$n_{air,use}$	average air change rate during heating season, related to the utilisation of the building	[1/h]
p_{aux}	price of electricity used for auxiliary devices	[€/kWh]
$p_{h,i}$ $p_{w,j}$	prices of the energyware used by heat generator i of the heating system and by heat generator j of the hot water system	[€/kWh]
$q_{del,h,adapt,i}$ $q_{del,w,adapt,j}$	expectation value of the measured consumption for space heating and DHW	[kWh/(m^2a)]
$q_{del,h,adapt,i}$ $q_{del,w,adapt,j}$	annual energy use of heat generator i of the heating system and of heat generator j of the hot water system per m^2 reference floor area, adapted to the typical level of measured consumption	[kWh/(m^2a)]
$q_{del,h,aux}$ $q_{del,w,aux}$	annual auxiliary energy use of heat generator i of the heating system and of heat generator j of the hot water system per m^2 reference floor area	[kWh/(m^2a)]
$q_{del,h,i}$ $q_{del,w,j}$	annual energy use (delivered energy) of heat generator i of the heating system and of heat generator j of the hot water system per m^2 reference floor area, calculated by applying the standard boundary conditions	[kWh/(m^2a)]
$q_{d,h}$	annual effective heat loss of the space heating distribution system per m^2 reference floor area	[kWh/(m^2a)]
$q_{d,w}$	annual heat loss of the DHW distribution system per m^2 reference floor area	[kWh/(m^2a)]
$q_{d,w,h}$	recoverable heat loss of the DHW distribution system per m^2 reference floor area	[kWh/(m^2a)]

$q_{g,h,out}$	heat output of heat generator i used for space heating	[kWh/(m²a)]
$q_{g,w,h}$	recoverable heat loss of the DHW heat generators per m² reference floor area	[kWh/(m²a)]
$q_{g,w,out}$	heat output of DHW heat generator i	[kWh/(m²a)]
$Q_{H,gn}$	total heat gains for the heating mode	[kWh/a]
$Q_{H,nd}$	building energy need for heating, assumed to be greater than or equal to 0	[kWh/a]
Q_{ht}	total heat transfer for the heating mode	[kWh/a]
$Q_{ht,tr}$	total heat transfer by transmission during the heating season	[kWh/a]
$Q_{ht,ve}$	total heat transfer by ventilation during the heating season	[kWh/a]
$q_{ht,ve}$	annual heat transfer by ventilation per m² reference floor area	[kWh/(m²a)]
$q_{nd,h}$	annual energy need for heating (useful heat) per m² reference floor area	[kWh/(m²a)]
$q_{nd,w}$	annual energy need for domestic hot water (useful heat) per m² reference floor area	[kWh/(m²a)]
$q_{p,nonren,h}$ $q_{p,nonren,w}$	non-renewable primary energy demand for heating and hot water	
$q_{p,total,h}$ $q_{p,total,w}$	total primary energy demand for heating and hot water	[kWh/(m²a)]
$q_{s,h}$	annual effective heat loss of the heating system storage per m² reference floor area	[kWh/(m²a)]
$q_{s,w}$	annual heat loss of the DHW storages per m² reference floor area	[kWh/(m²a)]
$q_{s,w,h}$	recoverable heat loss of the DHW storages per m² reference floor area	[kWh/(m²a)]
$q_{w,h}$	recoverable heat loss of the DHW system per m² reference floor area	[kWh/(m²a)]
$q_{ve,h,rec}$	space heating contribution of the ventilation heat recovery unit per m² reference floor area	[kWh/(m²a)]
$R_{0,i}$	thermal resistance of the envelope element i in the original state, calculated according to EN ISO 6946	[m²K/W]
$R_{add,i}$	additional thermal resistance due to unheated space bordering at the construction element i	[m²K/W]
$R_{eff,i}$	effective thermal resistance of the envelope element i	[m²K/W]
$R_{measure,i}$	(additional) thermal resistance of a thermal refurbishment measure applied to the element i in case of a simple insulation measure (additional layer of	[m²K/W]



	insulation) $R_{measure,i}$ is calculated by a quotient of the insulation thickness $d_{ins,i}$ and the thermal conductivity $\lambda_{ins,i}$; in other cases (e.g. in case of insulation between rafters) the thermal resistance is calculated by the rules of EN ISO 6946	
$U_{0,i}$	U-value of the envelope element i in the original state, calculated according to EN ISO 6946	[W/(m²K)]
$U_{eff,i}$	effective U-value of the envelope element i	[W/(m²K)]
V_C	conditioned building volume	[m³]

Appendix C

In this appendix all equations used to calculate the energy balance are presented. They are all based on the equations given in the TABULA method(Loga and Diefenbach, 2013)

Energy need for space heating: $Q_{H,nd} = Q_{ht,ve} + Q_{ht,tr} - n_{h,gn} \cdot (Q_{sol} + Q_{int})$

Heat loss/gain due to heat generators for space heating:

$$Q_{g.h} = Q_{del.h} + n_{h.gn} \cdot (Q_{ve.h.rec}+Q_{w.h}) - Q_{H.nd} - Q_{s.h} - Q_{d.h}$$

Heat loss/gain due to heat generators for DHW: $Q_{g.w} = Q_{del.w} - Q_{nd.w} - Q_{s.w} - Q_{d.w}$

Gain utilization factor for heating:

$$\eta_{h\_gn} = \frac{1 - y^{a_H}}{1 - y^{a_H+1}}$$

Solar heat load during heating season:

$Q_{sol} = F_{sh} \cdot (1-F_F) \cdot F_W \cdot g_{gl.n} \cdot (A_{window.hor} \cdot I_{sol\_hor} + A_{window.east} \cdot I_{sol\_east} + A_{window.west} \cdot I\_{sol\_west} + A_{window.north} \cdot I_{sol\_north} + A_{window.south} \cdot I_{sol\_south})$

Internal heat gains durig heating season: $Q_{int} = t_{døgn} \cdot \varphi_{int} \cdot d_{hs} \cdot A_{C.ref}$

Heat transfer by ventilation during heating season:

$Q_{ht,ve} = 0.024 \text{ kh/day} \cdot H_{ve} \cdot F_{nu} \cdot (u_{int} - u_e) \cdot d_{hs}$

Heat transfer by transmission during heating season:

$Q_{ht,tr} = 0.024 \text{ kh/day} \cdot H_{tr} \cdot F_{nu} \cdot (u_{int} - u_e) \cdot d_{hs}$

Energy use for heat generator 1 of the heating system:

$Q_{del,h,1} = a_{nd.h.1} \cdot e_{g.h.1} \cdot (Q_{H.nd} - n_{h.gn} \cdot (Q_{w.h} +Q_{ve.h.rec}) + Q_{d.h} + Q_{s.h})$

Energy use for heat generator 1 of the heating system:

$Q_{del,h,2} = a_{nd.h.2} \cdot e_{g.h.2} \cdot (Q_{H.nd} - n_{h.gn} \cdot (Q_{w.h} + Qv_{e.h.rec}) + Q_{d.h} + Q_{s.h})$

Energy use for heat generator 1 of the heating system:

$Q_{del,h,3} = a_{nd.h.3} \cdot e_{g.h.3} \cdot (Q_{H.nd} - n_{h.gn} \cdot (Q_{w.h} + Q_{ve.h.rec}) + Q_{d.h} + Q_{s.h})$

Energy use for all the heat generators of the heating system: $Q_{del,h} = Q_{del.h.1} + Q_{del.h.2} + Q_{del.h.3}$

The space heating contribution of the ventilation heat: $Q_{ve,h,rec} = n_{ve.rec} \cdot Q_{ht.ve}$

Recoverable heat loss from the DHW system: $Q\_{w,h} = (q_{g.w.h} + q_{s.w.h} + q_{d.w.h}) \cdot A_{C.ref}$

Annual effective heat loss from the heating system storage: $Q_{s,h} = q_{s.h} \cdot A_{C.ref}$

Annual effective heat loss of the space heating distribution: $Q_{d,h} = q_{d.h} \cdot A_{C.ref}$

Energy use for domestic hot water heat generator 1:

$$Q_{del,w,1} = a_{nd.w.1} \cdot e_{g.w.1} \cdot (Q_{nd.w} + Q_{d.w} + Q_{s.w})$$

Energy use for domestic hot water heat generator 2:

$$Q_{del,w,2} = a_{nd.w.2} \cdot e_{g.w.2} \cdot (Q_{nd.w} + Q_{d.w} + Q_{s.w})$$

Energy use for domestic hot water heat generator 3:

$$Q_{del,w,3} = a_{nd.w.3} \cdot e_{g.w.3} \cdot (Q_{nd.w} + Q_{d.w} + Q_{s.w})$$

Energy use for all the domestic hot water heat generators: $Q_{del,w} = Q_{del.w.1} + Q_{del.w.2} + Q_{del.w.3}$

Annual energy need for domestic hot water: $Q_{nd,w} = q_{nd.w} \cdot A_{C.ref}$

Annual heat loss from the DHW storage: $Q_{s,w} = q_{s.w} \cdot A_{C.ref}$

Annual heat loss from the DHW distribution: $Q_{d,w} = q_{d.w} \cdot A_{C.ref}$

Summary of changing parameters and the sources:

In the following table all parameters that are changed during the calculations are summarized together with the sources values have been based on.

Parameter	**Description**	**Source**
$A_{C,ref}$	Reference area	(Mjønes et al., 2012)
$A_{window.hor}$	Area of all windows with horizontal orientation	
$A_{window.east}$	Area of all windows with orientation east	
$A_{window.west}$	Area of all windows with orientation west	
$A_{window.north}$	Area of all windows with orientation north	
$A_{window.south}$	Area of all windows with orientation south	
$A_{env,wall}$	Area of envelope area wall	
$A_{env,window}$	Area of envelope area window	
$A_{env,floor}$	Area of envelope area floor	
$A_{env,door}$	Area of envelope area door	
$A_{env,roof}$	Area of envelope area roof	
$\alpha_{nd,h,1}$	Fraction of heat generator 1 for space heating system	Based on literary search these were chosen as described in chapter 3.2.1
$\alpha_{nd,h,2}$	Fraction of heat generator 2 for space heating system	
$\alpha_{nd,h,3}$	Fraction of heat generator 3 for space heating system	

$\alpha_{nd,w,1}$	Fraction of heat generator 1 for domestic hot water system	
$\alpha_{nd,w,2}$	Fraction of heat generator 2 for domestic hot water system	
$\alpha_{nd,w,3}$	Fraction of heat generator 3 for domestic hot water system	
d_{hs}	Length of the heating season	(Olseth and Skartveit, 1987) and (Norsk Standard, 2011)
$e_{g,h,1}$	Heat generation expenditure factor of heat generator 1 for space heating system	Direct electricity, value from (Loga and Diefenbach, 2013)
$e_{g,h,2}$	Heat generation expenditure factor of heat generator 2 for space heating system	Wood as energy source (Pettersen et al., 2005)
$e_{g,h,3}$	Heat generation expenditure factor of heat generator 3 for space heating system	Not used
$e_{g,w,1}$	Heat generation expenditure factor of heat generator 1 for domestic hot water system	Direct electricity (Loga and Diefenbach, 2013)
$e_{g,w,2}$	Heat generation expenditure factor of heat generator 2 for domestic hot water system	Not used
$e_{g,w,3}$	Heat generation expenditure factor of heat generator 3 for domestic hot water system	Not used
$g_{gl,n}$	Total solar energy transmittance for radiation perpendicular to the glazing	Depending on U-value of window, value found in: (TABULA, 2013)
$I_{sol,hor}$	Average global irradiation on horizontal surface during the heating season	As described in chapter 3.2.1 found from two sources: (Olseth and Skartveit, 1987) and (Norsk Standard, 2011)
$I_{sol,east}$	Average global irradiation on surfaces with orientation east during heating season	
$I_{sol,west}$	Average global irradiation on surfaces with orientation west during heating season	
$I_{sol,north}$	Average global irradiation on surfaces with orientation north during heating season	
$I_{sol,south}$	Average global irradiation on surfaces with orientation south during heating season	
ϑ_{int}	The internal temperature (set-point temperature for space heating)	(Mjønes et al., 2012)
ϑ_{e}	The temperature of the external environment (average value during heating season)	(Olseth and Skartveit, 1987) and (Norsk Standard, 2011)
$n_{air,use}$	Average air change rate during heating season, related to the utilisation of the building	(Mjønes et al., 2012)
$n_{air,infiltr}$	Air change by infiltration (see TABULA values)	(Loga and Diefenbach, 2013)
$\eta_{ve,rec}$	Efficiency of ventilation heat recovery	TEK 10 and NS3700
$q_{s,w,h}$	Recoverable heat loss of the storage of domestic	German values for direct

	hot water system per m2 reference floor area	electric heating (TABULA, 2013)
$q_{d,w,h}$	Recoverable heat loss of the distribution system of the domestic hot water per m2 reference floor area	
$q_{s,h}$	Annual effective heat loss of space heating storage per m2 reference floor area	No storage of heat
$q_{d,h}$	Annual effective heat loss of space heating distribution system per m2 reference floor area	No storage of heat
$q_{nd,w}$	Annual energy need for domestic hot water per m2 reference floor area	(Norsk Standard, 2011)
$q_{s,w}$	Annual heat loss of the DHW storage per m2 reference floor area	German values for direct electric heating (TABULA, 2013)
$q_{d,w}$	Annual heat loss of the DHW distribution system per m2 reference floor area	
$R_{0,wall}$	Thermal resistance of the walls in original state	(Mjønes et al., 2012)
$R_{0,window}$	Thermal resistance of the windows in original state	
$R_{0,floor}$	Thermal resistance of the floor in original state	
$R_{0,door}$	Thermal resistance of the door in original state	
$R_{0,roof}$	Thermal resistance of the roof in original state	
$R_{measure,wall}$	Additional thermal resistance of a thermal refurbishment measure applied to element wall	Based on U-values from either (Mjønes et al., 2012), TEK 10 or NS 3700
$R_{measure,window}$	Additional thermal resistance of a thermal refurbishment measure applied to element window	
$R_{measure,floor}$	Additional thermal resistance of a thermal refurbishment measure applied to element floor	
$R_{measure,door}$	Additional thermal resistance of a thermal refurbishment measure applied to element door	
$R_{measure,roof}$	Additional thermal resistance of a thermal refurbishment measure applied to element roof	
$R_{add,wall}$	Additional thermal resistance due to unheated space bordering at the construction element wall	As the Enova report calculated U-values for the original elements as effective U-values, taking cold adjacent rooms/attics etc. into account, these are always set to 0.
$R_{add,window}$	Additional thermal resistance due to unheated space bordering at the construction element window	
$R_{add,floor}$	Additional thermal resistance due to unheated space bordering at the construction element floor	
$R_{add,door}$	Additional thermal resistance due to unheated space bordering at the construction element door	
$R_{add,roof}$	Additional thermal resistance due to unheated space bordering at the construction element roof	

ΔU_{tbr}	Surcharge on all U-values	Based on (Loga and Diefenbach, 2013) in combination with TEK 10 and NS 3700.

Appendix D

The attached CD contains both the Energy Balance Model and the Project report.

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