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Typologies and energy demand modelling of the Norwegian building stock (single-family houses 1981-2010)

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Project thesis

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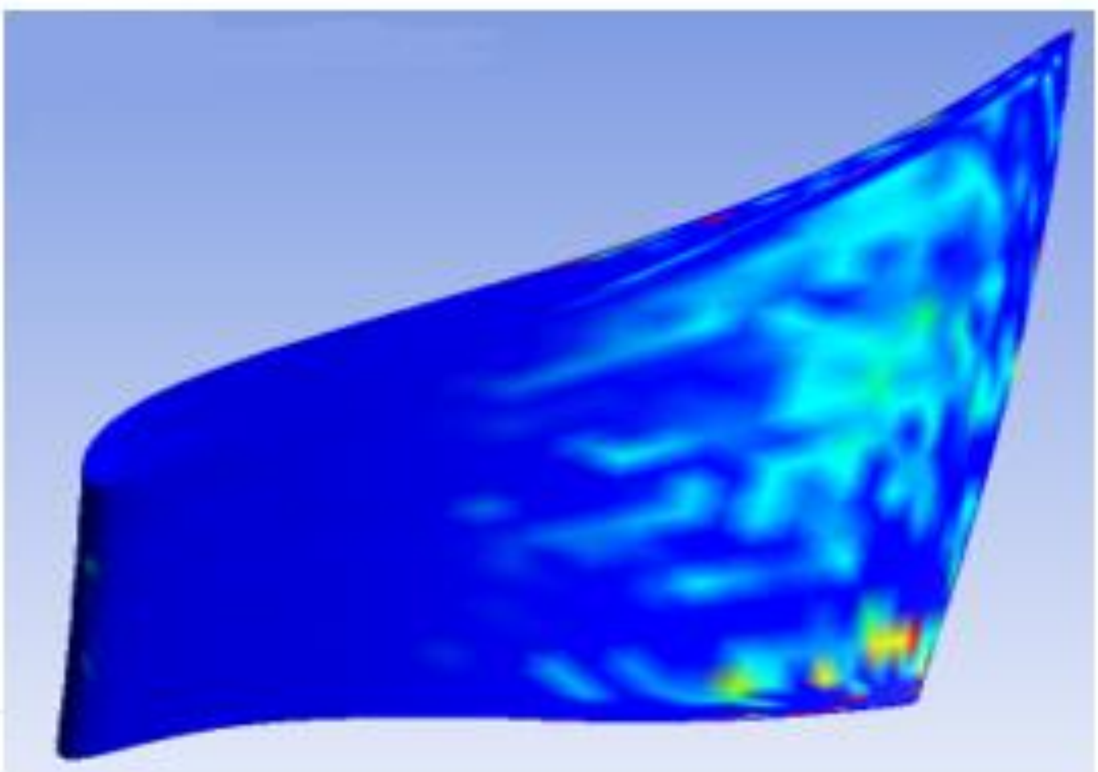

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Foreword

I would like to thank to Professor Helge Brattebø for supervising this project and to all group members that were cooperating with me during this semester, especially to Marie Folstad who developed the MFA model. In consultation with the supervisor, the following tasks of the project content was deleted from the work load: 2e – LCA and/or energy and carbon emission models and analysis; 5 – comparison results with Energimerking and 7- contributing to IndEcol's dynamic building stock modelling work.

Summary

Currently 40% of energy use in Norway is related to buildings (Igor Sartori, 2009). Almost half of the Norwegian dwelling stock consists of single-family houses (Risholt, 2011). The building stock is also growing due to structural changes in Norwegian society. The number of persons per dwelling has decreased. In 1920 only two per cent lived alone and by 1990 the percentage changed to 14% (SSB, 2013). In the beginning of 2013 the average household size was 2.2 persons per household (SSB, 2013). Social phenomena like an increased number of divorces and other lifestyle changes are driving demand for new housing (SSB, 2012b).

The energy demand for heating in the housing sectors, can be reduced by refurbishment of existing stock and by changing user behavior. In this rapport, the focus is set upon evaluation of existing single-family houses stock split by three periods: 1981-1990, 1991-2000 and 2001-2010. Each of the cohort is discussed according to the energy demand for space heating and domestic hot water system. Using Tabula Calculation Methodology, MFA model was developed. Equations for energy calculations given in Tabula Calculation Methodology were combined and applied in to the MFA system. The results give an overview over energy demand for an average single-family house split by three periods and by three scenarios: building in its original state, with standard renovation (to the level of TEK-10 standard) and with advanced renovation (to the level of NS3700 standard).

From the results, it can be seen that the success of lowering energy demand for house heavily depends on several parameters like: the situating of the building (climate zone), thickness of the insulation and quality of building's parts.

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1 Introduction

1.1 The motivation for the project

Nowadays 40% of energy use is related to buildings (Risholt, 2011). The dwelling stock in Norway accounts for 3,8 million buildings (Risholt, 2011). Almost one third of this number are single-family detached houses. Most of the existing houses will be still used by 2050. Therefore, it is needed to plan forehead for smart and innovative way of refurbishment of the existing stock, with use of the newest building standards. In 2001, 69% of the buildings had been using electricity as the main source to cover their demand for heating(Enova, 2012). In terms of exergy it is very inefficient way of use energy that can do 100% work, while there is no need for it (low energy values are more efficient for space heating). This project aims to show how by applying different measures to the single-family detached houses from different time-periods, energy demand for heating can be lowered.

1.1 Short introduction to the type of building chosen for the project

Single-family houses compose of 65% of the Norwegian building stock. Most of them (83%) were built from wood (Enova, 2012).

Typical single family houses from period 1981 to 2005 could be illustrated as follows (on the basis of the Advanced Housing Renovation by Solar and Conservation (Thyholt et al., 2009).

Figure 1. Example of typical single-family houses split in to three periods.

Using Tabula Calculation Methodology (Tabula, 2013) the model for calculation energy demand for space heating and DHW system, was created. Three different cohorts were taken to a consideration: single-family house from periods: 1981-1990, 1991-2000, 2001-2010.

The dimensions for envelope parts were chosen on the basis of the average values from statistics (SSB), standards: NS3031, TEK-10, NS3700 and Enova rapport (Enova, 2012). During each period, different type of buildings were built, with different energy demand. Below is a short overview over the most important characteristics of exemplary buildings chosen for the energy demand calculation purposes.

	time period		
single-family house	1981-1990	1991-2000	2001-2010
Reference area (m²)	181	159	168
Area of envelope area wall (m²)	131	124	127
Area of envelope area window (m²)	27	24	25
Area of envelope area floor (m²)	121	106	112
Area of envelope area door (m²)	4	4	4
Area of envelope area roof (m²)	121	106	112
Number of floors	2	2	2
fraction of heat generators for space heating system			
wood stove	0.1	0.2	0.2
direct electricity	0.9	0.8	0.8
fraction of heat generators for DHW system			
electric boiler	1	1	1

Table 1. Cross-comparison of envelope parts area and fraction of heat generators used for space heating and DHW systems, split by three time cohorts.

Looking on period between 1981-2010, most of single-family houses that are existing today, were built in the 80's (Enova, 2012). They account for around 14% of today's single-family houses stock. Dwellings from the 1980 have the highest energy use compared to any other average building in the given periods. In the same time, houses from this period are in the stage of the lifetime when the refurbishment is needed during the next 10 years (Risholt, 2011).

In 1980 upcoming new regulations and requirements for buildings were announced and they were implemented in 1987 as TEK-87. During time from 1991-2000, after implementing of TEK-87 standard, there was bigger focus on indoor air quality and energy efficiency for buildings. That was followed by implementation of TEK-97 in 1997. This standard was also influenced by EEA. Buildings were built with higher standards and had to be energy labeled.

1.2 Questions for the project

During this project, the goal was to answer few questions:

- What are the typical parameters for a single-family detached house during three different periods? What is the condition of existing stock of the single-family houses.

- How implementation of Norwegian building standard and requirements influenced energy demand for heating in the chosen types of houses?

- What parameters influence the most energy demand for heating?

- How the energy demand changes due to behavior of house users.

- Is it possible to achieve passive house standard in each climate zone in Norway?

- What kind of measures are the most energy-effected and which are the most typical to implement for single-family house?

2 Theory

2.1.1. Dynamics of aggregated Norwegian stock building

In 2005 there was around 1,2 million single-family houses (Thyholt et al., 2009). This number is constantly growing due to demand for new living space. In general, most of the existing Norwegian dwelling stock (around 90%) was built after Second World War (Thyholt et al., 2009). In a short 20 year period (from 1982 to 2005) the number of dwelling units increased by 40% (Thyholt et al., 2009). According to SSB, during the same time number of square meters per person increased by around 35% (SSB, 2012a).

On average, single-family type of building has bigger energy demand per square meter than blocks or apartment houses (SSB, 2009). The more compact house is, the less energy is used per square meter for space heating (ratio between number of floors versus total number of units per building).

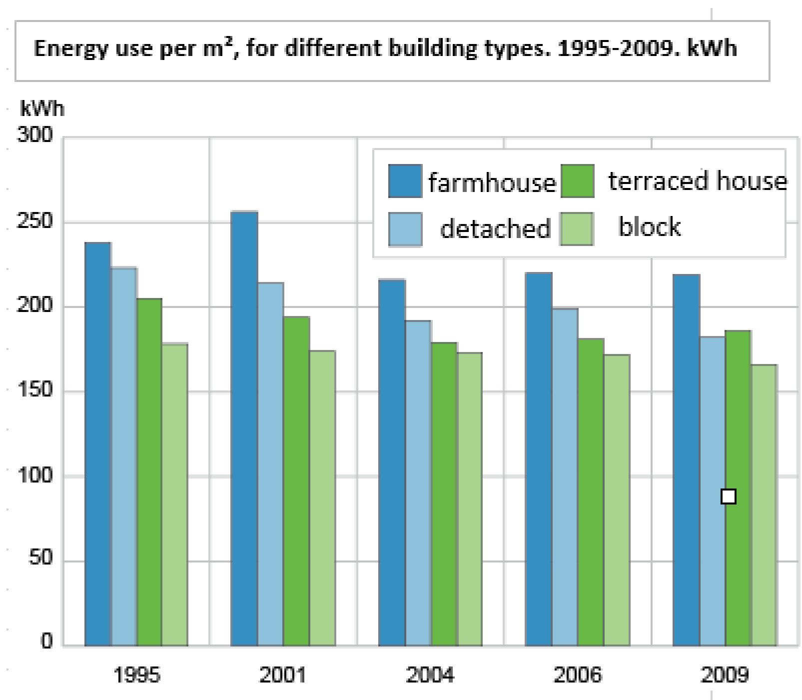

Figure 2. Energy use per m², for different building types. 1995-2009. kWh.

Although that the number of dwellings is increasing along with number of square meters of living area per person, the energy demand is slowly decreasing. This can be due to better insulation in the house and more energy-efficient electric appliances that are nowadays in use in houses.

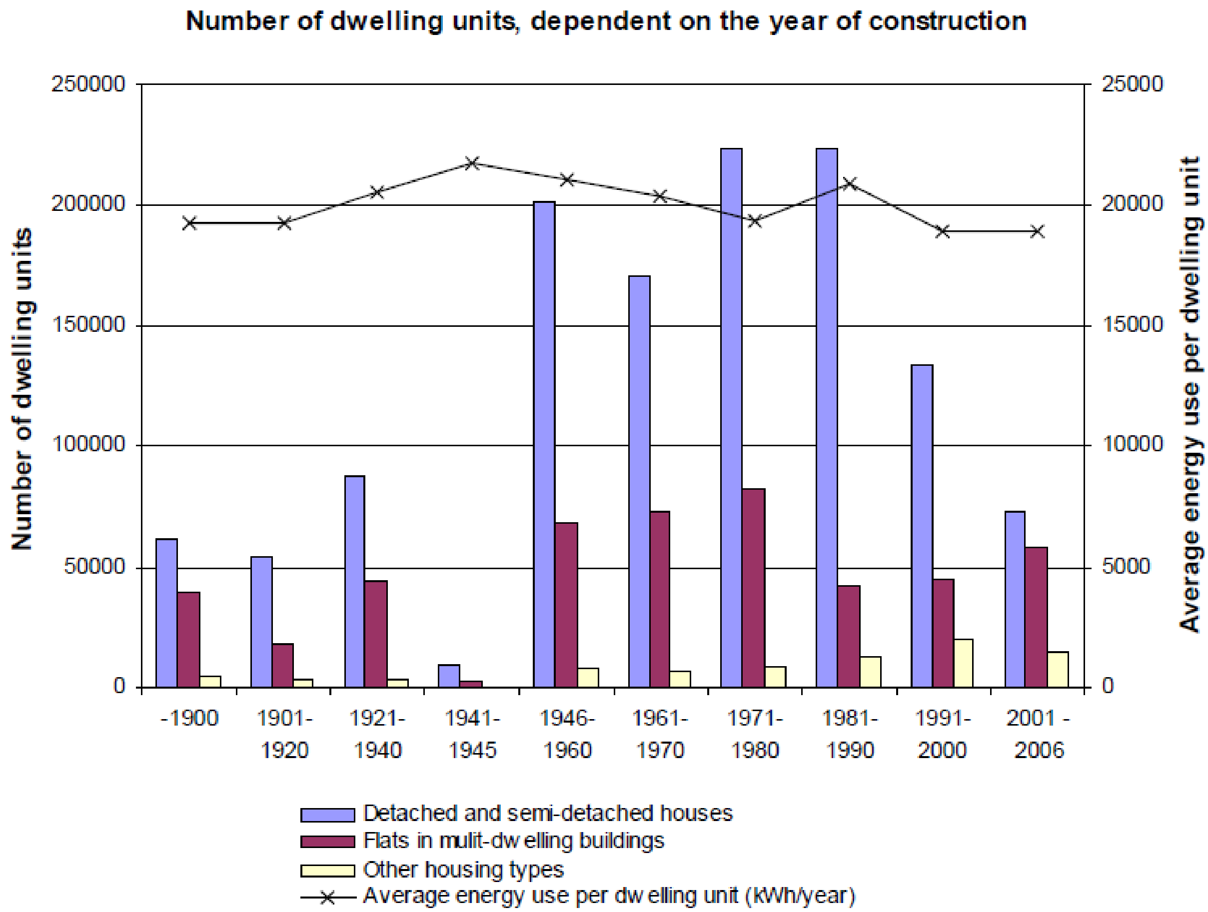

Figure 3. The number of dwellings units, depended on the year of construction. Sources: (Thyholt et al., 2009, SSB, 2007)

2.1.2. Energy demand for DHW and space heating in Norwegian stock

From 1982 to 2005 the stationary energy use in the residential sector has increased by 19%.

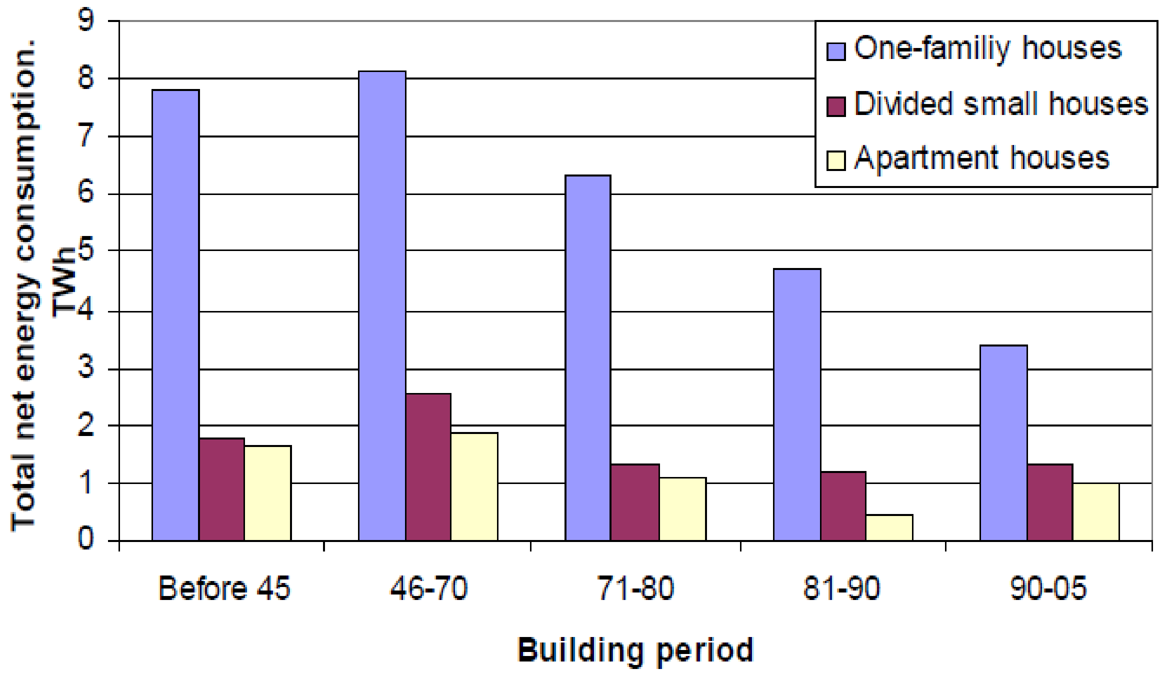

Figure 4. Total useful energy consumption per year for the housing sector (divided by types and building period) (Thyholt et al., 2009).

Nowadays most of dwellings in Norway use electricity as the main supplier for heating demand – about 78% of the 2005 energy use (Thyholt et al., 2009). Electric heating is the most common heating system in Norway (70% of the dwelling uses only this system or with combination with other heating systems). Even hydronic systems that are installed in new dwellings are based on electricity.

The power production in Norway was mostly based until present on hydropower. However, the increasing demand for energy, challenges Norwegian production; hence, more importing of energy from other countries is needed. That means more of European mix, which is ‘dirtier’ (using coal for example to electricity production) than Norwegian (Thyholt et al., 2009). Therefore, there is increased need for using other sources than direct electricity or/and fossil fuels for space heating, DHW systems and ventilation, that account for 75% of the total energy use in dwelling stock (Thyholt et al., 2009).

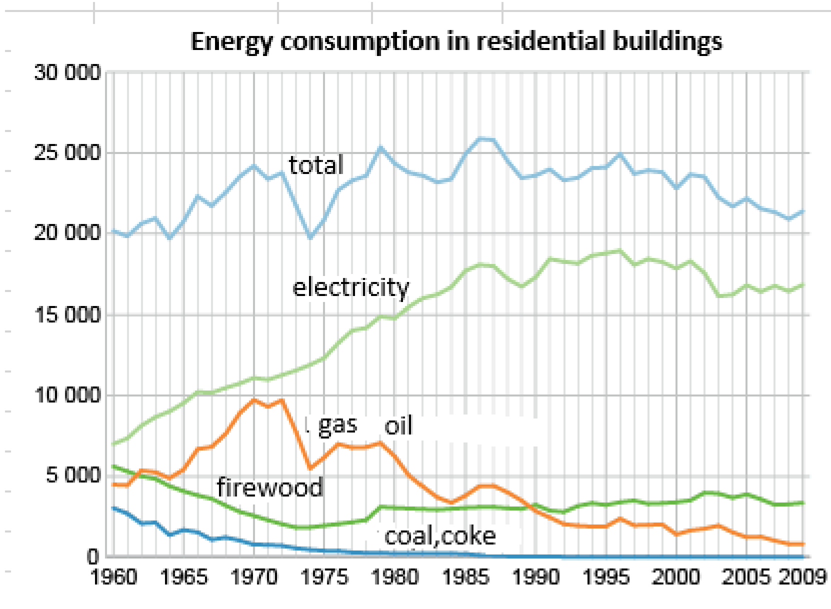

Figure 5. *Energy consumption in residential buildings. (SSB, 2009)*

The figure below shows which energy sources are on average used in different building types. One can see that electricity in Norway is used as the main energy source for energy use in buildings. This high use of electricity for space heating and DHW systems is special among European countries and can be linked to the lower prices for electricity on the Norwegian market, compared to other European countries (Bartlett, 1993).

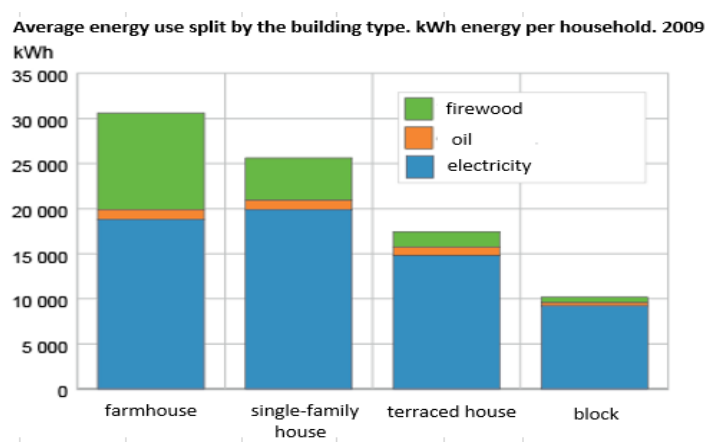

Figure 6. *Average energy use split by the building type (kWh per household) (SSB, 2009).*

2.2 Regulations

The development of the Norwegian standards goes in pair with the development of new technologies used to build. Below one can find a short overview over the Norwegian regulations and standards concerning buildings in Norway (Trond Ivar Bøhn, 2006).

Part of the building	U- value				
	Standard 1949	Standard 1969	Standard 1985	Standard 1987	Standard 1997
Wall	0.93-1.16	0.58-1.28	0.25-0.35 (detached house-0.45)	0.30	0.22
Roof	0.93	0.46-0.58	0.23	0.30	0.15
Floor	-	0.46	0.23-0.30	0.20-3.0	0.15
window	-	-	2.10-2.70	2.40	1.60

Table 2. U- Value requirements from Norwegian Standards for fully heated buildings (with Oslo as a reference climate).

Building regulations and requirements concerning use of energy in buildings serve interest of society. It might be not only profitable for the owners to invest in measures that improve environmental and energy performance of a building but also it serves overall societies' interest to lower energy demand for building stock. Main reason for it can be found in overall usage of energy in Norway and in Europe. In Europe 40% of total final energy use comes from energy consumption in residential and commercial buildings and in the same time this sector is responsible for 36% of the European Union's total CO2 emissions (EU2020, 2008). Below is a short overview over Norwegian standards and guideline for buildings. The selection of standards is linked to chosen periods (1981-20100 that are examined in this rapport.

2.2.1. TEK-97

This standard was revised in 2005 and then again in 2010 (TEK10). The focus in the standard was set on reducing the energy consumption for heating and ventilation compared to the old regulations (standard from 1987). The pressure on lifecycle perspective for materials used to construction was also set as a part of new regulations. Producing with as little energy as possible and reduction of pollution due to production, usage and demolition was strongly taken to consideration.

Building permits had to have documentation for thermal insulation, U-values, heat recovery, airflow, heat loss, building category, area of different parts of envelope, floor height, net heating demand for space heating and ventilation. Energy labeling had to be documented.

According to TEK-97 small houses should use 150 KWh/m2year (NTNU/SINTEF, 2007)

Building element	U-value in W/m²K for indoor temperature ≥20°C
External wall	0.22
Roof	0.15
Floor	1.60
Windows, doors	2.00

Table 3. Requirements for thermal transmittance coefficient (U-value) for building section according to TEK-97 for indoor temperature ≥20°C

2.2.2. TEK - 10

TEK-10 was introduced in 2010 and it is add-on to the plan-and buildings law from 2008. It is an up-date to the earlier standard (TEK-97) and it acknowledges technological solutions in the building sector developed over time (for example: new insulates like rock-wool, which is used to insulate external walls and roofs, or much higher thermal resistance of the windows due to developing three panes windows). Developing and popularization of new technology solutions drives the tightening up of requirements for buildings in standards. One can divide TEK-10 standard in three main parts:

1) General rules for quality of the building materials, environment (indoor and outdoor), security and land use. In this part, one can find specific technical requirements for different building measures (competitive and non- competitive). Verification of requirements is also included. Products for building and CE labeling are linked with EU regulations. TEK 10 sets up general rules for operation, management and maintenance of the building. Requirements for use (BRA-brukareal), outdoor and parking area, building height, and methods for calculations and measurement rules are given.

2) Attention is given to the nature and its forces. Building should be secured from floods, storm or landslides. Placement of the building should be also with respect to the nature of terrain. Adaptation building to the nature (not opposite !).
3) Requirements for building: construction safety and fire-safety. Placement of lifts, rooms, bathrooms, terrace is regulated. Requirements for environment and health: ventilation, thermal indoor clima, radiation, noise and vibrations, light and electrical installations. Low energy demand: here TEK 10 takes to consideration district heating and sets up minimum demands for measures.

In 2010, the EU directive EU 2010/31 came out. TEK 10 is in one way an answer to those more stringent requirements. The main goal is to improve performance of the new buildings and achieving a high level of energy efficiency. Building or renovating, one has to take to consideration TEK 10 standard. The building owner is obligated by this and responsible for following the regulations.

Building element	Minimum demand	Demand
External wall	0.22	0.18
Roof	0.18	0.13
Floor	0.18	0.15
Windows, doors	1.60	1.2

Table 4. U-values in (w/m2K) for TEK 10 standard.

Normalized thermal bridges=sum of all thermal bridges/ heated gross area	**Ψ** (psi) W/(m2K)
Small houses (single family houses, houses with 2-4 apartments and row houses)	0.03
Other buildings	0.06

Table 5. TEK 10 – values for normalized thermal bridges.

Airtightness	Demand	Minimum demand
Small houses (single family houses, houses with 2-4 apartments and row houses)	$N_{50} \leq 2.5$	$N_{50} \leq 3.0$

Other buildings	$N_{50} \leq 1.5$	

Table 6. TEK10 – requirements for airtightness for small houses and other buildings.

Annual Mean temperature efficiency factor for heat exchanger	**η**
	80%

Table 7. TEK 10 – Heat exchanger requirements.

Specific fan power for ventilation system, SFP- factor	Demand (KW/(m3s)
Daytime	2.0
At night	1.0
For dwellings all day	2.5

Table 8. TEK 10 – SFP- factor requirement.

Cooling and temperature control	Demand
Cooling	To avoid using local cooling automatic external solar screening or other measures should be applied to fulfill thermal comfort
Temperature regulation/ control	If it is possible to differ between night and weekend operation, it should be decrease of indoor temperature to 19 degrees Celsius. For sports buildings the indoor temperature should be lowered to 17 degrees.

Table 9. TEK 10 – requirements for cooling and temperature control.

TEK-10 also regulates energy sources for DHW and space heating systems. The oil ovens were banned from use. The standard sets minimum of 40% of energy demand for space heating that should be covered by different energy source than direct electricity and/or fossil fuels.

2.2.3. NS3031:2007+A1:2011

The full name for this standard is NS3031:2007+A1:2011 calculation of energy performance of buildings- methods and data. This standard is a baseline for all calculation method in NS3700.

NS 3031 is designed to provide a common basis for energy calculations for both: according to building regulations and energy requirements and for energy labeling of buildings. In this standard calculation methodology is presented . The parameters of the calculation and definition for different bases for evaluation, such as " Net energy " and " delivered energy" are given. NS 3031 is therefore an important prerequisite for the development of NVE (Norwegian water resources and energy directorate) energy labeling system. Good knowledge of this standard is also necessary to assess which parameters can be changed, in order to for example obtain a better grade on the energy label. Experts are assumed to know this standard. In NS3031 the changes are adapted to new criteria for passive and low energy houses. In the standard the energy requirements with technical requirements for construction are presented for buildings built from 2010. The minimum allowable airflow and internal loads for lighting , equipment and DHW are also included .

2.2.4. NS3700

NS3700 is not a standard that binds builders to comply. It is a guide for those who are showing long time perspective in choosing requirements for the house. NS3700 is a guideline for those who want to obtain a passive house standard. There are few new regulations written in this standard:

- The energy demand for heating should be calculated in accordance with NS3031 standard but it should use local climate data.

- Estimated amount of delivered electrical and fossil energy should be less than the total net energy minus 50% of net energy for hot water.

$$E_{del,el} + E_{del,oil} + E_{del,gas} < E_t - 0.5 * Q_{W,nd} \qquad (1.1)$$

- The more narrow regulations include climate data for monthly calculations – on the basis of data in NS3031 (table M1 and M2). NS3700 standard gives two ways of calculating energy demand for space heating: for external average temperature below 6.3°C:

$$15 + 5.4 * \frac{(250-Aff)}{100} + (2.1+0.59*\frac{(250-Aff)}{100}) *(6.3-\theta ym) \qquad (1.2)$$

And for external average yearly temperature bigger or equal to 6.3°C:

$$15 + 5.4 * \frac{(250 - Aff)}{100} \quad (1.3)$$

- NS3700 requires use of at least 40% for energy from other than direct electricity or/and oil. Also for DHW systems it is required to use not only direct electricity.

- The new lowest requirements for U-Values for different parts of envelope, were also introduced with differentiation between passive house and low-energy building:

Building element	Passive house (W/m²K)	Low-energy building (W/m²K)
External wall (U-value)	0.10-0.12	0.15-0.16
Roof (U-value)	0.08-0-09	0.10-0.12
Floor (U-value)	0.08	0.10-0.12

Table 10. Typical U-values for passive house and low-energy building in accordance with NS3700.

2.2.5. International standards

In the Norwegian standards, some of the methods for calculations are based on the international standard. NS-EN ISO 15927 for example provides guidelines to calculate and present climatic and environmental data that can be used during assessment of the technical qualities of a building (heat and humidity). Because of EU directive 2010/31 (under 20-20-20 objectives on energy efficiency), regarding the energy performance of building, the need for stringing regulations arise (EUcommission, 2008). The goal is to have regulations that will eventually result in our buildings reaching almost zero-energy house standard. The next regulations probably will be introduced in 2015 and then in 2020.

3 Methodology

3.1 Tabula classification

Tabula's Typology Approach is used to compare building stock for energy assessment between European countries. Each of the country has its own methods, comprehensive with national standards, to account for own dataset. Tabula calculation method is giving one way of categorization of the residential stock in Europe and own dataset according to which, each country can build tabula dataset.

Tabula is considering only residential buildings. According to the authors, making the typology for the non-residential building sector would be difficult due to many factors like: data availability or variety of uses.

3.2 How the building matrix is built in Tabula – examples from Sweden and Denmark

In Tabula, for each country there is a standardized typology matrix, which includes exemplary buildings by their size classes: single-family houses, terraced houses, multi-family houses, and apartment blocks. For the Danish and Swedish case, those typologies differ from each other, and each country has different kind of exemplary building.

Type of building	Single-family house	Terraced house	Multi Family house	Apartment Block
Sweden	x	none	x	none
Denmark	x	x	none	x

Table 11. Building types based on Tabula WebTool for Sweden and Denmark.

To give example of how Tabula Typology works below are presented results for energy demand for single-family house built in Denmark and Sweden in similar time, split by the three variants: existing state, usual refurbishment and advanced refurbishment.

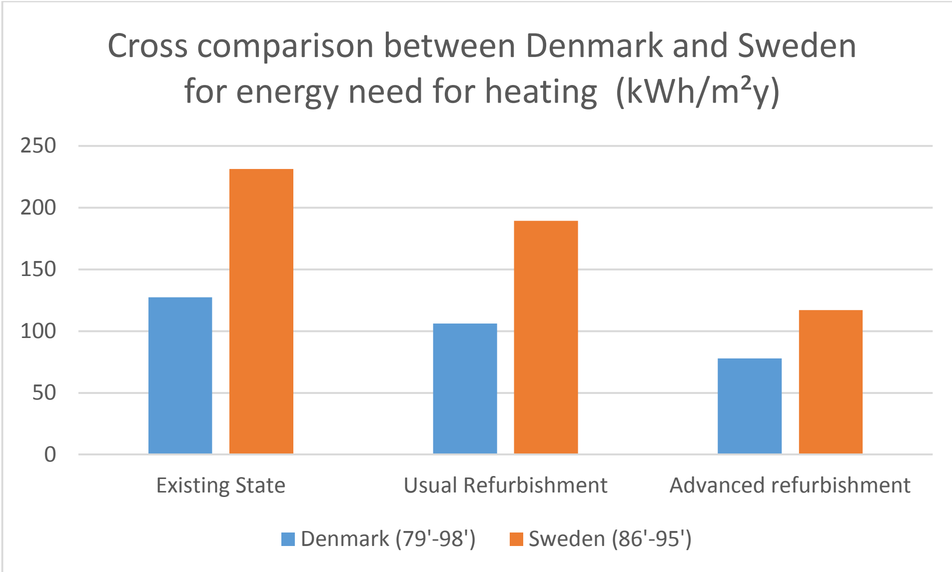

Figure 7. Cross comparison between Denmark and Sweden for energy need for heating for single-family house from one chosen period: Denmark (1979-1998) and Sweden (1986-1995) (source: Tabula Web Tool).

Both countries have parameters for classification of residential buildings: region or climate zone, construction year class, the building size class, thermal envelope values, heat supply system and additional parameters. Refurbishment scenarios presented in Tabula Web Tool for Sweden and Denmark, are taking to consideration measures for upgrading the thermal envelope and the heat supply system. In the Tabula Web Tool results are easy to read. To present short comparison for those countries, the difference between U value for thermal envelope with respect to both countries and state of the building is presented below:

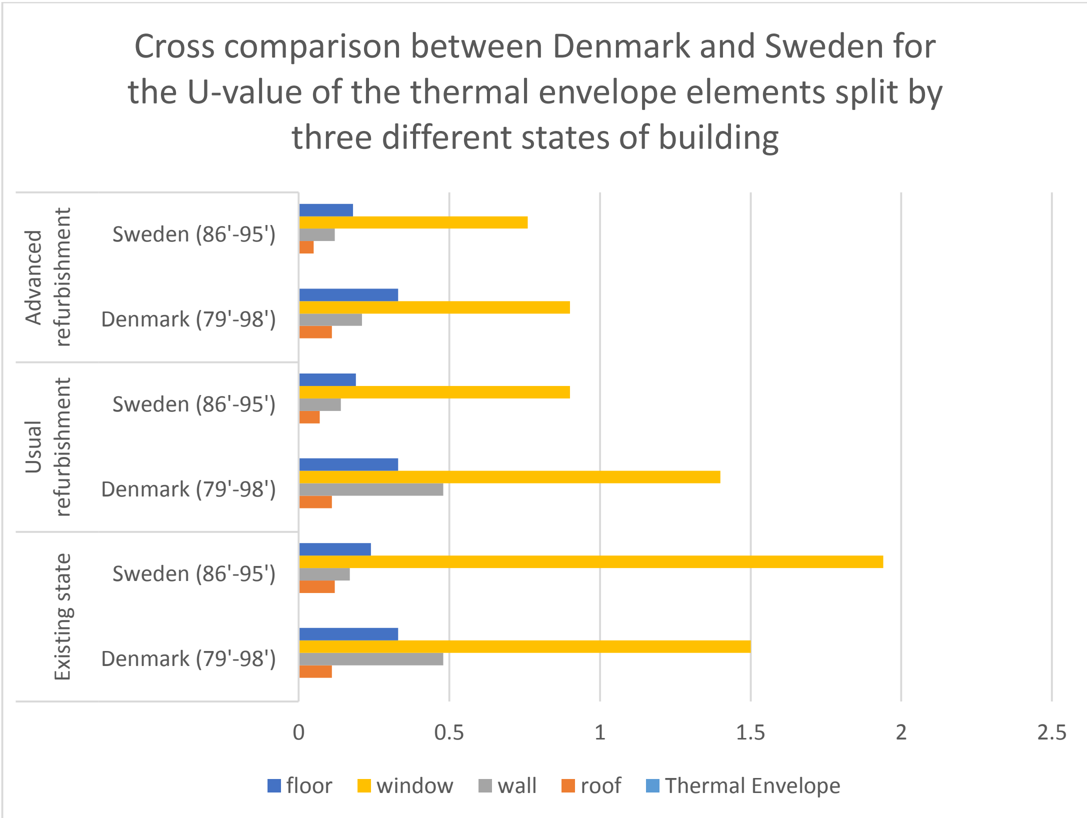

Figure 8. Cross comparison between Denmark and Sweden for the U-value of the thermal envelope elements split by three different states of building (existing, usual refurbishment, advanced refurbishment). Source: Tabula Web Tool.

It is easy to see that U- values differ a lot between Sweden and Denmark. Using different solution for refurbishment scenarios also play role in results for overall energy demand. In Denmark for the single-family house built in period (1979-1998), fossil fuels is the main energy carrier for the building in its original state. For Sweden it is the same. After refurbishment to advanced level, biomass is considered for Sweden case, and as before fossil fuel (but in lesser degree) for Denmark. Refurbishment of the thermal envelope plays the most significant role for reducing overall energy demand for space heating. Although U-values are worse for Denmark than Sweden, the warmer climate zone can play a significant role in the need for thinner or thicker insulation. For Norwegian case one can see from the figure below, that desired U-values for advanced refurbishment (here assumed NS3700 standard level) are much better that U-values expected for the same type of upgrade for Denmark.

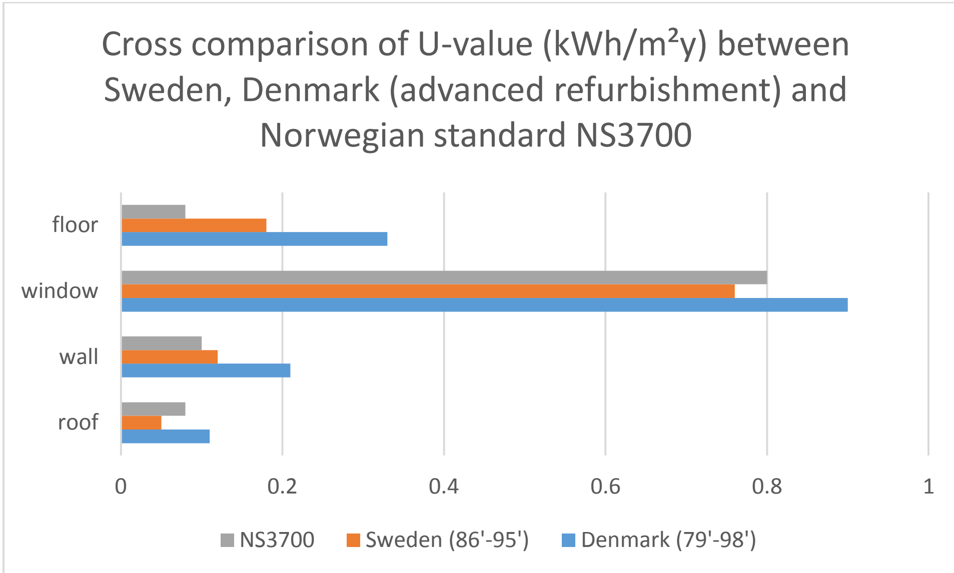

Figure 9. Cross comparison of U-values between Sweden and Denmark (exemplary single-family house for one chose period) with Norwegian standard NS3700.

3.3 Tabula calculation procedure – methods

In the Tabula Calculation Method, the focus is to evaluate what is energy consumption for hot water and space heating for different type of residential buildings considering different parameters like: age of the building, insulation, internal temperature. It is important to notice that cooling, air conditioning; lighting, electric appliances are not included in the calculation method. This has its implications in a choice for parameters used for calculation (assumed parameters). Simplification of calculation method is to 'ensure transparency of the calculations' (Tabula, 2013). The calculation procedure in the Tabula project has its aim to be simple and to be easily applied by users.

The calculations are defined in accordance with European Committee for Standardization. The method takes standard values for the utilization and national and regional climatic data.

3.4 Refurbishment scenarios in Tabula

In the Tabula project, three different scenarios are taken to consideration:

- existing state – the building in its original state,
- standard refurbishment,
- and advanced refurbishment (ambitious refurbishments, typically to the standard of the passive house).

Tabula does not specify what exactly means standard refurbishment. Each country has different national standards. Therefor a standard refurbishment is following the actual standards and 'typical' type of refurbishment done in given country. Usually it is improving of an insulation, replacing windows, installing more efficient ventilation system, modernization of heat and water systems. As one can see – it is quite big spectrum of possibilities that one can implement for standard refurbishment. In specific reports from each country we then can find how they define their typical standard refurbishment.

3.5 MFA model – modelling system for energy demand for space heating and DHW system.

For the purposes of this project, Material Flow Analysis (MFA) model developed by Marie Folstad was used. In the agreement with our supervisor our project group decided on using this model as a base for our calculations based on Tabula Calculation Method. The model is very illustrative and shows in a clear way all of the mass balanced flows and demand for energy usage from each part of the system.

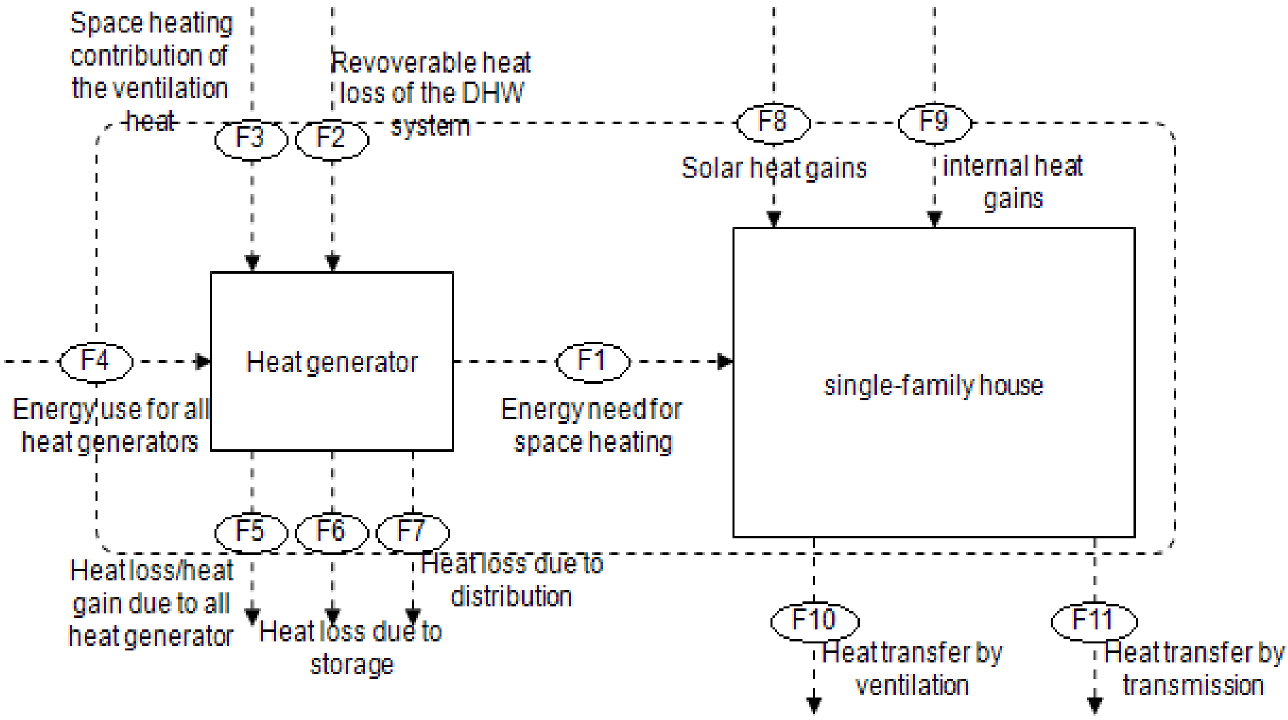

Figure 10. System for energy use for heat generators and space heating.

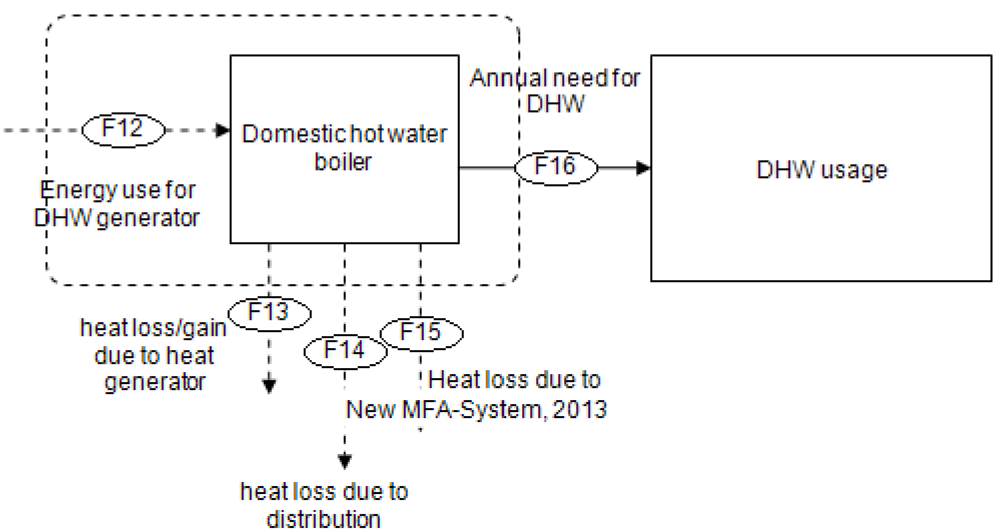

Figure 11. DHW system.

The MFA model is an analytical method of quantifying flows and stocks of materials in a defined system. For this project purposes this method was chosen to be able to show losses and gains of heat in different parts of the system. By changing parameters that are connected with this model (in excel file) it is easy to see at once how the overall energy demand for space heating and DHW system changes due to different scenarios for given building. It is also a good tool for defying the most sensitive parameters, which have influence on the overall system.

3.6 Parameters.

All of the parameters are created on the base of Tabula Calculation Method (Tabula, 2013). List of all of the parameters, values for them and sources is enlisted in the attached excel file.

The energy balance equations and model approach equations are built on the basis of the Tabula Calculation Method. Some of the equations are combination of a several, separate equations presented in Tabula Methodology. This is made for the MFA system purposes and to be able to energy-balance the system. The energy balance equation for the buildings energy need for space heating is based on the three equations (1,2and 8) from Tabula Calculation Method (Tabula, 2013). The values for parameters are based on the literature research, Norwegian standards or they are standard Tabula values.

$$Q_{H,nd} = Q_{ht.ve} + Q_{ht.tr} - n_{h.gn} * (Q_{sol} + Q_{int}) \quad (1.4)$$

Energy balance equation (the buildings energy need for space heating)

Standard Tabula values

$$Q_{ht.tr} = t_{døgn} * H_{tr} * F_{nu} * (\vartheta_{int} - \vartheta_e) * d_{hs} \quad (1.5)$$

Model approach equation: Heat transfer by transmission during the ventilation season

Researched values (Enova, 2012)

calculated value from given data for climate in Norway (Enova, 2012, Skartveit, 1987)

Researched value (Enova,2012, NS3700, TEK-10, NS3031 standards)

$$H_{tr} = \sum_i b_{tr,i} A_{env,i} U_{eff,i} + (\sum_i A_{env,i}) \Delta U_{tbr} \quad (1.6)$$

Overall heat transfer coefficient by transmission

Standard Tabula values – table 2 (Tabula, 2013)

$$Q_{ht.ve} = t_{døgn} * H_{ve} * F_{nu} * (\vartheta_{int} - \vartheta_e) * d_{hs} \quad (1.7)$$

Model approach equation: Heat transfer by ventilation during heating season

Standard Tabula values

$$H_{ve} = c_{p,air} * \left(n_{air,use} + n_{air,infiltr}\right) * A_{C,ref} * h_{room,ve\ ref} \quad (1.8)$$

Overall heat transfer coefficient by ventilation

$$n_{h.gn} = \frac{1 - \gamma^{a_H}}{1 - \gamma^{a_H + 1}} \quad (1.9)$$

Model approach equation: *Gain utilization factor for heating*

$$Q_{sol} = F_{sh} * (1 - F_F) * F_W * g_{gl,n} * \sum_j A_{window,j} * I_{sol,j} \quad (1.10)$$

Model approach equation: *Solar heat load during the heating season*

Standard Tabula values

$$Q_{int} = t_{døgn} * \varphi_{int} * d_{hs} * A_{C,ref} \quad (1.11)$$

Model approach equation: Internal heat gains during heating season

From above set of equations it is easy to notice that all of the energy balance and model approach equations are interconnected and interdepended. The values obtained from different sources has its consequence in results. Comparing results with other Norwegian rapports on energy use in residential sector, one can notice that Tabula standard values influence the overall results.

It is then possible to differ between three different types of parameters used for calculation method in this project:

Standard Tabula values: $a_{H,0}$, $b_{tr,i}$, $c_{p,air,}F_{sh}$, F_F, F_W, F_{nu}, $h_{room,ve\ ref}$, $n_{air,use}$, $n_{air,infiltr}$, $t_{døgn}$, φ_{int}. All of these values are given in the Tabula Calculation Methodology and they are standard values that supposed to be used in case of cross-country comparisons

Assumed values

-Values for fraction of heat generator for space heating and for domestic heating are based on the statics obtained from (SSB, 2009). The task was to introduce typical three single-family houses that would be representative to the given time period. That is why some assumptions had to be made. From statistics, we can see that for space heating two main energy sources are used: electricity and wooden pallets oven (SSB, 2009). Only for the renovation scenarios, it is assumed that renovated house would have heat pump. According to TEK10 standard, it is recommended to use energy from renewable sources for covering 40% of total heat demand (TEK10, 2010). The electricity is also used as a main source for energy needed to heat domestic hot water.

- Values for the number of floors in an average single-family house are also assumed. Enova Rapport gives value of 1.5 number of floors for an average single-family house, but for the more realistic calculations, value of 2 floors per building is assumed.

- In the Table 1 of Tabula Calculation Method (Tabula, 2013), the value for a parameter φ_int (average thermal output of internal heat sources) is equal to 3 w/m2. Tabula does not account for internal heat gains from equipment and light, therefor I choose to use value of 5.25 from both standard NS3031 (Table A2) and NS3700 (Table A1). The reason for using this value is to get more realistic results that could be comparable in bigger degree with data from other research on energy use in building that is taking to consideration those internal gains.

If one would choose to account for internal gains from lights, electrical equipment and people those numbers (taken from Enova rapport) are representative for a standard building (Enova, 2012).

kWh/m²y	lighting	Electric appliances	Heat gains from persons
Standard building	11.4	17.5	1.5

Table 12. Heat gains from lighting, electric appliances and from persons for a standard building.

- For the renovations to the level of TEK10 and NS3700 standard, the focus was set on the envelope elements parameters. The fraction of heat generator for space heating in both scenarios was assumed and set to the ratio of 60:40, where 60% of energy demand for space heating is covered by direct electricity and 40% by air-to-air heat pump. This ratio relates to the requirements for energy sources for space heating set in TEK-10 standard. Although this ratio would change depending from the climatic zone (in Finnmark where the average external temperature is much lower, the efficiency of the heat pump would not be high enough for implementing this measure). For the calculation, Oslo climate is assumed as a reference climate for all of the types of buildings. In this climate, air-to-air heat pump has efficiency that could cover 60% of heat demand.

- For domestic hot water system, all scenarios have 100% demand covered by electric boilers. NS3700 standard for passive house is explicitly requiring using not only electric boilers for heating warm water, but also other heat recovery exchangers for DHW systems. Despite this fact, for simplicity of the calculation this requirement is omitted in the results. The focus is set on the non-competing measures. If one would take this requirement to a consideration, the choice of heat generators for different buildings would be difficult, especially if one would like to show average building. Most of the existing buildings do not use other than electric boilers heat generators for DHW. The objective of renovation up to NS3700 standard is to show advantages mainly from insulating the building.

- Some of the values are based on results obtained on the Danish and Swedish case. For example all of the heat generation expenditure factor of heat generators are taken from Tabula tables for

Denmark. It is assumed to be similar with Norwegian case due to use of similar technology in both countries.

- For the parameters for climate zones, some assumptions was also made – and they are explained further.

Researched values

- All of the values for dimensions of different part of buildings envelope and U values, are chosen on the basis of Enova Rapport , TEK-10 and NS3700 standards (Enova, 2012, TEK10, 2010, NS-3700, 2013).

- For all periods, the baseline for U-values was Enova rapport "Potensial og barrierestudien". This source gives values for thermal envelope and heat supply system on average for buildings from different time. It takes to consideration Oslo as a reference climate zone (as it is NS 3031:2007 standard).

3.7 Climate zones

The values for average global irradiation on surfaces were calculated using three different sources. First, the values for average daily solar global radiation with five different orientations for seven climatic zones (given in UiB rapport). In Enova Enøk report are given values for length of heating season (NTNU/SINTEF, 2007). Multiplying them together gave results for average monthly irradiation in the heating season for give climatic zone. For example:

$$I_{Sol_{Hor_{01}}}(\frac{kWh}{(m^2*month)} = I_{Sol_{Hor_{01}}}\left(\frac{kWh}{m^2*d}\right) * d_{hs}(\text{d/month}) \qquad (1.12)$$

Below is given methodology for calculation for the average monthly irradiation in heating season for horizontal orientation (on the example of climatic zone 1 - South Norway-inland):

Average daily solar global radiation – horizontal orientation (kWh/m^2*d)

Average irradiation, sorted by direction and month	I_Sol_Hor_01	I_Sol_Hor_02	I_Sol_Hor_03	I_Sol_Hor_04	I_Sol_Hor_05	I_Sol_Hor_06	I_Sol_Hor_07	I_Sol_Hor_08	I_Sol_Hor_09	I_Sol_Hor_10	I_Sol_Hor_11	I_Sol_Hor_12
	average daily solar global radiation - HORIZONTAL orientation	average daily solar global radiation - HORIZONTAL orientation	average daily solar global radiation - HORIZONTAL orientation	average daily solar global radiation - HORIZONTAL orientation	average daily solar global radiation - HORIZONTAL orientation	average daily solar global radiation - HORIZONTAL orientation	average daily solar global radiation - HORIZONTAL orientation	average daily solar global radiation - HORIZONTAL orientation	average daily solar global radiation - HORIZONTAL orientation	average daily solar global radiation - HORIZONTAL orientation	average daily solar global radiation - HORIZONTAL orientation	average daily solar global radiation - HORIZONTAL orientation
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	kWh/(m²·d)	kWh/(m²·d)	kWh/(m²·d)	kWh/(m²·d)	kWh/(m²·d)	kWh/(m²·d)	kWh/(m²·d)	kWh/(m²·d)	kWh/(m²·d)	kWh/(m²·d)	kWh/(m²·d)	kWh/(m²·d)
Klimasone 1 Sør-Norge, innland	2.90E-01	1.04E+00	2.37E+00	3.78E+00	5.11E+00	5.28E+00	4.76E+00	3.98E+00	2.47E+00	1.10E+00	3.00E-01	1.45E-01
Klimasone 2 Sør-Norge, kyst	2.95E-01	9.03E-01	2.09E+00	3.50E+00	4.91E+00	5.13E+00	4.59E+00	3.77E+00	2.34E+00	1.12E+00	3.57E-01	1.80E-01
Klimasone 3 Sør-Norge, høyfjell	3.55E-01	1.18E+00	2.68E+00	4.90E+00	6.52E+00	6.03E+00	4.97E+00	4.13E+00	2.53E+00	1.29E+00	3.33E-01	1.94E-01
Klimasone 4 Midt-Norge, kyst	1.61E-01	6.79E-01	1.68E+00	3.20E+00	4.58E+00	4.80E+00	4.26E+00	3.42E+00	2.10E+00	9.35E-01	3.00E-01	9.68E-02
Klimasone 5 Midt-Norge, innland	1.29E-01	7.50E-01	2.03E+00	3.53E+00	4.90E+00	4.97E+00	4.81E+00	3.87E+00	2.23E+00	9.68E-01	2.67E-01	6.45E-02
Klimasone 6 Nord- Norge, kyst	3.23E-02	4.29E-01	1.46E+00	3.13E+00	4.48E+00	4.74E+00	4.39E+00	3.09E+00	1.72E+00	6.34E-01	8.89E-02	0.00E+00
Klimasone 7 Finnmark og innlands, Tromsø	0.00E+00	3.21E-01	1.65E+00	3.53E+00	4.45E+00	4.63E+00	4.45E+00	2.97E+00	1.60E+00	5.16E-01	3.33E-02	0.00E+00

Multiply with number of days per month in heating season (d)

	length of the heating season	heating days per month											
Number of days per month in heating season	SUM	Jan	Feb	Mars	April	Mai	Juni	Juli	Aug	Sept	Okt	Nov	Des
Klimasone 1 Sør-Norge, innland	250	31	28	31	30	8	0	0	0	30	31	30	31

= average monthly irradiation (with horizontal orientation) in heating season kWh/m^2*month)

Average monthly irradiation in heating season												
kWh/(m²·month)	I_Sol_Hor_01	I_Sol_Hor_02	I_Sol_Hor_03	I_Sol_Hor_04	I_Sol_Hor_05	I_Sol_Hor_06	I_Sol_Hor_07	I_Sol_Hor_08	I_Sol_Hor_09	I_Sol_Hor_10	I_Sol_Hor_11	I_Sol_Hor_12
Klimasone 1 Sør-Norge, innland	9	29	73.5	113.5	40.9032258	0	0	0	74	34	9	4.5

Summing up all of the values for each orientation from each month, gave results for a year. To calculate then ϑ_e, the sum from all of the months in a year of temperatures*days in heating season divided by length of heating season gave result for the temperature of the external environment (average value during heating season).

Monthly average temperature for give climatic zone

Monthly average temperatures	Jan	Feb	Mars	April	Mai	Juni	Juli	Aug	Sept	Okt	Nov	Des
Sone 1	-3.9	-4.2	-1.2	3.7	9.2	13.2	15.6	14.2	10.2	5.6	1.5	-1.2

Multiply with sum of length of heating season

Number of days per month in heating season	length of the heating season	heating days per month											
	SUM	Jan	Feb	Mars	April	Mai	Juni	Juli	Aug	Sept	Okt	Nov	Des
Sone 1	250	31	28	31	30	8	0	0	0	30	31	30	31

= Temperatures*days in heating season

Temperatures*days in heating season	Jan	Feb	Mars	April	Mai	Juni	Juli	Aug	Sept	Okt	Nov	Des
Sone 1	-120.9	-117.6	-37.2	111	73.6	0	0	0	306	173.6	45	-37.2

Summing up result and dividing again with length of heating season = ϑ_e (kWh/m^2*year)

Average yearly irradiation in heating season						
kWh/(m²·year)	Horisontal	East	South	West	North	ϑ_e
Klimasone 1	387.40	381.65	531.74	381.65	128.16	1.6

ϑ_e according to tabula is calculated for the length of the heating season. Therefore, average external temperature during heating season is much lower than during all year.

According to NS3031 method of calculation, highest energy demand for space heating should be calculated in the following way for passive house standard:

highest netto energi demand for heating (kWh/m²*year)			Referance area (m²)					
Calculation Method	avg. Temp.		181	m²	159	m²	168	m²
$15 + 5.4 * \frac{(250-Aff)}{100}$ + (2.1+0.59*$\frac{(250-Aff)}{100}$) *(6.3-θy)	7	°C	17		18		18	
	4.1	°C	24		26		25	
$15 + 5.4 * \frac{(250-Aff)}{100}$	6.3	°C	19		20		19	

Table 13. Calculation Method for the highest netto energy demand for heating, on the example of the single-family house from three different periods.

Θym is average external temperature calculated after NS-EN ISO 15927-1 (chapter 5.4 equation 8) standard, which takes to account not only length of heating season but also length of all year:

$$\theta_{ym} = \frac{\sum_{d-1}^{dy} \theta dm}{dy} \tag{1.13}$$

In this example the average temperature for Oslo is 6.3 degrees, 7 for second climatic zone (South-Norway, coast), and average external temperature for all Norway is 4.1 degrees. For the calculation method 3.4 degrees were assumed, the same as for South- Norway, coast climatic zone. This value is much lower than 7°C because of not including warm months with much higher average temperature. The results then for energy demand for space heating will be much higher for the passive house standard – but this is due to the calculation method of external temperature, which includes only heating season.

NS3700 is differentiating between average yearly temperature equal or more than 6.3 degrees and less than 6.3 degrees. Bigger house is, the demand drops. For blocks NS3700 has demand of 15 kWh/m2year. For the calculation, I assume yearly average temperature equal to 3.4.

For the length of heating days per month, number of days when the heating is needed during each month had to be estimated. Given length of heating season from Enova Enøk and assuming that during the summer time, the need for heating is reduced to zero, estimation for the rest of the months could be made. Depending on the climatic zone it is assumed if demand for heating during months Mai-August occurs or not. For climatic zone seven – Finnmark and inland Tromsø the heating season is the longest, therefor number of days per month in the heating season is distributed in the way that demand for heating is also assumed for half of June.

	length of the heating season	heating days per month											
Number of days per month in heating season	SUM	Jan	Feb	Mars	April	Mai	Juni	Juli	Aug	Sept	Okt	Nov	Des
Klimasone 1 Sør-Norge, innland	250	31	28	31	30	8	0	0	0	30	31	30	31
Klimasone 2 Sør-Norge, kyst	237	31	28	31	30	0	0	0	0	25	31	30	31
Klimasone 3 Sør-Norge, høyfjell	277	31	28	31	30	31	0	0	4	30	31	30	31
Klimasone 4 Midt-Norge, kyst	265	31	28	31	30	23	0	0	0	30	31	30	31
Klimasone 5 Midt-Norge, innland	274	31	28	31	30	31	0	0	1	30	31	30	31
Klimasone 6 Nord-Norge, kyst	286	31	28	31	30	31	0	0	13	30	31	30	31
Klimasone 7 Finnmark og innlands, Tromsø	319	31	28	31	30	31	15	0	31	30	31	30	31
Averaged	272.6												

Table 14. Number of days per month in heating season split by seven climate zone (including value for the average number of days per month).

For the calculation method, Oslo climate is used for control calculation of the framework.

3.8 Standard vs advanced renovation. Usage of TEK-10 and NS3700 standards.

For the renovation scenarios: standard and ambitious renovation types were chosen. The case study takes to consideration single-family houses built between 1980 and 2010 therefore, historical upgrade is only relevant for houses built in 1980. For simplicity reasons, upgrading to TEK- 10 (standard renovation) and NS3700 (ambitious renovation) were chosen, excluding historical upgrade for 1981-1990 period.

The focus is on non-competitive measures. Upgraded parts of the building usually are: change of the windows, isolating of outside walls, façade, roof, floors.

	original building	renovated	changed windows	isolated wall	isolated floor/roof
1981-1990	83%	17%	12%	3%	14%
1991-2000	95%	5%	4%	3%	2%
2001-2010	10%	0%	0%	0%	0%

Table 15. State of renovation for each period. Original building means no renovation (original state) (Enova, 2012).

From the table above one can see that the most intensively renovated buildings are from period 1981-1990. The most common measure is changing of the windows and isolating floors/roof (Enova, 2012).

3.8.1. Standard renovation (TEK-10 level)

For the standard renovation, the TEK-10 standard serves for a baseline. According to this standard, it is not allowed to install oil boilers for base load. It is recommended to use at least 40% of energy for space heating, from other sources than direct electricity and fossil fuels at end user. This does not apply if the demand for energy is not possible to meet because of the natural conditions (TEK10, 2010). The calculation method used for case scenarios assume 40% of heat demand covered by air-to-air heat pump. The reason for choice of this type of heat pump is that 95% of all heat pumps installed in Norway are air-to-air heat pumps (Enova, 2012).

Standard renovation also includes upgrading of U-values and smaller thermal bridges. This scenario supposed to show how better insulated envelope's element together with heat recovery systems can lower the annual energy demand for space heating.

3.8.2. Ambitious renovation

For this scenario passive-house standard NS3700 is a baseline. In this scenario, building/system combination should comply with the more ambitious long-term performance targets like NZEB for example. Therefor requirements for different measures are stricter than in other, previous standards.

3.8.3. The average vs exemplary building

For the Tabula Calculation Method one can use a standard building, which would be a not-real, virtual building that has typical parameters for its defined group (single – family house, block etc). Those standard values are established based on the statistical, typical values for given element of the house in a given country.

According to Tabula, the exemplary building is an excising building that is somehow representative for the group of building that it supposed to represent.

In this project, values for an average building are used. The values were obtained from different sources like SSB, ENOVA, Norwegian building standards (TEK 10, NS 3700, NS3031). In the end, it was possible to get results that are representative for typical building (according to the type, climatic zone and age of building).

4 Case study – single-family detached houses.

4.1 Presenting the results form calculating energy use for chosen types of building original state

All of the results for each period are available in attached excel file. Below is the summary of the most important results for given period, that influenced the most energy demand for space heating and DHW system.

size (%change over time in reference to previous period)						
Comparison of dimension (m²)		1981-1990	1991-2000		2001-2010	
Reference area	m²	181	159	-14%	168	5%
Area of all windows with horizontal orientation	m²	0	0	0%	0	0%
Area of all windows with orientation east	m²	0	0	0%	0	0%
Area of all windows with orientation west	m²	0	0	0%	0	0%
Area of all windows with orientation north	m²	11	10	-14%	10	5%
Area of all windows with orientation south	m²	16	14	-14%	15	5%
Area of envelope area wall	m²	131	124	-6%	127	3%
Area of envelope area window	m²	27	24	-14%	25	5%
Area of envelope area floor	m²	121	106	-14%	112	5%
Area of envelope area door	m²	4	4	0%	4	0%
Area of envelope area roof	m²	121	106	-14%	112	5%

Table 16. Change over time of dimensions of the reference area and parts of buildings envelope (m²) and relative change in respect to the previous time period.

	heat generation expenditure factor					
	delivered energy demand (Hs) devided by produced heat	1981-1990	1991-2000	2001-2010	TEK-10	NS3700
	heat generation expenditure factor (heating system)					
e_g,h,1	direct electricity	1.02	1	1	1	1
e_g,h,2	wood stove	1.92	1.4	1.4	1.4	1.4
e_g,h,3	air-to-air heat pump	0.37	0.3	0.3	0.3	0.3
	fraction of heat generators for DHW system					
e_g,w,1	electric boiler	1.04	1.02	1.02	1.02	1.02

Table 17. Heat generation expenditure factor split by different periods. Values in accordance with Tabula Methodology Calculation standard values for Denmark.

With better heating systems it was possible to avoid heat losses from distribution and storage linked to heat generators and DHW system, which had impact on lowering overall demand for energy for heating.

As it was commented in the methodology part, the values for calculations have different sources. Also the methodology of calculating energy demand differ in some parts from the methodology used by Enova.

energy demand for space heating (kWh/m²y)	original state (for Oslo climate)	result from Enova rapport 2012	deviation
1981-1990	97	80.7	17%
1991-2000	92	70.9	23%
2001-2010	73	62	15%

Table 18. The comparison between results obtained using Tabula methodology and by Enova (2012).

From the table above we can see that the deviation between those two results for single-family houses, is quite significant. Those differences might occur due to several differences in values for parameters. The method for climate calculation differ. Standard values in Tabula methodology might be also different from the one used in Enova. Tabula does not have typology for Norway; therefore some of the values had to be used on the basis of the neighboring countries, that have similar climate and/or structure of buildings (Sweden, Denmark). For example, the adjustment factor soil have standard values in Tabula methodology. Those values play significant role in overall heat transfer coefficient by transmission (Htr – which is one of the main components of the calculation for buildings energy need for space heating). Enova might use lower values for this parameter and as a result have lower heat transfer coefficient (important to notice is that $A_{env,i}U_{eff,i}$ and)ΔU_{tbr} have exactly the same values as in Enova rapport).

$$H_{tr} = \sum_i b_{tr,i} A_{env,i} U_{eff,i} + (\sum_i A_{env,i}) \Delta U_{tbr} \qquad (1.14)$$

Other values like external average temperature are also different from the one used in Enova.

Cross comparison of U-values shows how quickly some technologies of producing for example windows, were developed.

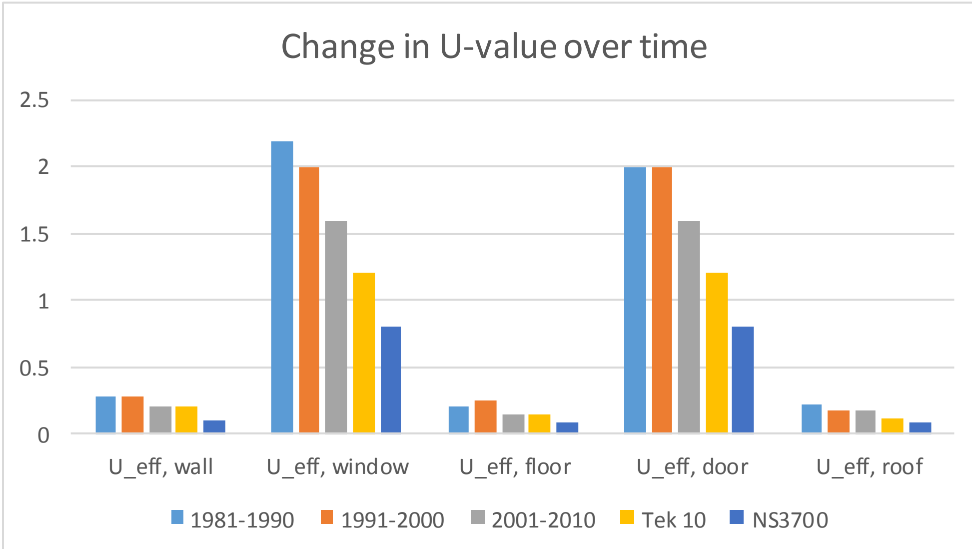

Figure 12. Change in U-value over time with increased building requirements.

From the figure above, we can conclude that the fastest changes in the building sector could be observe in the way of production of windows and doors. Nowadays windows are filled with noble gas (argon or krypton) in between the panes (before it was only a dry air). This measure reduces convection and conduction in the cavity between. Using metal oxide as a damper on one or more surfaces in the slits, reduces emissivity to 2-5% of the original (NTNU/SINTEF, 2007). Radiation exchange is then reduced between glass surfaces. This reduces the transfer of considerable energy and more than halves the U-value of the windows. Coatings can also play a role in a significant reduction of the solar radiation through window glass. New improved distance list reduces the thermal bridge at the edge and improves overall U-value for windows.

4.2 Climate zones factor – sensitivity analysis considering climatic zones

Increased demand for energy need for space heating depends from climate zone. If external average temperature is lower, heating season is longer and average global irradiation on surfaces during heating season is higher, the demand for more energy for space heating is increased. If one would like to keep the energy demand on the same level, but instead increase insulation of envelope's elements, then in the result one would have to invest over five times more to insulate walls, roof and floors in Finnmark than in Oslo area in order to obtain the same usage of energy for space heating as for NS3700 passive house standard. That is alsmost impossible because of the thickness of the wall that one would have to have and because of the technology solutions which are not developed to that extent (to have better insulation and smaller thickness). This result could be achieved by implementing competitive measures. Recovery of heat ventilation, recoverable heat for DHW, could help decreasing overall demand for energy need in higher latitude in Norway.

For Oslo climate, with each refurbishment thickness of wall is higher:

Thickness of added mineral wool insulation (m)	**1981-1990**	**Tek 10**	**NS3700**
d_wall	0.121	0.162	0.340
d_floor	0.162	0.227	0.425
d_roof	0.155	0.283	0.425

Table 19. Thickness of added mineral wool insulation (m) for 1981-1990 single-family house in original state and after refurbishment to TEK10 and NS3700 standard.

Assuming that thermal conductivity of mineral wool is 0.034 W/mK , the thickness of insulation on the external wall typically had around 0.120 m. With the refurbishment to the TEK10 standard around 50mm was on average added and for NS3700 around 180mm in addition was added. In total a building built in 80's needed to have around 350mm of mineral wool in order to fulfill lower U-value requirement.

4.3 Sensitive parameters – insulation (U values) and internal temperature.

Internal temperature is one of the most sensitive parameter in this analysis. In the older buildings, desired inner temperature is more difficult to sustain. To keep thermal comfort inside of the house, energy used for heating is then bigger than in the newer houses, which have less losses due to heat transmission. With more developed building technologies and more tight building's envelope, the inner temperature is easier to control throughout all year. The graph below presents dependency of growing energy use for space heating due to increased internal temperature.

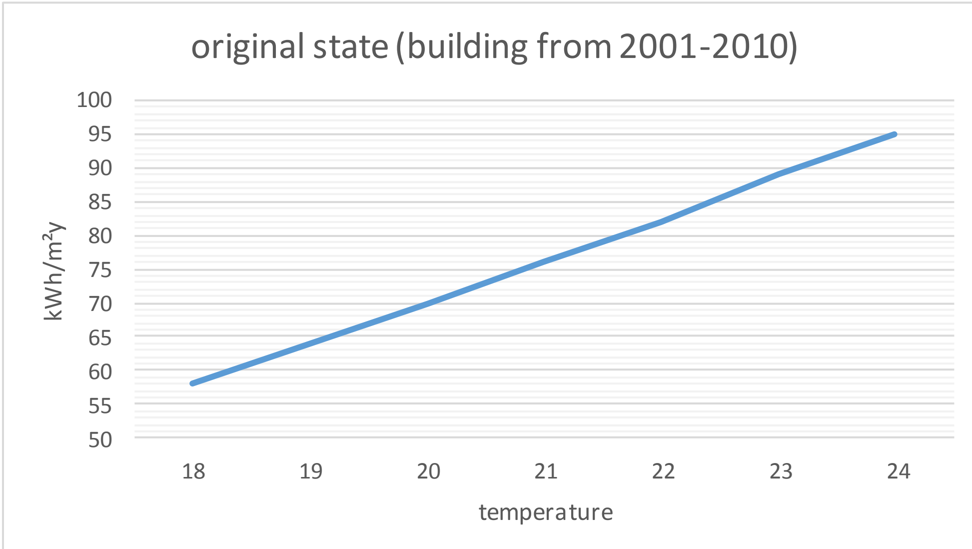

Figure 13. Inner temperature vs. energy demand for space heating. On the example of single-family house 2001-2010 in the original state.

From this example, one can see that the need for good internal environment in the building plays significant role in energy used for heating. Behavior of users and how the perceive their thermal comfort, plays crucial role in assessment of energy needed for heating.

The other parameter that plays significant role in reducing energy need for space heating, are effective U-values parameters. The better-insulated envelope, less air-leakages might occur. To show how tightness of the buildings envelope can influence the overall demand for space heating shows the graph below:

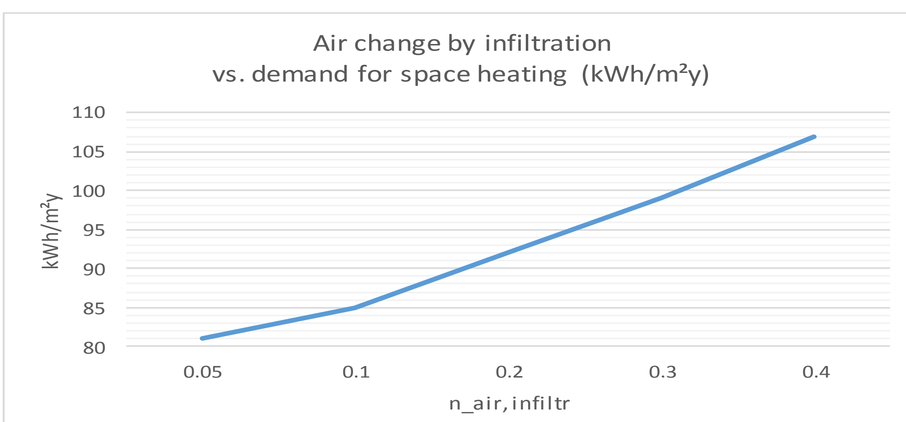

Figure 14. Demand for space heating depending on air change by infiltration (on example of building from 1991-2000 in original state).

4.3.1. 1981-1990

Physical dimensions

- The single-family houses from 1980's have the biggest reference area among all of the three average buildings. During this time houses had on average 180 square meters of floor area. One of the most popular model was so called Block 180 with over 200 square meters (Risholt, 2011).

Ventilation/Infiltration

- The natural ventilation was typical for the most of the houses in the 80's. Due to this, average rate during heating season is 0.4 1/h, which improved after implementing mechanical ventilation later on.
- Single-family houses built in 1980 were not as air-tight as buildings constructed in 1990's and 200's. Availability of better insolents and developing of construction technology lowered average air change by infiltration, which created in the same time demand for mechanical ventilation. With the house that is not tighten enough and have thermal bridges, unintentional ventilation might occur. In this type of infiltration, air is flowing through leaks in the walls and around doors and windows.

U-values

- From 70's the U-value for the windows was improved (Bøhn, 2006). Two panes windows gave better result for thermal resistance than before on pane windows. Total solar energy transmittance for radiation perpendicular to the glazing due to lower quality of windows, was also higher.

With the standard and advanced refurbishment, thermal resistance of buildings parts increases. That also decreases heat loss due to transmission of heat through the buildings envelope. Hence, better U-value, less heat losses and infiltration.

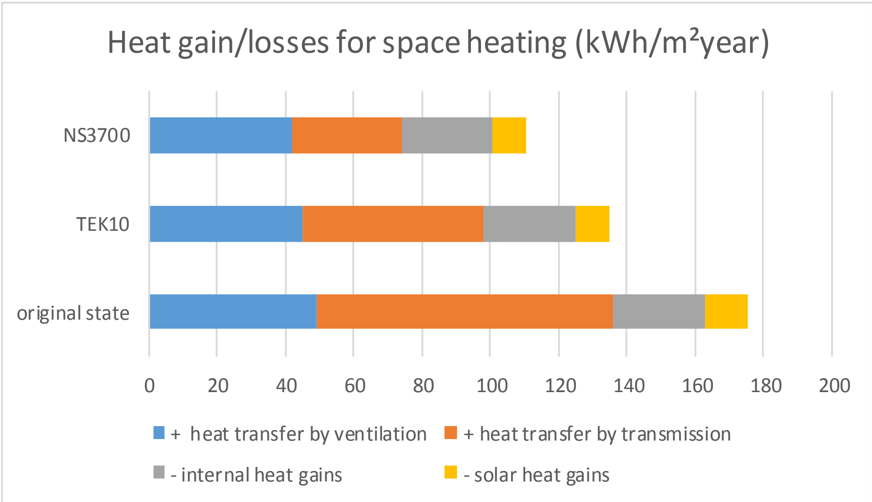

Figure 15. Heat gain/losses for space heating in single-family house for period 1981-1990.

Thickness of added mineral wool insulation (m)	1981-1990	Tek 10	NS3700
d_wall	0.121	0.162	0.340
d_floor	0.162	0.227	0.425
d_roof	0.155	0.283	0.425

Table 20. Thickness of mineral wool added to the envelope parts, for single-family house in original state and after standard and advanced refurbishment.

Energy carrier/internal environment

- In the early 1980's the price for electricity was rising, but the direct electricity was on average used as a main source for space heating. The same was for heating hot water (DHW) with electric boilers. Recoverable heat loss of the storage of domestic hot water system had higher value for the single-family house built in1981-1990, than for houses built in later periods. Heat losses from storage and distribution in DHW systems were therefore bigger.
- The average internal temperature was 19.5°C, which is lower than for two other cohorts (growing demand for thermal comfort).
- Heat generators expenditure factor of heat generators were lower than in houses from periods 1991-2000 and 2001-2010 (more loss from distribution).

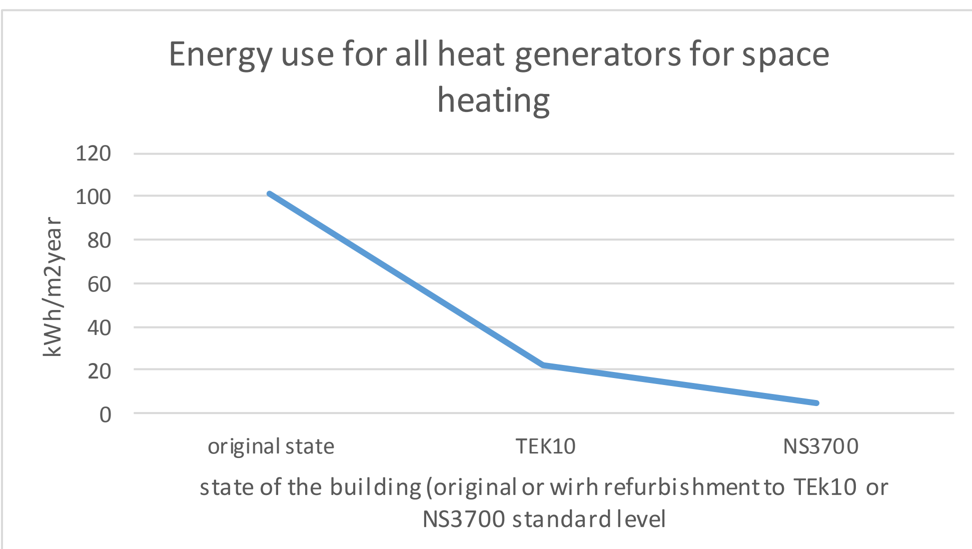

Figure 16. Energy use for all heat generators for space heating for single-family house from 1981-1990.

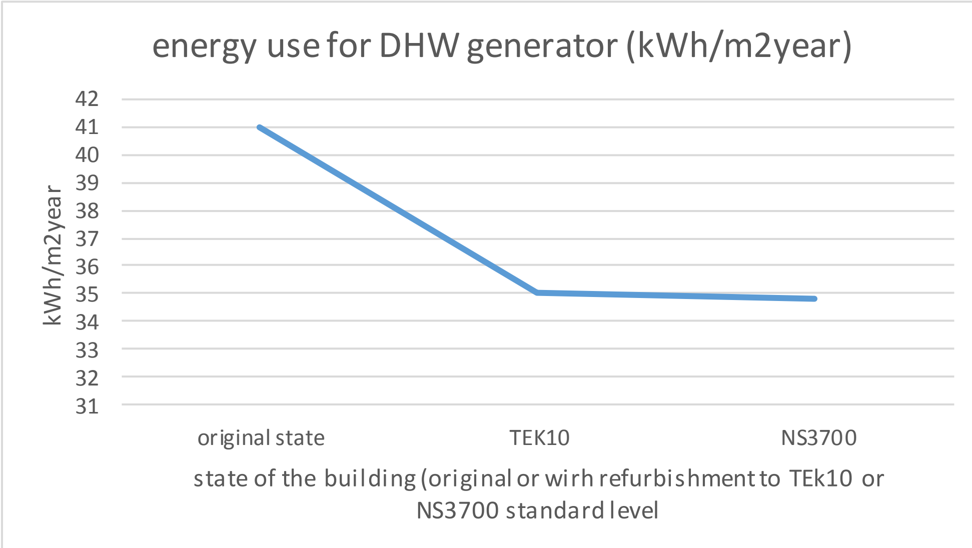

Figure 17. Energy use for DHW generator for single-family house 1981-1990.

The energy use for DHW was lowered due to fewer losses from the distribution and storage. With the renovation of the building, improvement of DHW systems implies installation of the new boiler. With solutions that are more modern the losses of heat are smaller.

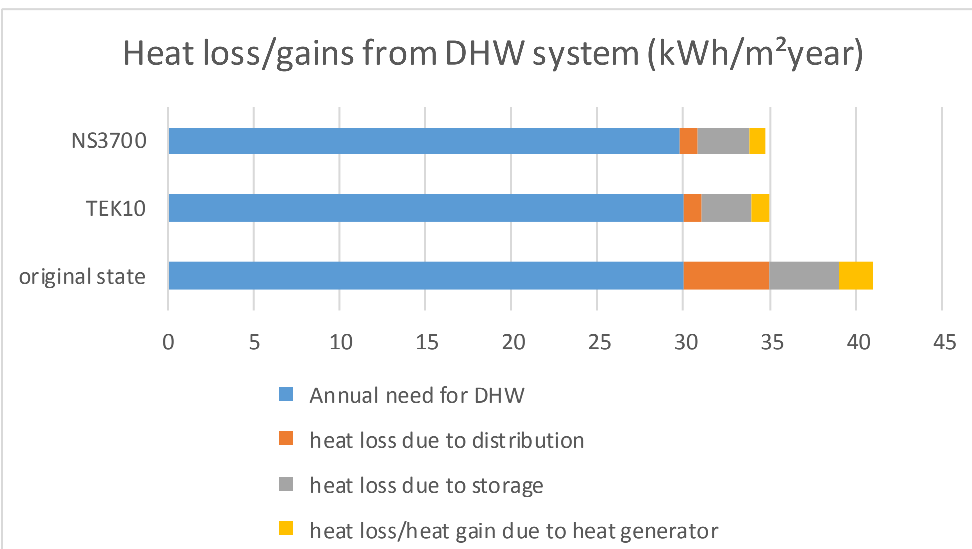

Figure 18. Heat loss/gains from DHW system (kWh/m²year). Single-family house 1981-1990.

With the improvements of envelopes element the dependency on the external temperature drops. Below, presented two Energy Temperature-Curves (ET –curve) are showing how the energy efficiency measures can lower down the temperature dependency:

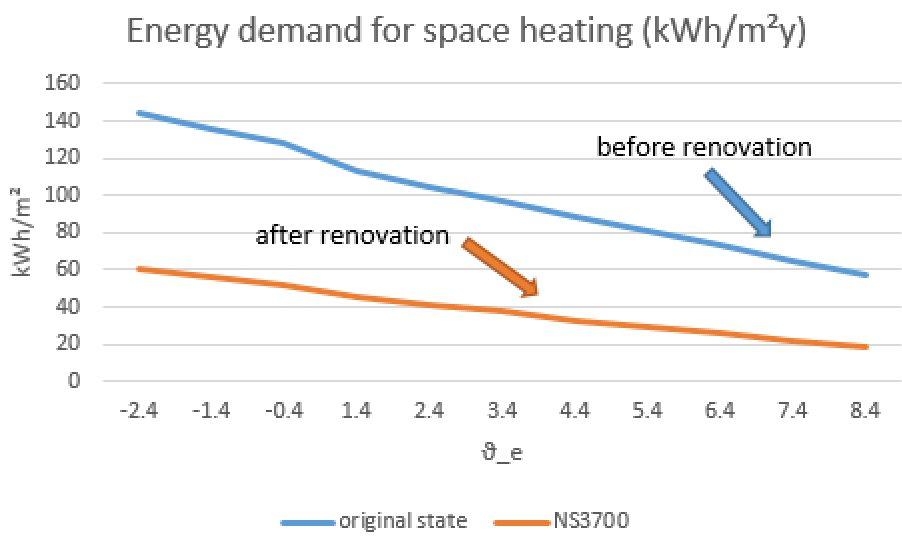

Figure 19.

The building in its original state is more temperature depended than the same building with implemented energy efficiency measures. This is a consequence of better insulation and more air-tight building (less heat is lost through transmission and infiltration).

4.3.2. 1991-2000

Growing demand for square meters per person, higher number of divorces, more people living alone, all of those changes in society lead to increase of number of buildings in Norway. The number of divorces grew from more than 100 annually in the beginning of XX century to almost 1000 when the II World War broke and more than 10 000 per year since 1990 (SSB). Divorced people need new place for living, hence demand for new buildings arise. A lot of people live alone, which also increases total square meter of living area per person.

In the 90's the biggest percentage of building stock was single-family houses. In 2000 and onward, this percentage drops in favor for blocks. More people live alone and although the number of square meters per person increases, the size of the houses decrease (due to higher price for buildings)(SSB, 2012a).

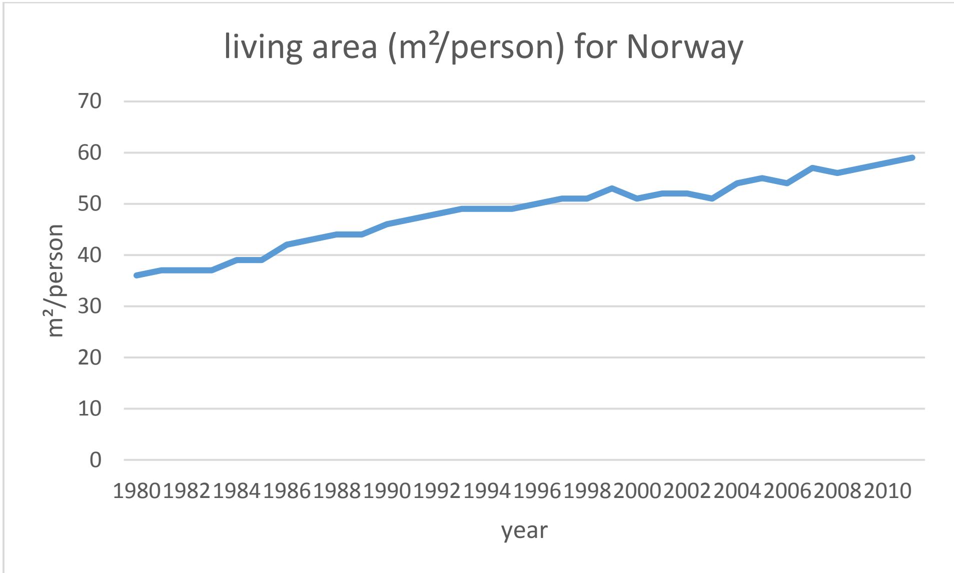

Figure 20. *Living area (square meters per person) for Norway. 1980-2010.*

In the early 1990's in the average single-family house both electricity (combined with warm cables) and wood pallets oven were used for space heating (SSB, 2009). For the pick load during heating season wood pallets oven were used as additional energy source to fulfill pick load energy demand for heating. Higher internal temperature might have two factors: demand for higher thermal comfort and better-insulted building that has less infiltration and ventilation losses allowed using less energy for heating.

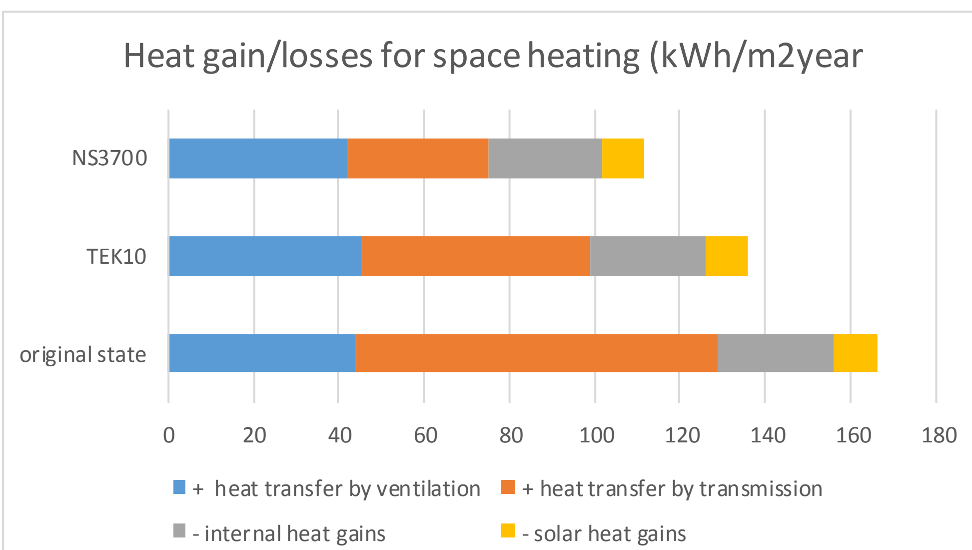

Figure 21. *Heat gain/losses for space heating. Single-family house 1991-2000.*

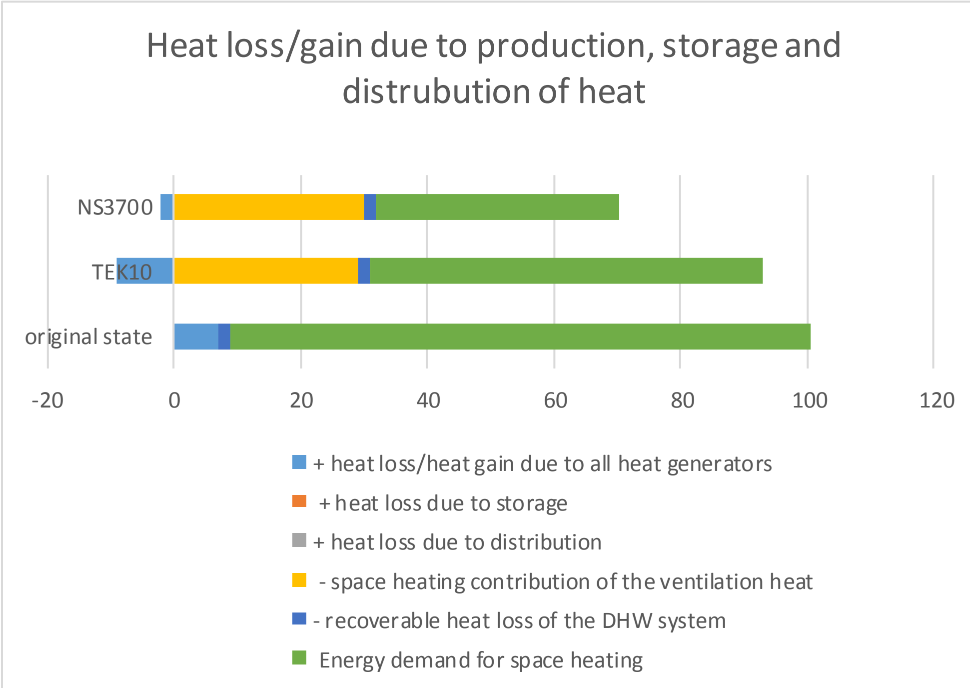

Figure 22. Heat loss/gain due to production, storage and distribution of heat. Single-family house 1991-2000 (kWh/m²y).

The results for thermal resistance for envelope elements for single-family house reflect the state of the average house from that time. In the end of the 80's TEK-87 standard was introduced. Houses built after this standard had to fulfill given requirements for energy demand. The average house built in the 90's has better U-values than TEK-87 requires. The reason for it might be tendency for the owners to insulate with a higher standard than it is required.

Effective U-value (W/m²K) comparison	TEK-87	1991-2000	TEK-97
Effective U-value of the envelope element wall	0.3	0.28	0.22
Effective U-value of the envelope element window	2.4	2.00	1.6
Effective U-value of the envelope element floor	0.20-3.0	0.25	0.15
Effective U-value of the envelope element door	2.00	2.00	2.00
Effective U-value of the envelope element roof	0.3	0.18	0.15

Table 21. Cross comparison of average U-value for the single-family house from 1991-2000 with energy requirements from years 1987 (TEK-87) and 1997 (TEK-97).

From the table above one can see that the houses built in 90’s and before implementing of the standard TEK-87, had better insulated envelope elements than it was required from the home owners. The reason for it can lie in the willingness to save more money with better insulation, or trying to adjust also to the upcoming requirements.

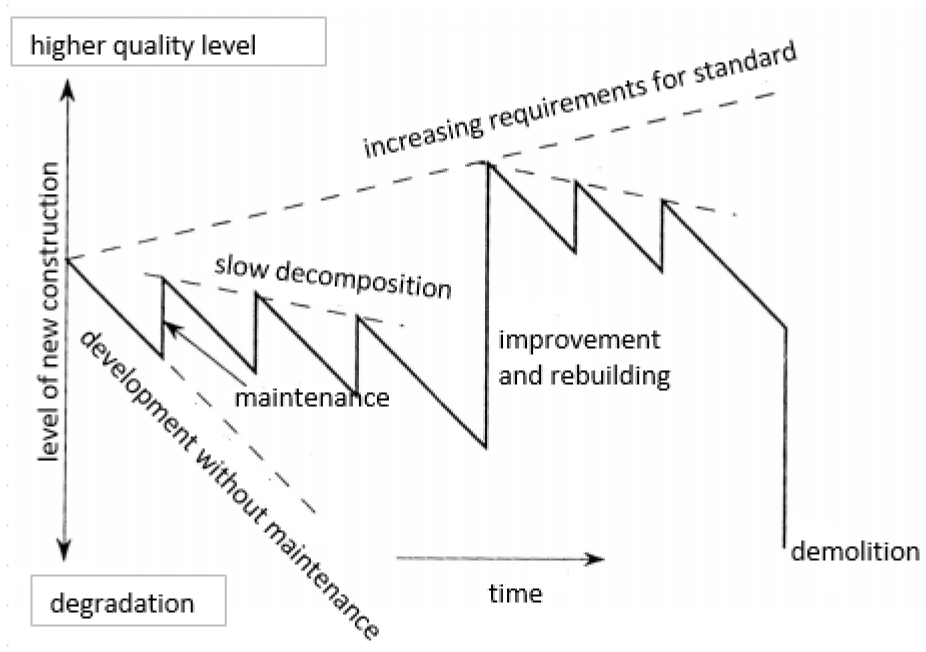

Figure 23. Decay of the quality of the building and installations during the time. (NTNU/SINTEF, 2007)

For the private owners the cost plays main role for refurbishment of the house. Upgrading the building by the lowest cost possible is usual a goal. The figure above represents the decay of the building considering periodical maintenance and at least one bigger improvement rebuilding of the building during its lifetime. During those bigger refurbishments typical measures are: installing new windows, adding insulation, replacing the ventilation system. One can also see that improvement and rebuilding is made according to the current standards. For the period 1991-200 only 5% of single-family houses went through a renovation. The most common parts to renovate were: changing windows and isolating external walls (Enova, 2012).

4.3.3. 2001-2010

Single-family houses built in 2001-2010 are group of buildings that are relatively new and didn't have any refurbishments done yet (Enova, 2012). Built with TEK-97 requirements (or better), have the lowest energy demand from all of the introduced three cohorts.

Due to social changes, the number of single-family houses dropped in this period in favor for apartment's blocks (Enova, 2012). It is also estimated that this trend will follow in next 10 years.

Considering the refurbishment scenarios, the energy demand for space heating is almost twice as big for original state of building from this period than if it would be with upgraded to the NS3700 level (ambitious renovation).

Energy demand (kWh/m²year)	**original state**	**TEK10**	**% change (with ref. original state)**	**NS3700**	**% change (with ref. original state)**
+ heat transfer by ventilation	45	45	0%	42	7%
+ heat transfer by transmission	65	54	17%	32	51%
- internal heat gains	27.1	27	0%	26.6	2%
- solar heat gains	10.1	10	1%	9.9	2%
= Energy demand for space heating	72.8	62	15%	37.5	48%
+ heat loss/heat gain due to all hat generators	4	-9	325%	-1	125%
+ heat loss due to storage	0	0	0%	0	0%
+ heat loss due to distribution	0	0	0%	0	0%
- space heating contribution of the ventilation heat	20	29	-45%	30	-50%
- recoverable heat loss of the DHW system	2	2	0%	2	0%
= Energy use for all heat generators	54.8	22	60%	4.5	92%

Table 22. Energy demand for space heating and all heat generators with relation to different refurbishment scenarios.

The biggest differences are for heat transfer by transmission. With better U-values and more insulation added to buildings envelope, heat transfer by transmission could drop by 50% from original state to the passive house standard (NS3700).

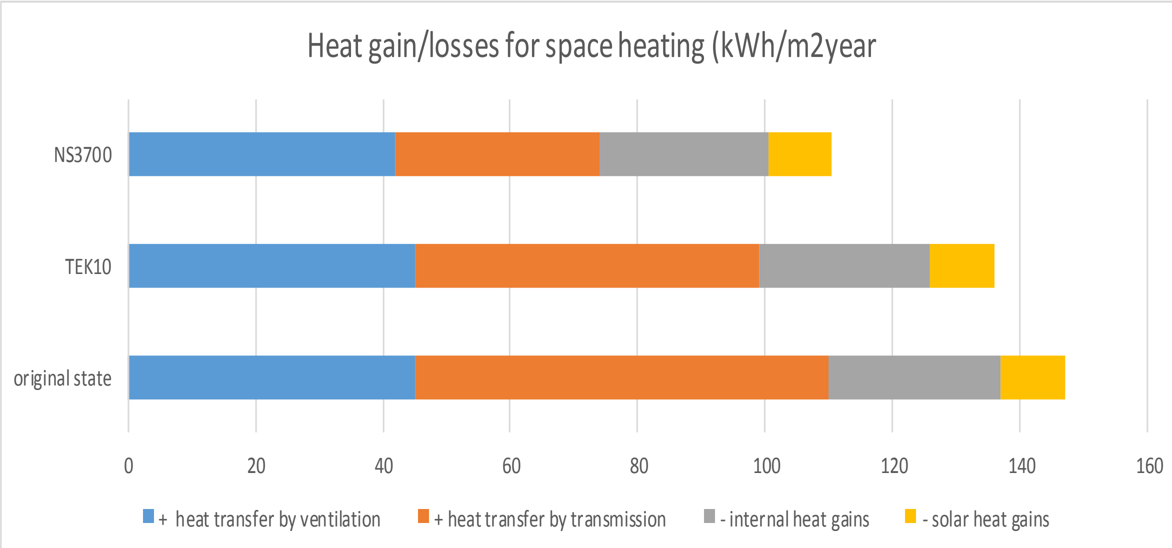

Figure 24. Heat gain/losses for space heating for single-family house from 2001-2010 period.

The NS3700 guideline takes to consideration influence of local climate. For the exemplary building presented in this project, heat demand is sensitive to climate zones. To give an illustrative example, three contrary climate zones can be compared: northern Finnmark, middle of Norway and southern Norway:

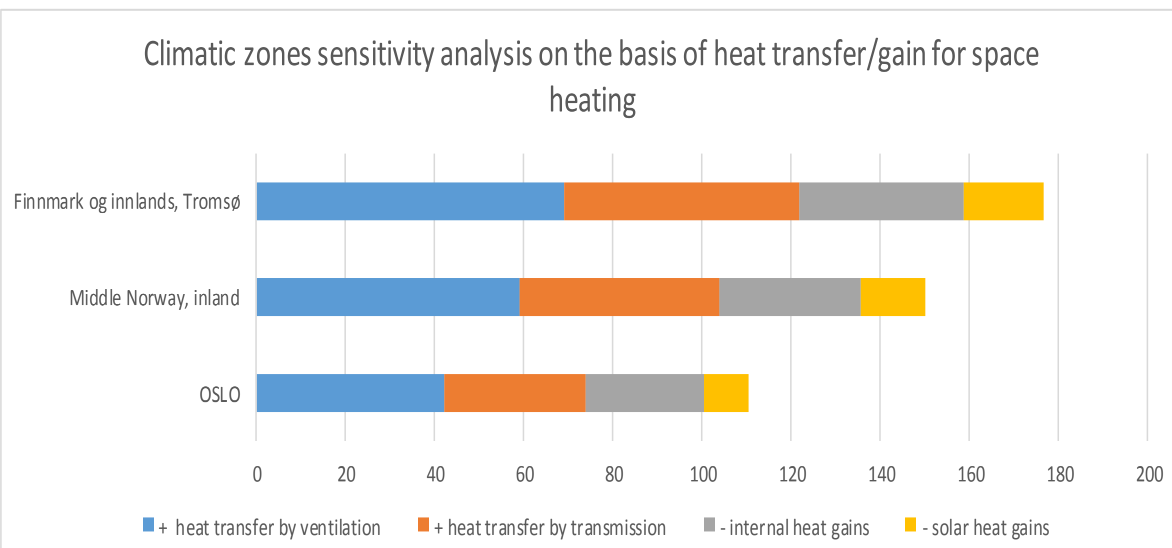

Figure 25. Heat transfer/gain for space heating depending on a climate zone for single-family house (2001-2010).

With colder climate heat transfer by transmission increases, hence demand for space heating. It would be possible to add additional insulation to the buildings envelope in order to improve U-values, but one cannot build walls that are over half meter thick. Considering improving of ventilation system in addition to better insulation, should be one of the solution for refurbishment those building in colder climates.

Thickness of mineral wool added as an insulation (m)		2001-2010	TEK-10	NS3700
d_wall with lambda (W/mK) =	0.034	0.162	0.162	0.340
d_floor with lambda (W/mK) =	0.034	0.227	0.227	0.425
d_roof with lambda (W/mK) =	0.034	0.189	0.283	0.425

Table 23. Thickness of mineral wool added as an insulation for different parts of envelope, for the single-family house from 2001-2010 period. For Oslo-reference climate.

5 Discussion

5.1 Tabula methods.

The method does not consider energy use for cooling, air conditioning, lighting and electric appliances. One could argue that this omission in case of Norway can make a difference in the final results. Norway among all the European countries is using significant amount of electricity, (in 2009 Norway's electricity use per capita reached 23 000 kWh and was second after Iceland ((IEA), 2011). This is due to the relatively small costs of electricity compared to other European countries ((IEA), 2011). In the end of 1960's costs per kWh for electricity where significantly lower and this resulted in change from using electricity and oil ovens for space to mainly direct electricity heaters (SSB, 2009). The habits of Norwegian society also changed due to these circumstances, where they were paying significantly lower amount of money than other countries for their electricity ((IEA), 2011). It caused such a behavior that saving energy measures were not important (since it costs so little). Forgetting to switch off lights in the bathroom and corridors, leaving electrical appliances on or on standby mode all the time, all of those factors are actively adding significant amount of electricity usage to overall energy balance for dwellings. For Norwegian case scenario, one should include impacts from such a behavior to account. This is one of the reasons why in the calculations the value for internal gains includes heat gains from people, lighting and electric appliances.

Using averages values in the Tabula Calculation Method might not serve its purposes. In Norwegian case using average values might lower down actual results for colder climate zones. For example, the big disparities between Southern Norway climatic zone and Finnmark, can be noticed.

In the Tabula Calculation Method, the energy need for space heating is calculated by applying the seasonal method according to EN ISO 13790. The calculation takes to account average temperature during heating season, not during all year. For the same type of seasonal calculation used in NS3700, the standard NS3031 is a base for calculation. The average external temperature throughout all year is a base for the calculations. This might result in differences between values obtained using Tabula methodology and the one that are in Enova's rapport. When one takes to consideration cross comparison between different countries, it is reasonable to compare using values valid for heating season.

5.2 How realistic the solutions are to apply

One should take to consideration not only the possibilities of upgrading the given building but also costs included in it. Even though some measures might be more energy efficient, the house owner might not chose this type of renovation, because it is too expensive. Therefore, planning future scenarios for renovation of existing building stock should be made with taking to a consideration economical part of implementing measures (not only what is needed to be done, but also if it is cost-effective for the home-owners).

Considering that 80% of buildings owner are single-family houses owners, and in total 57% of the total floor area is privately owned in Norway (Thyholt et al., 2009), they can fully influence the robustness of renovations. The end-consumer is often content with only 'good enough' measures which may be focused solely on the short term, increasing the risk of energy lock–in effects (Risholt and Berker, 2013). Energy behavior (and how it can be changed) is one of the biggest challenges within implementation of upgrading solutions.

Therefor it is important to realize what kind of renovations are essential when one is considering upgrading of their homes. In the same time those owners have to be often persuaded to carry out improvements (Thyholt et al., 2009).

5.3 Users behavior: energy efficiency vs need for higher thermal comfort

A good example of how user behavior can influence the need for energy demand even if efficient solutions were applied, can be an example of implementing the heat pump. Research made by SSB shows that 50% of those who installed air-to-air heat pump experience none or negative energy savings (Enova, 2012, SSB, 2009) It might be due to the rebound effect. When one has cost-saving solution, he might use those 'saved' money for other expenses with effect of zero/or negative savings result. If a building has unheated rooms; installing heat pump might lead to heating those spaces or using potentially saved energy for increasing thermal comfort by increasing internal temperature.

5.4 Climatic zones – relevance of Oslo climate zone used as a reference for calculations.

The Oslo climate is not relevant for all of the Norway. As presented before in the results section, the energy demand for space heating is very sensitive to external average temperature. The Oslo climate zone has much higher average temperature than other regions in Norway, like middle of

Norway, or Finnmark area. The difference in the demand between Oslo climate and northern parts of Norway can be even up to 76%. That implies that for the Norwegian case and energy calculations, two or three references climate zones could be consider in order to give better overview over energy demand for buildings. Depending on the climate zone it is required more effort to be put in to the measures in order to obtain high standard of envelope insulation. The demand for better-insulated parts of envelope is increasing due to the external temperature.

From the other hand, taking Oslo climate zone as a reference climate for all energy calculation can be representative if one would look on how buildings stock in Norway is situated across the land. The number of the single-family houses in the Northern part of Norway is relatively small compared to the southern parts.

	number of inhavbited houses	**percentage of total inhabited houses (%)**
single family house	1080995.00	100%
1 Southern Norway, inland	415382.00	38%
2 Southern Norway, coast	325325.00	30%
3 Southern Norway, mountains	115658.00	11%
4 Mid-Norway, coast	111812.00	10%
5 Mid Norway, inland	18184.00	2%
6 Northern Norway, coast	70800.00	7%
7 Finnmark + inland Trmsø	23834.00	2%

Table 24. Number of inhabited houses split by different climate zones in Norway. (Enova, 2012).

6 Conclusion

Tabula Calculation Methodology provides a simple tool for energy demand calculations for different kinds of buildings. The method gives an easy to understand and use set of equations for calculations along with set of standard values that are averaged for each country. One could discuss the accuracy of using this kind of method for calculations. As it is said in Tabula, the aim is not to be precise with the obtained values but to have an overview on a current building stock in Europe and to be able to plan for robust renovations. With respect to this point of view, Tabula Calculation Method provides a standardized tool for planning scenarios for building stock. In this project, one can see pros and cons for using this method for a Norwegian case. To conclude, Tabula method is a good starting point for dynamic modelling for Norwegian dwelling stock, but more accurate tools might be in need for planning more detail analysis of the existing stock.

References

1. (IEA), I. E. A. 2011. Energy Policies of IEA Countries - Norway.

2. BARTLETT, S. 1993. Evolution of Norwegian energy Use 1950 to 1991.

3. BØHN, E. A. T. I. 2006. Veiledning for næringsbyggrådgivere (Multiconsult rapport). *ENOVA SF*.

4. ENOVA 2012. Potensial- og barrierestudie Energieffektivisering i norske bygg.

5. EU2020. 2008. *Energy efficiency for the 2020 goal.* [Online]. Available: http://europa.eu/legislation_summaries/energy/energy_efficiency/en0002_en.htm [Accessed 10.12.2013 2013].

6. EUCOMMISSION. 2008. *Energy efficiency: delivering the 20% targe* [Online]. Available: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52008DC0772:EN:NOT [Accessed 10.12.2013 2013].

7. IGOR SARTORI, B. J. W., ANNE GRETE HESTNES 2009. Energy demand in the Norwegian building stock: Scenarios on potential reduction. *Energy Policy***,** 1614–1627.

8. NS-3700 2013. Kommunal- og regionaldepartementet.

9. NTNU/SINTEF 2007. *Enøk i bygninger. Effektiv energibruk*, Gyldendal Norsk.

10. OLAV ISACHSEN, E. A. 2010. Implementatuin of the EPBD in Norway. . *Energy Performance of Buildings*.

11. RISHOLT, B. 2011. Strategies for renovation of single family dwellings from the 1980s towards zero energy levels.

12. RISHOLT, B. & BERKER, T. 2013. Success for energy efficient renovation of dwellings—Learning from private homeowners. *Energy Policy*, 61**,** 1022-1030.

13. SKARTVEIT, J. A. O. A. 1987. Varighetstabeller for timesvis solstråling mot 11 flater på 16 norkse stasjoner. *Meteorological Report Series, University of Bergen*.

14. SSB Population - summary.

15. SSB. 2007. *Dwelling units completed by type of building* [Online]. Available: http://ssb.no/a/histstat/tabeller/17-6-en.html [Accessed 10.12.2013 2013].

16. SSB. 2009. *Energibruk i husholdningene* [Online]. Available: http://ssb.no/energi-og-industri/statistikker/husenergi/hvert-2-aar/2011-04-19 [Accessed 10.12.2013 2013].

17. SSB. 2012a. *Housing and housing finance assessment bases* [Online]. Available: http://ssb.no/sosiale-forhold-og-kriminalitet/artikler-og-publikasjoner/sosiale-indikatorer?tabell=91523 [Accessed 10.12.2013 2013].

18. SSB. 2012b. *Marriages and divorces, 2012* [Online]. Statistics Norway Available: http://www.ssb.no/en/befolkning/statistikker/ekteskap/aar/2013-02-21 [Accessed 5.10.2013 2013].

19. SSB. 2013. *Families and households, 1 January 2013* [Online]. Available: http://www.ssb.no/en/befolkning/statistikker/familie [Accessed 05.10.2013 2012].

20. TABULA, P. T. 2013. Tabula Calculation Method -Energy Use for Heating ad Domestic Hot Water-.

21. TEK10 2010. Kommunal- og regionaldepartementet. Norway.

22. THYHOLT, M., PETTERSEN, T. D., HAAVIK, T. & WACHENFELDT, B. J. 2009. Energy Analysis of the Norwegian Dwelling Stock. *IEA SHC Task 37 Advanced Housing Renovation by Solar Conservation.*

23. TROND IVAR BØHN, T. U., ERLING WEYDAHL. 2006. *Bygningsenergidirektivet; Energiattestens tiltaksliste.*

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