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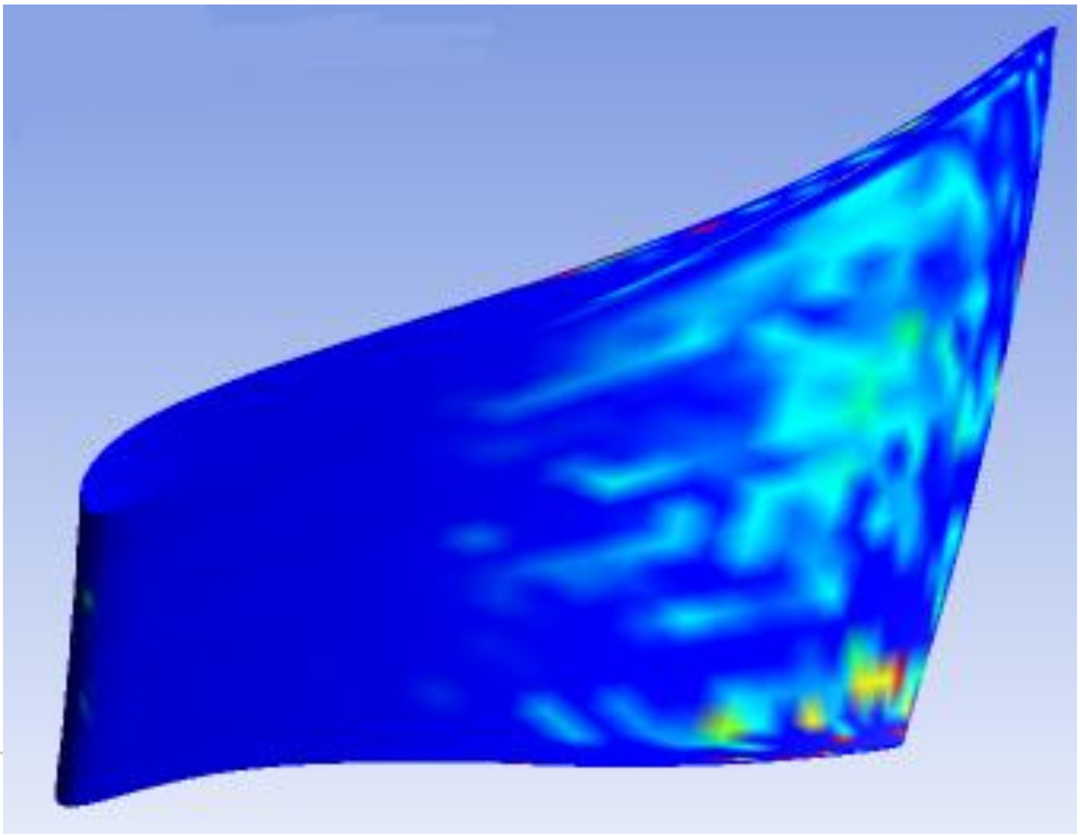
Typologies and energy demand modelling of the Norwegian building stock – Part 2

Apartment blocks built after 1980

Trondheim, December, 2013

Project thesis

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



Norwegian University of Science and Technology

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

EPT-P-2013-107

PROJECT WORK

for

student Anja Myreng Skaran

Autumn 2013

Typologies and energy demand modelling of the Norwegian building stock - Part 2

Typologier og modellering av energibehov i norsk bygningsmasse – Del 2

Background and objective

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

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

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

The following tasks are to be considered:

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

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The project work comprises 15 ECTS credits.

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

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

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

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

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

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

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

Submission deadline: *December 20, 2013.*

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

Department for Energy and Process Engineering, 22 August 2013.

Olav Bolland
Olav Bolland
Department Head

H. Brattebø
Helge Brattebø
Supervisor

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

Preface

I would like to thank my supervisor Helge Brattebø and co-supervisor Nina Sandberg for their valuable guidance, as well as fellow students Ragni Storvolleng, Marie Folstad, and Marta Baltruszewicz for helpful discussions and cooperation.

Following discussions with the supervisors, the tasks 2e, 5 and 7 have been excluded from the project work. The focus of the calculations has been chosen to be on energy, rather than costs and emissions. Renovation strategies including changes in energy carriers has not been included.

Parts of this project have been done in collaboration with the other students Ragni Storvolleng, Marie Folstad, and Marta Baltruszewicz. We have divided four typology groups in Norway among us: Pre-1980 and post-1980 buildings, single houses and apartment blocks. We have strived to make our projects compatible, in order to make it possible to combine our results in future research. We have therefore had regular meetings where we have discussed our assumptions and values, and used the same model as a basis for our calculations.

A TABULA standard worksheet for calculation already exists, but we created our own energy balance model based on the TABULA method (instead of using the original TABULA worksheet) in order to make sure it fitted the project, and to gain a deeper understanding of the calculation model. We each developed a model draft, and then chose the most suitable one after a discussion with the supervisors. Marie Folstad’s model was chosen, and provided a basis for the energy balance model I used in this project (Appendix 7.5).

Summary

This project focused on Norwegian apartment blocks constructed later than 1980, and aimed at finding the strategies best suited for reducing the energy demand for this particular set of buildings.

The calculations were carried out by developing an energy balance model in Microsoft Excel based on the TABULA calculation method. Three test buildings based on typical construction values and energy carriers for different time periods were used as a basis for the simulation, and the energy reductions of implementing a standard and an extensive rehabilitation package were calculated for all buildings. These rehabilitation packages were first defined based on the Norwegian regulation TEK 10 and standard NS 3700, but as the buildings already before renovation had a sufficiently low energy demand as to satisfy the TEK 10 requirements, the standard renovation package was altered.

The energy balance model produced reliable estimations for the original buildings and the standard renovation projects, but it is not recommended for low energy houses. The input values are the main source for errors, and further research should be applied to costs and renovation technologies.

Based on the results from this project, Norwegian apartment blocks built after 1980 have an energy reduction potential of between 425 and 644 GWh for the standard renovation package, and the extensive renovation package could give twice the energy savings. However, when comparing this number to goals in energy reduction and potential energy saving in other parts of the building stock, it is apparent that these particular buildings should not be a prioritized area for energy reduction policies. This is in line with a report from Enova, where no upgrades have been recommended for this part of the building stock at all.

Air exchange through the ventilation system must be increased for the oldest building types in order to satisfy the requirements in TEK 10. This contributes to high energy losses, which need to be minimized by implementing or improving the heat recovery system. For the two oldest building types, this type of renovation is the most efficient, while for the buildings constructed after 2000, change of windows gave the greatest decrease in energy use. Additional insulation of roof and walls are also good renovation measurements. Changing the heat delivery system would probably be an efficient renovation strategy, but this has not been tested in these calculations.

The energy demand varies significantly among the different climatic zones, but the distribution of energy losses seems to be more stable. The same renovation recommendations might therefore fit buildings in different locations.

Table of contents

List of abbreviations

BRA = Bruksareal (available area)
DHW = Direct hot water
EPBD = European Building Directive
NS = Norwegian Standard
TEK = Byggeforskrift
SSB = Statistics Norway

List of symbols

A = Area of building element [m^2]
d_n = Thickness of building element layer n [m]
λ_n = Heat conductivity of building element n [W/mK]
Q = Heat transfer by transmission through a certain building element [W]
R_n = Thermal resistance of building element n [m^2K/W]
ϑ_{ym} = Yearly average temperature [°C]
U = Coefficient of thermal transmittance (U-value) [W/m^2K]

All symbols used for the TABULA equations are given in appendix 7.3.

1 Introduction

Reduction of energy demand is important in order to limit emissions and depletion of fossil energy sources. As a substantial share of the total energy demand is connected to the energy demand in buildings, and this is therefore a prioritised area for reduction. Both Norway and the EU have set regulations regarding energy consumption in this field, but more research remains on the strategies best suited for reaching the targets set by these regulations.

This project will focus on Norwegian apartment blocks constructed after 1980, and the possible renovation strategies for energy reduction here. Current regulations will be used as a basis for standardised renovation packages, and these will be applied to some test buildings through simulation in an energy balance model. The test buildings will be chosen based on typical properties for different construction periods, with regards to energy use, heating source, and building construction.

The goal is to evaluate the results of the different renovation strategies on typical Norwegian buildings, find the most important factors influencing the energy demand, and calculate the energy saving potential of this particular part of the Norwegian building stock. The calculations will be based on the TABULA method – a standardized method developed by the EU's Intelligent Energy Europe for calculating energy demands for heating in buildings.

The results will be used for contributing to the research on the future aggregated building stock and its energy dynamics at the faculty of Industrial Ecology at NTNU.

2 Background

2.1 Building definition

The building type chosen for examination in this project is Norwegian apartment blocks, constructed in 1981 or later. The first issue in this project is therefore to define which buildings are involved in this category.

The TABULA method does not specify any definition of apartment blocks, only stating that building definitions vary among countries (Loga et al., 2012b).

Mjønes et al. (2012) define apartment blocks as detached blocks of housing units, consisting of concrete elements. They further state that the units are small, contain one inhabited floor each, and that the building type consists of 18 units in average, spread over 4 floors. The report is based on statistical data from Statistics Norway (SSB), from 2010.

SSB uses two different definitions of apartment blocks, according to SINTEF Byggforsk and NTNU Samfunnsforskning (2009): For SSB's centennial populations and housing census, all dwellings of 3 floors or more are counted. In their general building statistics, the definition is any dwelling of more than 2 floors and with at least 5 apartments.

Most other major sources in this project do not include a clear definition of which buildings they include as "apartment blocks". It is, however, likely that Norwegian numbers are based on research from SSB, and SSB's two definitions are not different enough to indicate that they will produce significantly different results. Therefore, the numbers from the various sources are from here on assumed to involve the same buildings.

2.2 Dynamics of the building stock

Figure 1 and Figure 2 describe the development of the Norwegian residential building stock in terms of area and building type. It is apparent that apartment blocks were unpopular between 1981 and 1990, but they have later become increasingly common again. According to Figure 1, the total area of new buildings has also decreased since this time, stabilizing after 1990.

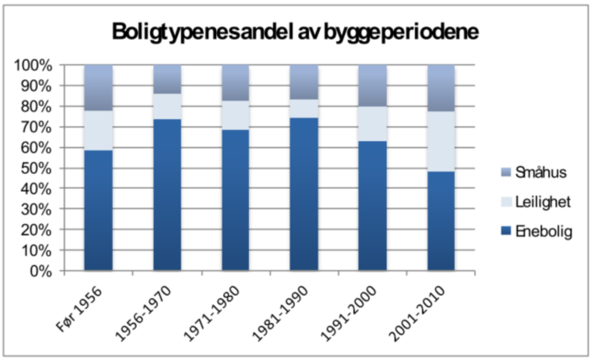

Figure 1: Distribution of building types in Norway by share of total area per time frame, sorted by year of construction. Top part = terraced houses, middle part = apartment blocks, bottom part = detached houses (Mjønes et al., 2012)

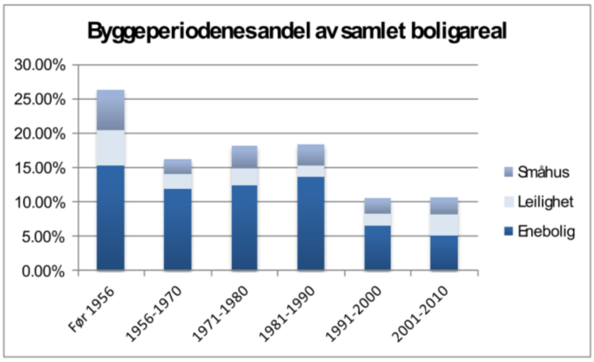

Figure 2: Distribution of building types in Norway by share of total area, sorted by year of construction. Top part = terraced houses, middle part = apartment blocks, bottom part = detached houses (Mjønes et al., 2012)

Although the newly constructed building area has sunk, Hille et al. (2011) proves that this trend does not apply to apartments. Both the number and area of apartments have increased for the relevant time frame. The average area has shrunk between the two first time frames, again to increase slightly in the most current past, resulting in a standard building size identical to that of the total average over time.

Comparing the buildings constructed in the time scale of this project (1981 and later) with the total amount of buildings in Norway, gives an indication that this is not the largest typology group at the moment. Buildings newer than 1980 represent less than half of the total building stock (Figure 2), and this applies to apartment blocks as a bounded category as well, both in terms of area and amount (Table 1).

Table 1: Amount and area of Norwegian existing apartment buildings, sorted by construction year (Mjønes et al., 2012)

Construction year	**Number of apartments**	**Average area per unit [m^2]**	**Total area [m^2]**
1981-1990	56,379	76	4,310,185
1991-2000	63,820	69	4,835,626
2000-	115,080	71	8,114,649
Total	593,598	71	42,126,802

In 1920, the average household would include 4.3 persons. This number had decreased to 2.3 in 2001. The area per person decreased between 1980 and 1989, but has later stabilized. The average area of buildings follow the same trend at first, but increase slightly after 1994 (Bøeng, 2005).

Mjønes et al. (2012) list typical compositions of the building envelope for apartments, and the relevant values are gathered in Table 2 to Table 4.

Table 2: Typical composition of apartment walls 1981-2010 (Mjønes et al., 2012)

Construction year	**Composition**	**U-value [W/m^{2}K]**
1981-2000	Wood frame house, 150 mm mineral wool, 50 mm thermal breaker	0,29
2001 - 2010	Wood frame house, 200 mm mineral wool, 50 mm thermal breaker	0.27

Table 3: Typical composition of apartment roof 1981-2010 (Mjønes et al., 2012)

Construction year	**Composition**	**U-value [W/m^{2}K]**
1981-2000	Concrete slab, 180 mm mineral wool	0,2
2001 – 2010	Hollow core slabs, 220 mm mineral wool	0.14

Table 4 Typical composition of apartment floor 1981-2010 (Mjønes et al., 2012)

Construction year	**Composition**	**U-value [W/m^{2}K]**
1981-2000	Concrete floor, 120 mm mineral wool	0.2
2001 – 2010	Hollow core slabs, 220 mm mineral wool	0.14

Mjønes et al. (2012) provide U-values for typical apartments from different times, and Broli (2000) provide a table for matching U-values with window types. By looking at these two sources in combination, the development of the typical window type becomes clear. For the early buildings, two-layered, sealed insulated windows with one metal coated glass, filled with air was the most common. Newer window technology has been developed in order to decrease the U-values. These include additional metal coated glasses and argon filling (Broli, 2000).

2.3 Energy use in buildings

The energy demand of Norwegian buildings can be very different than the energy demand of buildings in other parts of Europe, because of the cold climate. Norwegian residential buildings need most of the energy for heating purposes, and traditionally no or very little energy for cooling purposes. Additionally, Norway has an abundance of cheap electricity and wood, which makes these the main energy sources, as opposed to other European countries, where sources such as oil, gas and district heating are more common. Therefore, Norway has the lowest CO_2 emissions per useful floor area of all the European countries (Laustsen et al., 2011).

The development of energy need for all residential buildings in Norway can be read from Figure 3 and Figure 4. It is clear that the energy demand for the residential building sector has increased over the years (mostly due to population growth and larger living spaces per person), but the energy use for each building has been more stable. The energy savings from more energy efficient and better insulated buildings were to an extent neutralized by the increasing energy use for appliances and increased living areas per person (Hille et al., 2011).The dip in 1974 was caused by the oil crisis in 1973-1974 when oil prices were doubled, combined with a warm year. The highest values are mostly connected with cold winters (Bøeng, 2005).

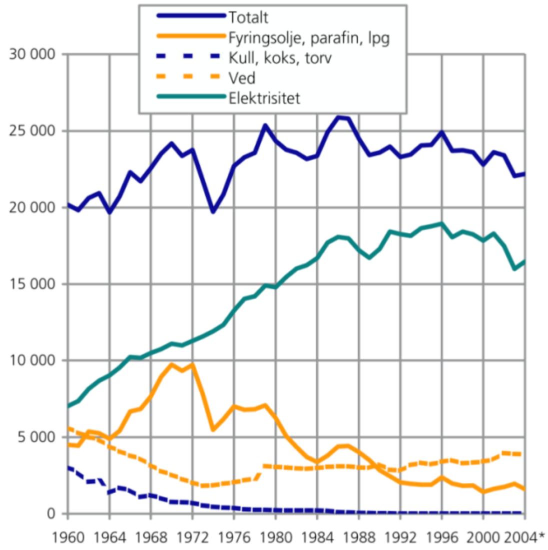

Figure 3: Norwegian average energy use per household 1960-2004 in kWh supplied energy. Blue = total, yellow = heating oil, blue stapled = coal, coke, and peat, yellow stapled = wood, green = electricity (Bøeng, 2005)

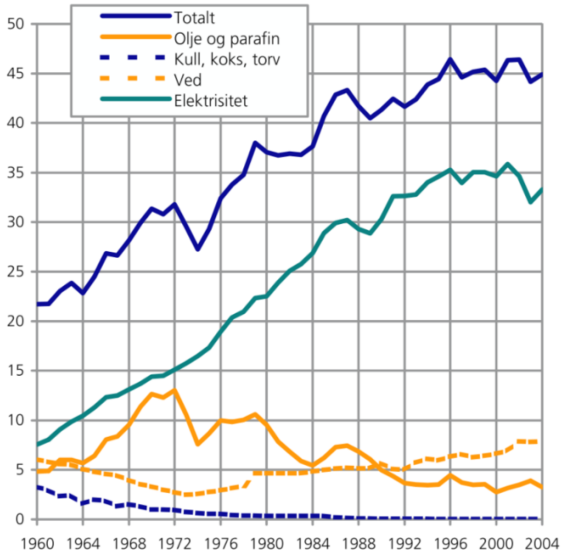

Figure 4: Total Norwegian domestic energy use 1960-2004 in TWh supplied energy. Blue = total, yellow = heating oil, blue stapled = coal, coke, and peat, yellow stapled = wood, green = electricity (Bøeng, 2005)

Figure 5 shows the development of energy use in more recent years, and how the energy use varies depending on building type. The energy consumption has decreased slightly for apartment blocks between the last two time frames, continuing the historical trend. The other building types stay on the same level for the last two time frames.

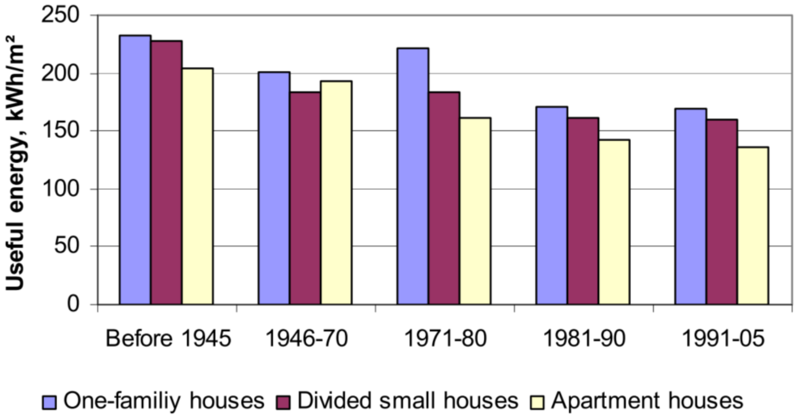

Figure 5: Specific net energy consumption for Norwegian residential buildings, sorted by construction year and type (Thyholt et al., 2009)

Table 5 gives a more detailed picture of the energy use in apartments, as it separates the energy used for room heating from the other energy demands. This table does not, however, include energy used for DHW (direct hot water). According to Hille et al. (2011), out of the delivered energy for a typical apartment, 25 % is used for DHW and 23 % for room heating.

Table 5: Delivered yearly energy for apartment blocks (excluding DHW), sorted by year of construction. Values calculated from (Mjønes et al., 2012)

Construction year	**Total delivered energy [kWh/m^2]**	**Delivered energy for room heating [kWh/m^2]**	**Room heating share of total energy**
1981-1990	114	55	48 %
1991-2000	123	55	45 %
2000-2010	107	49	46 %

The average indoor temperature varies depending on the age of the apartment. Older apartments generally have a lower temperature, because the heat loss through the building envelope is greater, and the users do not want to spend as much money on energy. Additionally, the increased installations of central heating in apartments cause the apartments to be warmer due to not being as easily controlled by the residents as electrical heating (Mjønes et al., 2012).

One can safely assume that every housing, apart some of the ones in apartment buildings, in the years after 1990 contain a single water heater (Bøeng, 2005). These are generally heated directly by electricity (Ulseth and Tjelflaat, 2013).

According to Ljones (1983), 85 % of the apartment blocks built after 1970 utilized electrical heating as their main heat source, either from radiators or floor heating. This was a doubling from the previous time frame. Central heating (mostly heated by oil) and solid fuel was decreasing, and liquid fuel was not the main heating source for any of the apartments. The same report says that for all the existing apartment blocks, the most common was to have no additional heating source. Only 16 % had an additional heating source (excluding electricity). This indicates that the typical building in the early 1980's had only one heating source, and that this was electricity.

It has not been possible to gather as detailed data on the typical energy source in the 1990's in the previous time frame. However, according to Mjønes et al. (2012), the amount of apartment buildings with electricity as the main heating source increased from 82 % between 1971 to 1980 to 93 % in the second time frame. The distribution for the stereotype buildings defined by Thyholt et al. (2009) is 65 % direct electricity, 13 % firewood, 10 % heat pump (air to air), 7 % oil and gas, and 5 % electrical floor heating for every time frame. That means 70 % electric heating, excluding heat pumps. Bøeng (2005) states that this number was 49 % in 2001. All these sources strongly indicate that direct electric heating must be the typical main heating source for buildings newer than 1991.

In 2010, the total Norwegian building stock had a net energy demand of 43.69 TWh. Apartment blocks contributed to 6.59 TWh of these, and the apartments built later than 1980 had an energy use of 2.45 TWh or 5.6 % (Mjønes et al., 2012).

Looking at Sweden, the country with the most similar climate to Norway in the TABULA project, it is apparent that the energy carriers have developed differently. Figure 6 shows that district heating has been one of the main energy carriers, and its share has increased to almost a third of the present delivered energy. Electricity accounts for the largest share of heat delivered, but its share is significantly smaller than it is for Norway. Oil for heating has decreased, while use of biomass has remained constant. The total residential energy demand in Sweden has remained fairly constant since 1983, while Norwegian energy demand has increased.

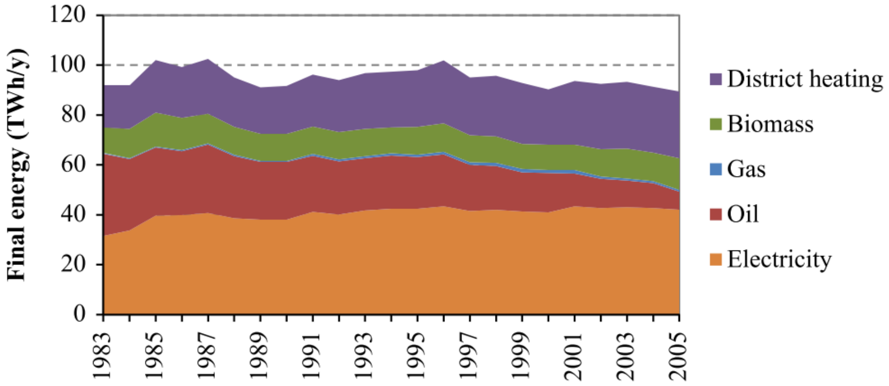

Figure 6; Final annual energy use by carrier over time for the Swedish residential sector in TWh per year (Mata et al., 2013b)

2.4 European regulations

Directive (EC) 2002/91 of 16 December 2002 on the energy performance of buildings, often referred to as The European Building Directive (EPBD) has been implemented in most of the European countries, and it is also the basis for the Norwegian regulations on energy use in buildings (Husbanken, 2013). The directive lays down requirements regarding:

- Generating a general framework for a methodology of calculation of the integrated energy performance of buildings.
- Applying minimum requirements on the energy performance of new buildings and large buildings subject to major renovations.
- Energy certification of buildings.
- Regular inspection of boilers and air-conditioning systems in buildings, and an assessment of heating installations with boilers that are more than 15 years old.

The EPBD was revised, and the new requirements were published in 2009. These revisions involve that all buildings built after 2020 must be nearly zero-energy buildings, and new buildings occupied and owned by public authorities must be nearly zero-energy buildings after 2018. In addition, the energy used in the buildings must involve a substantial share of renewable energy (Husbanken, 2013).

The EPBD was fully implemented in Norway in 2010. As from that year, all Norwegian buildings must be certified through “Energimerkeordningen” (“The energy grading arrangement”) before they can be sold or leased to new tenants. This certificate includes an energy labelling based on the calculated delivered energy (irrespective of energy carrier), using the standard NS 3031 (Standard Norge, 2011). The grading system goes from A to G, where C is based on the minimum requirements in the current technical regulation (Isachsen et al., 2010).

Table 6: Energy grading from "Energimerkeordningen" as of 1.7.2013 (NVE, 2013). A = heated part of building related area [m^2].

Building grade	**Maximum delivered energy [kWh/m^2·year]**	
	Single housing	**Apartment block**
A	85,00+800/A	75,00+600/A
B	115,00+1600/A	95,00+1000/A
C	145,00+2500/A	110,00+1500/A
D	175,00+4100/A	135,00+2200/A
E	205,00+5800/A	160,00+3000/A
F	250,00+8000/A	200,00+4000/A
G	> F	> F

Table 7: Calculated maximum energy use for different building grades according to "Energimerkeordningen", calculated from average area for the different time steps.

Building grade	**Maximum energy use [kWh/m^2]**		
	1981-1990	**1991-2000**	**2001-**
A	95.53	96.59	96.27
B	136.05	138.19	137.54
C	177.89	181.23	180.21
D	228.95	234.42	232.75
E	281.32	289.06	286.69
F	355.26	365.94	362.68
G	Less than F	Less than F	Less than F

2.5 Norwegian regulations

2.5.1 General information

The Norwegian government has not a set energy savings target for buildings. However, the last government declared a target of 15 TWh energy saved in buildings within 2020 (Olje- og energidepartementet, 2012). Areas used for calculations in the Norwegian regulations are based on BRA (available area), which simply put is the area within the walls of the building. The details are covered in NS 3940 (Standard Norge, 2012).

Building properties such as U-values, total energy use, thermal bridging, etc. are to be calculated using other given standards in order to control if the building meets the requirements. Most of the calculation methods are covered in NS 3031. Here, detailed calculations of energy for air heating and cooling are given, along with a table for standardized data for calculating energy need for lighting, equipment and DHW. The data that applies to apartment blocks is given in Table 8.

Table 8: Standardised yearly net energy need for apartment blocks, according to Table A.1 in NS 3031

Energy purpose	**Yearly energy need [kWh/m^2]**
Lighting	11.4
Equipment	17.5
Tap water heating	5.1

The regulations set standards according to building type, room type (especially relevant for ventilation), and the length of time it is expected for someone to stay inside of the room. The numbers presented below are selected for rooms in apartment blocks where people are assumed to stay for longer periods of time. Apartments in blocks are usually not very large, and are less likely to contain rarely used rooms. Special requirements for kitchens and bathrooms are not included in the following summaries.

2.5.2 The “Byggeforskrift” and TEK series

The regulation Byggeforskrift 1949 (1949) set requirements to insulation in new buildings by defining minimum λ-values. The bank “Husbanken”, which financed 62 % of all new buildings between 1952 and 1964, defined a maximum U-value of 0.4 in walls and roof (Mjønes et al., 2012).

Byggeforskrift 1949 was later replaced by TEK 69 (1969), where chapter 54 defines minimum λ-values for walls, roof and floor, according to the expected air temperature of the room, as well as a maximum infiltration loss (4 air exchanges at 50 Pa).

Later updates (TEK 87 (1987), TEK 97 (1997), updated as TEK 07 (Statens bygningstekniske etat, 2007), and TEK 10 (2010)) set increasingly stricter demands for the maximum U-values. These are collected in Table 9.

Table 9: Maximum U-values [W/m^{2}K] for apartment blocks specified by the TEK regulations and NS 3700 for passive houses. Median of typical U-values for passive houses (Table B.1 in NS 3700) is marked with parentheses.

Regulation	**Walls**	**Roof**	**Floor**	**Window**	**Door**
TEK 87	0.30	0.20	0.3	2.4	2.00
TEK 97	0.22	0.15	0.15	1.60	1.60
TEK 07	0.18	0.13	0.15	1.2	1.2
TEK 10	0.18	0.13	0.15	1.2	1.2
NS 3700*	0.18 (0.11)	0.13 (0.085)	0.15 (0.08)	0.8	0.8

The U-values from the TEK regulations in Table 9 do not necessarily need to be followed in order for a building to be approved. It can also be approved if the U-values of the construction parts are lower than some less strict U-values, and if the yearly energy demand for space heating per m^2 is lower than a certain limit. The can be calculated by Equation 1 for TEK 97 and Equation 2 for TEK 10.

$$\frac{Q_{H,nd}}{A_{C,ref}}\left[\frac{kWh}{m^2}\right] < 120 + \frac{1600}{A_{C,ref}} \tag{1}$$

$$\frac{Q_{H,nd}}{A_{C,ref}}\left[\frac{kWh}{m^2}\right] < 115 + \frac{1600}{A_{C,ref}} \tag{2}$$

Maximum thermal bridging was set to 0.06 W/m^2 in TEK 07.

Specific requirements for ventilation were introduced in TEK 97. The maximum air exchange could not exceed 1.5 exchanges per hour. In TEK 07, a minimum air exchange value of 0.5 exchanges per hour was introduced. A certain air exchange is important in order to achieve satisfactory indoor air quality. In older original buildings, the natural infiltration due to leakages through the building envelope is large, and this ensures most of the fresh air supply. As building regulations requires increasingly tighter building envelopes in order to minimize the heat losses related to infiltration, the air quality is no longer be satisfactory by default, and must be supplied by the ventilation system.

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* Will be described in chapter 2.5.3

According to Mjønes et al. (2012), early apartment blocks utilized natural ventilation, but this began to change in the 1970's as mechanical ventilation became increasingly more common. Mechanical ventilation allows for heat recovery, and TEK 97 set a requirement for the efficiency of the heat recovery unit of at least 70 %. This was later increased to 80 % in TEK 10.

TEK 97 also set some requirements to the heating source: Buildings constructed in areas with "tilknytningsplikt" (requires buildings to be attached to the district heating system) must utilize energy from district heating. Also, "a significant part" (at least 40 % in TEK 10) of the energy for the building must be covered by other sources than electricity or fossil. Installing oil boilers for base load heating was forbidden by TEK 10.

2.5.3 NS 3700

The Norwegian standard NS 3700 (Standard Norge, 2013) was first published in 2010, and an updated version followed in 2013. It contains criteria for three different buildings: Class 1 low energy buildings, class 2 low energy buildings and passive houses. The standard is not mandatory, but it must be followed in order to approve a building as a passive house or low energy building. It is based on TEK 10, but with some extra demands. As low energy buildings are not relevant to the work of this project, only the requirements relevant for passive houses are covered here.

A passive house must satisfy both the maximum U-levels in Table 9 and the maximum air heating demand given in equation 3 and 4, according to the average outside temperature. As there is no guarantee that the U-levels in Table 9 will result in a satisfactory energy air heating demand, the standard also adds a table of typical U-values for a passive house. The median of these values are added to Table 9, as they are useful for the calculations later on.

If the average outside temperature $\vartheta_{ym} \geq 6.3$ °C:

$$\frac{Q_{H,nd}}{A_{C,ref}}\left[\frac{kWh}{m^2}\right] \leq 15 + 5.4 \cdot \frac{(250 - A_{C,ref})}{100} \tag{3}$$

If the average outside temperature $\vartheta_{ym} < 6.3$ °C:

$$\frac{Q_{H,nd}}{A_{C,ref}}\left[\frac{kWh}{m^2}\right] \leq 15 + 5.4 \cdot \frac{(250 - A_{C,ref})}{100} + \left(2.1 + 0.59 \cdot \frac{(250 - A_{C,ref})}{100}\right) \cdot (6.3 - \vartheta_{\mathrm{ym}}) \tag{4}$$

Maximum heat loss by transmission and infiltration is 0.53 W/m^{2}K, and the thermal bridge values must be less than 0.03 W/m^{2}K. No energy for cooling is allowed.

Delivered electrical and fossil energy must be smaller than the total energy need minus 50 % of the net energy need for DHW.

2.6 Common strategies for renovation

There are a number of renovation options for residential buildings, such as: changing the windows, adding insulation to walls, floor, or roof, installing a heat pump, solar collector, photovoltaic cells, or a bio energy boiler, in addition to other solutions (Mjønes et al., 2012).

According to Mjønes et al. (2012), 91 % of the buildings constructed between 1981 and 1990 have not been subject to any energy related refurbishment, and this number is even higher for newer buildings. The same report contains calculations of the potential economic savings of some popular renovations strategies on apartment blocks. For all apartments newer than 1980, an air/air heat pump is considered profitable, and the same applies for changing the windows in buildings built earlier than 2001. However, the report has calculated that upgrading the same apartments to a full TEK 10 standard would not be profitable, but that it will be for buildings built between 2001 and 2010.

Mjønes et al. (2012) suggest adding mineral wool as a standard insulation measurement. Reduction of thermal bridging depends on whether the insulation has been added from the inside or the outside. If the insulation is added from the outside, the thermal bridging will be reduced, but it will stay almost unaffected if the insulation is added from the inside. Because of this, and additional problems such as reduced living area, insulation is usually added on the outside of the wall (Aschehoug et al., 2007).

Mata et al. (2013a) calculated that the greatest energy saving potentials for the Swedish residential sector involve heat recovery systems, ideally in a combination with slight reduction in the indoor temperature. However, this is not necessarily the case for Norwegian buildings, because of the different standard heat delivery systems. Mata et al. (2013a) concluded the potential energy in the Swedish residential sector had a total reduction potential of 55 % when applying all energy savings measures evaluated.

2.7 The EPISCOPE and TABULA projects

Various measures have been implemented in the European countries in order to fulfil the climate protection targets set by the EPBD. In order to track the effects of energy refurbishment of national building stocks in European countries, various institutions in Europe (including NTNU) are cooperating in a project called EPISCOPE. The project focuses on building typologies, building stock monitoring and scenario analysis. The goals are to establish a set method for monitoring energy use and comparing the results to the policy targets and to other countries, and recommendations for energy measurements and how to monitor them. The building types that are to be examined in this project are existing buildings, new buildings and Nearly Zero Energy Buildings (NZEBs) (Institut Wohnen und Umwelt GmbH, 2013a).

The conceptual framework of the EPISCOPE project will be based on the building typologies from the finished IEEE project TABULA (Institut Wohnen und Umwelt GmbH, 2013a).

Similarly to EPISCOPE, this project was done in collaboration between European institutes, but not including Norway. In TABULA, residential building typologies were developed for 13 European countries. These typologies were classified according to age, size, and other parameters. Additionally, energy related features and possible energy savings from refurbishments were calculated for example buildings from each category (Loga et al., 2012c).

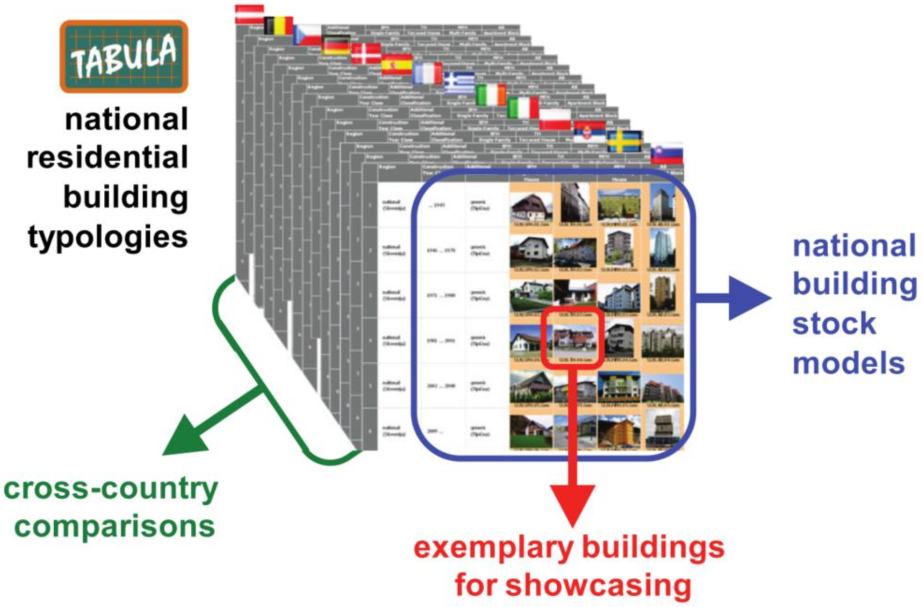


Figure 7: General idea of TABULA building typologies (Loga et al., 2012c)

TABULA does not classify the various building typologies, but the contributing various classifications by the contributing countries can be read from Loga et al. (2012b): The countries separated the building sizes into between two and four groups, consisting of apartment blocks and detached houses, and some subcategories in between where this applied. Apartment buildings falling under the definitions for Norway described in chapter 2.1 seem to fit under the definitions similar to “apartment blocks” and “multi-family houses”. The time frames of the buildings varied, but were generally based on time steps of ten years, leading up to present time. Some countries did calculations based on typical buildings, in addition to average buildings.

In order to calculate the energy demands, the model takes into account energy used for tap water heating and room heating (including losses from production, storage and distribution in the close vicinity of the building), internal heat gains, solar heat gains and heat transfer by ventilation and transmission. These values are mainly calculated based on the characteristics of the construction of the building, heating sources, and climate data. The model does not consider the energy demand of other appliances within the building, such as kitchen appliances and electronics. A full description of the model can be found in Loga and Diefenbach (2012a).

3 Methodology

3.1 Preliminary case study

3.1.1 Description

In this case study, a typical Norwegian apartment block will be selected for different time frames and locations, and be subject to two different renovation strategies in order to examine the typology characteristics and changes in energy balance factors. The typical values will be found through literature, and the final values will be calculated using the TABULA method described in chapter 2.7. Appendix 7.3 contains an excerpt of all values needed for the calculation. Appendix 7.4 contains the compressed equations used for the calculations in this project, further described in chapter 3.1.2.

No Norwegian institution took part in the TABULA project, and as a result, Norwegian typologies have not been defined yet. (However, some Norwegian values have been chosen for the newer TABULA model (Institut Wohnen und Umwelt GmbH, 2013b) that will be used as a basis for the EPISCOPE project.) As a result, typologies have to be made specifically for this project in order to complete the necessary calculations. In chapters 3.1.3 to 3.1.9, the typology values related to Norwegian apartment blocks will be assigned.

Calculations from the energy balance model will consist of:

- Calculating the total energy used in original and renovated buildings, as well as all energy flows affecting the total energy need
- Calculating the changes in all energy flows for renovation projects, as well as their share of the total energy change
- Comparing calculated energy needs to actual values and values used as basis for Norwegian regulations
- Examine the relationship between changes in energy flows and total energy use, in order to find the most efficient renovation strategies
- Calculating the influence of renovation of different building envelope parts on the energy need

3.1.2 Digital worksheet

In order to better understand and simplify the TABULA calculation method, a worksheet has been made in Microsoft Excel for all calculations done in this project. This worksheet and instructions for using it is delivered electronically with the project in appendix 7.5, and all values used for calculations can be found here. The calculations in the worksheet follow the TABULA method, with a few exceptions:

The $R_{measure}$ values are set to 0. Instead of adding R-values from the refurbishment measure to the original R-value, the R_{total} values are changed to a final value defined by the Norwegian standards.

Some equations are not properly defined in the TABULA Calculation Procedure (Loga and Diefenbach, 2012a), as their denominations either makes little sense or do not match up in the equations. In these cases, assumptions have been made as to how these equations probably should be. All equations used for the calculations can be found in appendix 7.4.

3.1.3 Renovation projects

As the vast majority of the building stock relevant to this project has not been subject to energy refurbishment, the original state of the sample buildings are based on the condition of which they were built. Mjønes et al. (2012) provide extensive information on the typical historical buildings, sorted into time frames of ten years at a time, and this project will use these same time frames in order to classify the renovation typologies. If the necessary values are not found in the report by Mjønes et al. (2012), the numbers will be based on minimum values in the relevant regulations, other sources, or assumptions.

The renovation strategies will be based on the requirements of TEK 10 (typical project) and NS 3700 (extensive project), with some exceptions. The reasoning for the values chosen is described in detail in the following chapters, and a full summary of the values chosen for calculation can be found in chapter 3.1.10.

This report will not calculate whether the buildings actually qualify as passive houses or not, as this would require extensive calculations in accordance to several Norwegian standards.

3.1.4 Heating source

As mentioned in chapter 2.3, electricity was the most common heat source for air heating in apartments before 2000. Thus, 100 % electricity is assumed for the original buildings in this time period.

The heating source for newer buildings is more difficult to decide. TEK 97 demands that over half of the energy should be from another source. The apartment block might be connected to district heating, but only if there are pipelines in the vicinity. Another popular option is heat pumps, but there are great differences in their efficiencies, especially concerning the geographical placement of the building. This makes it difficult to compare energy usage in the different heating zones, as a heat pump that is ideal for use in the southern coast never should be used in the north. As there are even more additional options and no statistics has been found on which combination is the most common, only electricity will be used as a reference here as well. This also makes it easier to compare the insulation effects of the different time frames.

Changing the heating system is a valid rehabilitation measure. However, this would normally require adding pipes for water-borne heating or / and a heat pump. In order to limit the complexity of this project, it was agreed with the supervisor that the energy source for room heating should not be changed, despite the fact that this is against the current regulations.

Sweden and Denmark did not include values for decentralized water heating systems in their TABULA calculations, and the German values were therefore used for the calculations. The German values distinguish between tap water heaters before 1994 and after 1995 (Institut Wohnen und Umwelt GmbH, 2013b). The early values were chosen for the oldest building type, while the later values were chosen for the others. Changing the tap water heater is assumed to be part of an extensive rehabilitation process.

An advantage of electrical heaters is the energy efficiency. The energy lost in the generation of heat is practically 0. $e_{g,h}$ and $e_{g,w}$ are therefore set to 1.

3.1.5 Ventilation

Mjønes et al. (2012) assume exhaust system for pre-2001 buildings and balanced ventilation for all newer buildings, and this will also be the basis for the calculations. They define infiltration losses for all buildings within the time frame of this project as 1.5 air changes per hour at 50 Pa pressure difference. This means a TABULA air exchange rate of between 0.1 and 0.2, according to Table 4 in Loga and Diefenbach (2012a). In order to assure that the values are met, the infiltration loss is set to 0.1 per hour for these buildings. NS 3700 requires passive houses to have an air tightness of maximum 0.6 1/h at 50 Pa pressure difference. This gives a TABULA air exchange rate of 0.05 1/h.

Air exchange values are also given by Mjønes et al. (2012) for the original buildings. The air exchange from ventilation is calculated by subtracting the air exchange by infiltration from these values. For the upgraded building, the minimum air exchange rate from TEK 10 is used.

All rehabilitation projects will include changing to balanced ventilation in order to meet the air exchange demands set by the current standards.

3.1.6 Insulation

Thermal transmittance values for the existing buildings are based on the U-values from Mjønes et al. (2012). The table on page 56 in the report shows slightly different U-values for roof and floor for the building from 1991-2000 than the tables on page 50 and 51. As the last two tables allow for more detailed information on the structure of the building parts, these numbers are chosen as a basis for the calculations. The upgrades are based on minimum values from TEK 10 and NS 3700, except for the upgrade package for floors in the newest building type. Here, the U-value for the basic building is higher than the minimum requirements in TEK 10, and by following these numbers, this would make for a removal of insulation in the refurbishment process. Therefore, the thermal transmittance values for the floor are assumed to be unchanged in this specific scenario.

Insulation must be added in order to satisfy the demands posed by the Norwegian standards. Mjønes et al. (2012) suggest adding mineral wool as an insulation measure, and this will be the basis for the calculations in this method as well. Mineral wool has a heat conductivity of between 0.034 and 0.040 W/mK (Kristensen, 2003). By rearranging equation 6, and assuming a heat conductivity of 0.040 W/mK of the wool, the required thickness of the added layer of mineral wool in order to reach the renovation goals have been calculated using the formulas in appendix 7.1. The results are gathered in Table 10.

Table 10: Calculated extra layer of mineral wool needed for upgrading apartment walls to the standards set by the typical and extensive renovation projects

Construction year	Thickness of layer, typical renovation [mm]	Thickness of layer, extensive renovation [mm]
1981-1990	84	226
1991-2000	84	226
2000-2010	74	215

Table 11: Calculated extra layer of mineral wool needed for upgrading apartment roof to the standards set by the typical and extensive renovation projects

Construction year	Thickness of layer, typical renovation [mm]	Thickness of layer, extensive renovation [mm]
1981-1990	108	271
1991-2000	108	271
2000-2010	22	185

Table 12: Calculated extra layer of mineral wool needed for upgrading apartment floor to the standards set by the typical and extensive renovation projects

Construction year	Thickness of layer, typical renovation [mm]	Thickness of layer, extensive renovation [mm]
1981-1990	67	300
1991-2000	67	300
2000-2010	0	214

The insulation is assumed to be added to the outside wall, and therefore, the thermal bridging will be reduced for both refurbishment packages. Calculating thermal bridges is complicated, and is usually based on simplifications. Table A4 in NS 3031defines typical thermal bridges for newer buildings, based on the insulation thickness and thermal bridge barriers in the wall. As no better source has been found, these numbers are assumed to be valid for the two oldest building typologies. The wall type with 20 cm thick mineral wool insulation and 5 cm thick thermal bridge barrier is the closest match to the typical wall in these buildings, which gives a thermal bridge value of 0.12 W/m^{2}K.

3.1.7 Windows

By comparing U-values for the different times from (Mjønes et al., 2012) with the U-values for different technologies from Broli (2000), the buildings from 1981-2000 are assumed to have two-layered, sealed insulated windows with one metal coated glass, filled with air. The newest original buildings have an additional glass sheet and argon filling in one of the cavities. The standard rehabilitation is assumed to involve one ordinary and two metal coated glass sheets with argon filling in both cavities. The table does not provide a technology with as low U-values as required for passive houses, but according to Enova (n.d.), this can be achieved by using the same type of windows with better insulated frames.

The TABULA sheet (Institut Wohnen und Umwelt GmbH, 2013b) provides some values for energy transmittance through radiation for different window technologies for Norwegian buildings. The transmittance values are thus selected by assuming the technology distribution assumed above. The value was not defined for the windows chosen for extensive rehabilitation, and is therefore assumed to be the same as for the other rehabilitation window type. As they have the same structure, this is not unlikely.

3.1.8 Climatic zones

Table 13 contains the climate data used for specific heating seasons in the calculations. The values are based on vertical irradiation data from Olseth and Skartveit (1987) and temperature and other irradiation data from Enova (2004). As the data from the sources was given on a yearly basis, the values in the table had to be calculated in order to find the average values of the heating season. The beginning and end of the heating season was assumed based on the coldest months, in order to calculate the values in the table. The mean value is calculated based on the averages of the different heating seasons. (Because of Norway's population pattern, this is not the same as for the average Norwegian building.)

The climatic zones defined by Enova (2004) are used as a basis for the calculations, and three of them have been selected for more thorough calculations in this project. The selection is based on the placement of major cities in Norway, but also on geographical diversity in order to see how differences in radiation and temperatures affect the energy need.

The three zones are defined as following:
Zone 2 = Southern Norway, coast (Oslo, Kristiansand, Bergen)
Zone 5 = Middle Norway, inland (Trondheim)
Zone 6 = Northern Norway, coast (Tromsø, Bodø)

Norwegian standard calculations are based on climate data from Oslo, given by NS 3031. The heating season in Oslo is assumed to be the same as for climatic zone 2. The rest of the values are calculated in the same way as described above.

Table 13: Climatic zone values

Parameter	**Oslo**	**Zone 2**	**Zone 5**	**Zone 6**	**Mean**
Length of heating season [days/year]	237	237	274	286	273
Solar irradiation, horizontal [kWh/(m²·d_{hs})]	336	314	457	405	443
Solar irradiation, east [kWh/(m²·d_{hs})]	240	237	337	359	350
Solar irradiation, west [kWh/(m²·d_{hs})]	240	237	337	359	350
Solar irradiation, north [kWh/(m²·d_{hs})]	114	109	142	153	146
Solar irradiation, south [kWh/(m²·d_{hs})]	413	503	613	647	619
Average temperature in heating season [°C]	3.4	3.4	-0.3	1.4	1.3
Average temperature [°C]	6.3	7.1	3.0	3.8	3.9

3.1.9 Other definitions

Some values could not be found through literature search, and some uncertainties about the calculation method are still present. In order to carry out the calculation, these assumptions and simplifications have been made:

- Spaces for basement, attic and stairways are not included in the calculations. This assumption holds if these areas are unheated.

- The calculations in this project are based on apartments with no central heating, which means that the temperatures for the newest buildings in Mjønes et al. (2012) could be inaccurate here. Keeping the indoor temperature constant for all time frames can also be beneficial when comparing the effects of refurbishment measures of the buildings in different time frames. However, the actual conditions of the buildings are chosen as a basis for the calculations, and by that definition, the indoor temperatures should not be the same for all typologies. Additionally, the impact of central heating on the indoor temperature is unknown, and it would be difficult to estimate a more accurate temperature for the newest building typologies than what is already given in the report. Because of these last two arguments, the indoor temperatures will follow those defined by Mjønes et al. (2012): 20.7 °C for the oldest building typology, and 22 °C for the two newest and for all refurbished buildings.

- The buildings are assumed to have six doors: Three in the front and three back doors, because of there are six apartments on every floor, according to Mjønes et al. (2012). The door areas are based on the minimum requirements from TEK 10 § 12-15.

- The roof is assumed to be flat, and without windows.

3.1.10 Renovation values for testing

The following tables contain all values that vary according to building typologies and renovation projects, given by the definitions chosen for the calculation method.

Table 14: Values for calculations of effects of renovation packages for buildings constructed between 1981 and 1990

TABULA abbreviation	Original state 1981-1990	Standard renovation	Extensive renovation
$g_{gl,n}$	0.63	0.5	0.5
ϑ_{int}	20.7	22	22
$n_{air,use}$	0.3	0.4	0.45
$n_{air,infiltr}$	0.1	Unchanged	0.05
$\eta_{ve,rec}$	0	0.8	0.8
$q_{s,w,h}$	2.4	Unchanged	1.9
$q_{d,w,h}$	3	Unchanged	0.8
$q_{s,w}$	3.6	Unchanged	2.9
$q_{d,w}$	4.6	Unchanged	1.4
$R_{0,wall}$	3.45	5.56	9.09
$R_{0,window}$	0.45	0.83	1.25
$R_{0,floor}$	5.00	6.67	12.50
$R_{0,door}$	0.50	0.83	1.25
$R_{0,roof}$	5.00	7.69	11.76
ΔU_{thr}	0.12	0.06	0.03

Table 15: Values for calculations of effects of renovation packages for buildings constructed between 1991 and 2000

TABULA abbreviation	Original state 1991-2000	Standard renovation	Extensive renovation
$g_{gl,n}$	0.63	0.5	0.5
ϑ_{int}	22	Unchanged	Unchanged
$n_{air,use}$	0.3	0.4	0.45
$n_{air,infiltr}$	0.1	Unchanged	0.05
$\eta_{ve,rec}$	0	0.8	0.8
$q_{s,w,h}$	1,9	Unchanged	Unchanged
$q_{d,w,h}$	0.8	Unchanged	Unchanged
$q_{s,w}$	2.9	Unchanged	Unchanged
$q_{d,w}$	1.4	Unchanged	Unchanged
$R_{0,wall}$	3.45	5.56	9.09
$R_{0,window}$	0.50	0.83	1.25
$R_{0,floor}$	5.00	6.67	12.50
$R_{0,door}$	0.50	0.83	1.25
$R_{0,roof}$	5.00	7.69	11.76
ΔU_{thr}	0.12	0.06	0.03

Table 16: Values for calculations of effects of renovation packages for buildings constructed in 2001 or later

TABULA abbreviation	Original state 2001-	Standard renovation	Extensive renovation
$g_{gl,n}$	0.5	Unchanged	Unchanged
ϑ_{int}	22	Unchanged	Unchanged
$n_{air,use}$	0.4	Unchanged	0.45
$n_{air,infiltr}$	0.1	Unchanged	0.05
$\eta_{ve,rec}$	0.5	0.8	0.8
$q_{s,w,h}$	1,9	Unchanged	Unchanged
$q_{d,w,h}$	0.8	Unchanged	Unchanged
$q_{s,w}$	2.9	Unchanged	Unchanged
$q_{d,w}$	1.4	Unchanged	Unchanged
$R_{0,wall}$	3.70	5.56	9.09
$R_{0,window}$	0.63	0.83	1.25
$R_{0,floor}$	7.14	Unchanged	12.50
$R_{0,door}$	0.63	0.83	1.25
$R_{0,roof}$	7,14	7.69	11.76
ΔU_{thr}	0.06	Unchanged	0.03

3.2 Revised renovation projects

After reviewing the results of the case study, suggested renovation strategies will be chosen, based on the efficiency of the different renovation parts. The energy use for these strategies will be calculated using the same method as for the preliminary case study, but for several climate zones.

The revised renovation project will be used as a basis for calculating the energy saving potentials of renovation of all newer apartment blocks in Norway.

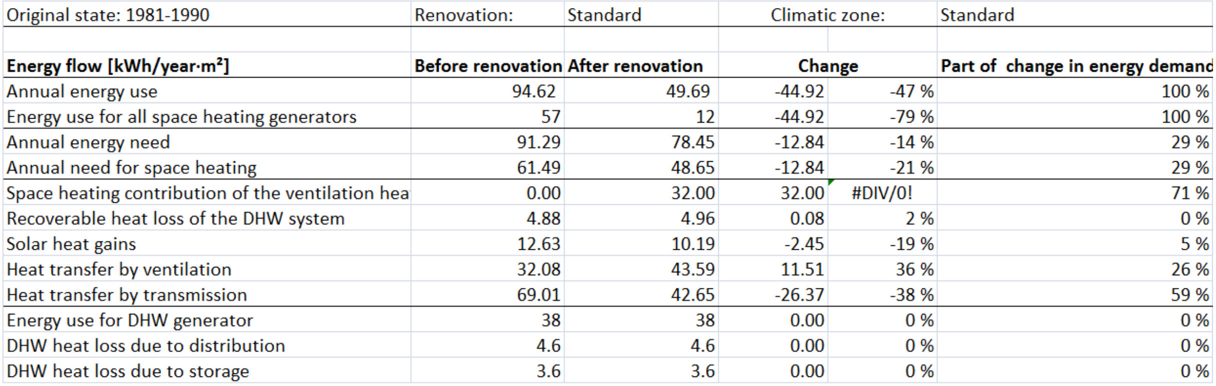
4 Results and discussion

4.1 Case study simulation

4.1.1 Results

All results are presented as energy demand per year for Oslo climate. All results from the energy balance model are available in the Excel file in tables in the same format as in Table 17.

Table 17: Example of result file in the Excel document.



Original state: 1981-1990	Renovation:	Standard	Climatic zone:		Standard
Energy flow [kWh/year·m²]	**Before renovation**	**After renovation**	**Change**		**Part of change in energy demand**
Annual energy use	94.62	49.69	-44.92	-47 %	100 %
Energy use for all space heating generators	57	12	-44.92	-79 %	100 %
Annual energy need	91.29	78.45	-12.84	-14 %	29 %
Annual need for space heating	61.49	48.65	-12.84	-21 %	29 %
Space heating contribution of the ventilation hea	0.00	32.00	32.00	#DIV/0!	71 %
Recoverable heat loss of the DHW system	4.88	4.96	0.08	2 %	0 %
Solar heat gains	12.63	10.19	-2.45	-19 %	5 %
Heat transfer by ventilation	32.08	43.59	11.51	36 %	26 %
Heat transfer by transmission	69.01	42.65	-26.37	-38 %	59 %
Energy use for DHW generator	38	38	0.00	0 %	0 %
DHW heat loss due to distribution	4.6	4.6	0.00	0 %	0 %
DHW heat loss due to storage	3.6	3.6	0.00	0 %	0 %

Table 18: Total energy delivered to buildings per year, based on statistical data from Mjønes et al. (2012) and values calculated as described in methodology with added energy for lighting and equipment from NS 3031.

	Total energy use [kWh/m^2]		
Refurbishment	**1981-1990**	**1991-2000**	**2001-**
None (statistical)	114	123	107
None (calculated)	124	120	95
Standard	50	45	44
Extensive	33	31	31

Heat losses due to storage and distribution for room heating, and all heat loss due to heat generation are 0 for all cases, because of the definition of electricity. Internal heat gains are constant for every building, at 27.22 kWh/m^2. Required energy for DHW is also constant at 29.80 kWh/m^2.

Figure 8: Comparision of annual energy use for heating for the original and rehabilitated buildings (calculated from preliminary rehabilitation measurements), statistical values from Mjønes et al. (2012) (assuming space heating and DHW heating consisting of 23 % and 25 % of total energy need), and TEK 10 and TEK 97 (assuming standardized energy need for other sources as given in Table 8).

Figure 9: Comparision of annual energy use for space heating equipment in the original and rehabilitated buildings (calculated from preliminary rehabilitation measurements), statistical values from Mjønes et al. (2012), and TEK 10 and TEK 97 (using standardized values given in Table 8).

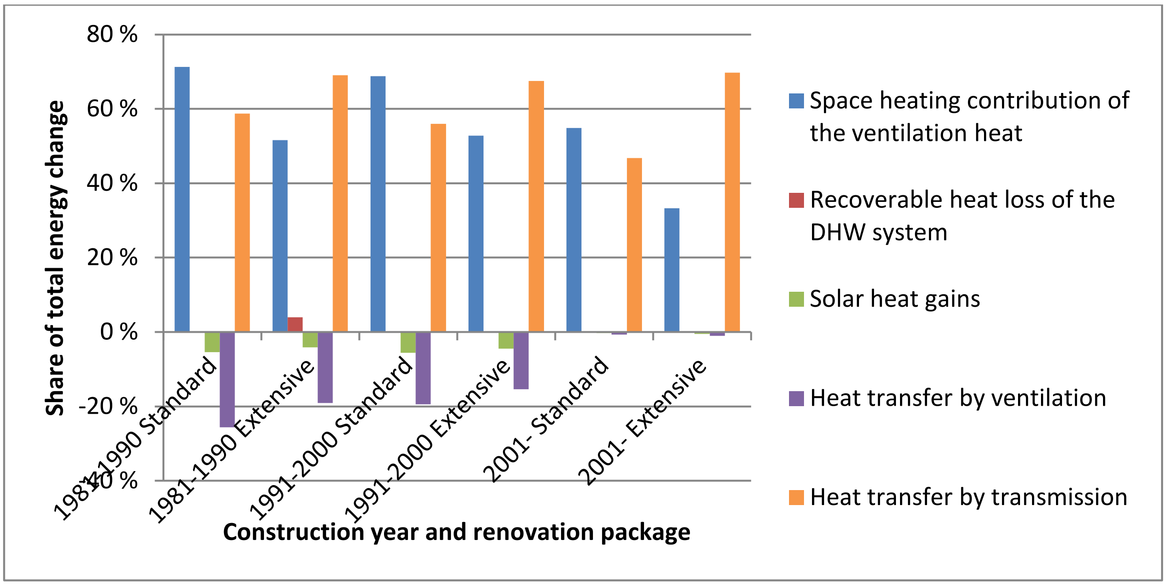


Figure 10: Contribution to total energy savings for heating, sorted by parts of refurbishment measurements

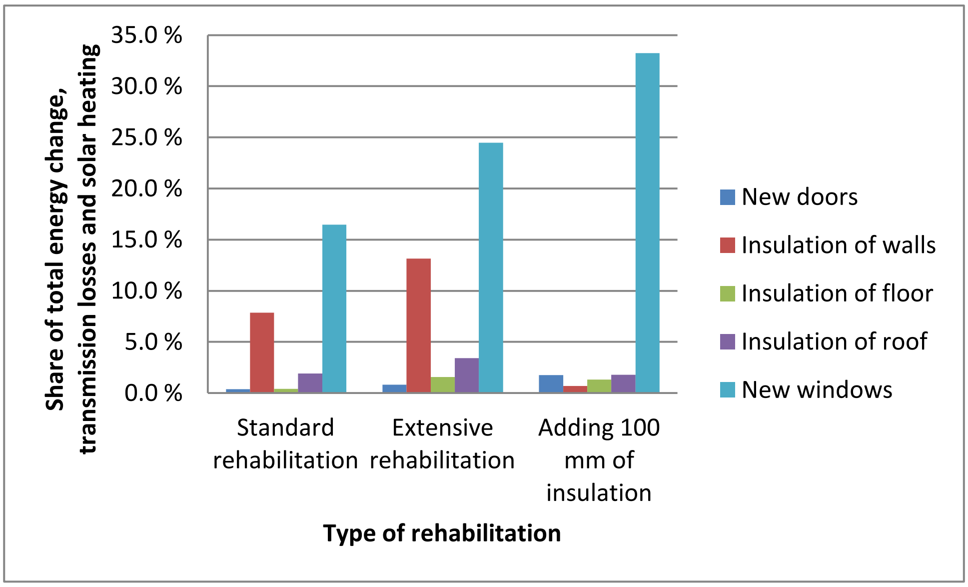


Figure 11: Change in energy losses from transmission and solar heating with standard and extensive refurbishment and added thermal resistance equivalent to 100 mm added insulation for buildings constructed between 1981 and 1990

4.1.2 Discussion

Looking at Table 18 and Figure 8, it seems like the methods and numbers chosen for the energy balance model are a good match for the two oldest original building types. This strengthens the reliability of the TABULA and energy balance model. For the newest building typology, the simulated value is noticeably lower than the statistical value. This implies that the values chosen for the building parts in the model have a higher standard than the real building parts. If the model is to be used for further research, these values should be looked into in order to reach a more realistic energy profile for this typology. In this project work, however, the values are kept unchanged in order to limit the scope of the project.

All in all, the energy efficiency of the building type chosen in this project seems to be of a high standard. By comparing the values in Table 18 with Table 6, the original buildings based on statistical data should receive energy grade B from “Energimerkeordningen”, and so do the simulated buildings, except for the newest buildings, which would receive an A, thus reflecting the energy use of a passive house according to NS 3700. It is a little surprising to see that the original buildings already use less energy than the minimum requirements for TEK 97 and TEK 10. One could certainly question the necessity of introducing the regulations when the average building already fulfils the requirements years in advance. However, the variations in energy use between different buildings are not known, and some of the least energy efficient apartment blocks might be much higher than the TEK 97 and TEK 10 requirements. Also, the energy use of single housings and other building types are not considered in this project, and might be higher than the TEK maximum levels.

Another interesting aspect is the differences between the energy use of the simulated renovated buildings and the standards set by TEK 10 and NS 3700 passive houses, as the renovation packages are based on these requirements. However, the numbers are based on different parts of the regulations. The renovation strategies are based on the requirements for the different building parts, while the NS and TEK graphs (Figure 8) show the maximum energy use for the entire building. (Only one of the requirements must be fulfilled for TEK 10, while they both need to be fulfilled for a passive house.) It is unexpected that the requirements are so different for TEK 10 – the one requirement allows for an almost twice as large energy use for heating as the other. This difference might explain the difference in energy use between the newer original buildings and calculated buildings. The real buildings might not have been following the TEK 97 requirements for U-values, cold bridges, etc, as this is not needed in order to meet the requirements for overall energy use for heating.

With the already defined renovation measures, the renovated buildings all achieve an energy grade of A by a good margin. An A is supposed to reflect the requirements for a passive house, but the standard renovated house will still not be a passive house, since the requirements for all building parts in NS 3700 are not met. The extensively renovated houses should be able to pass as passive houses.

Figure 9 shows the energy use for space heaters only. Here, the differences between the maximum energy demand defined by the TEK requirements are even larger. This implies that

this is the main source of the variations. The energy use in buildings subject to extensive renovation are shown to be negative in this graph. This means that the energy provided by internal heat sources, solar radiation, and energy leaks from tap water heating is so high that it outweighs the energy need for heating, and in theory, this building has an excess of heat. There are several issues connected to these negative numbers. Firstly, this implies that there is a cooling need in the building, as the heat is accumulated. This might be prevented by turning off the heat recovery in the ventilation system, but this is not necessarily enough. One of the main disadvantages with the calculation is that it does not account for cooling need, and that it is not dynamic. If the total energy need for heating is 0, this could mean that there is no energy use all year or that there is a great need for energy in the winter and an equal need for cooling in the summer. It is safe to assume that the building subject to extensive renovation will be too hot to live in for certain parts of the year. Also, as this renovation is supposed to lead to a passive house standard, no cooling is allowed, according to NS 3700. The promising values in
Table 18 are therefore not likely to be achieved in reality – at least not using the ventilation system and building envelope defined in the extensive refurbishment defined so far in this project.

The values in Figure 10 are calculated by dividing the changes in different energy flow by the total energy change when the refurbishment measurements were applied. As some of the energy flows depend on each other, the different flows do not add up to 100 %. The increase of transmission heat and the reduced heating losses are the dominant sources of change. The increases are caused by adding a heat recovery unit and by tightening and adding insulation to the building envelope. As the ventilation changes are constant for all refurbishment measures, but the envelope is more improved when applying the extensive renovation package, the effects from ventilation is greatest for this refurbishment measure. However, the energy lost by the ventilation system also increases for the two oldest building types, as the refurbishment packages include larger air changes. Even though this leads to a greater energy loss, the air change values will be kept in order to assure a satisfactory air quality.

Energy change due to changing the DHW system is not substantial, but might be expensive, especially since heat losses from both storage and distribution has been included in the calculations, which will include changing both the water heater itself and the distribution pipes. This measure will therefore be removed from the refurbishment package where it was previously applied. The decrease in solar heat gains is caused by exchanging the windows. Newer windows have a lower U-value, but also let less solar radiation through. However, as the values from Figure 11 show, this energy loss is minimal compared to the gains achieved from changing the windows.

The values in Figure 11 are calculated by changing only one part of the building envelope at a time and see how the energy through transmission and heat gains is affected. These changes are divided by the total transmission losses in the original building in order to compare the effects. The last renovation package is added in order to compare the effects of changing the thermal resistance for all the building envelope parts by the same factor, R = 2.5 K/W, which is equivalent to adding 100 mm of mineral wool insulation. For the windows, the reduced heat loss from solar radiation is subtracted from the gains of the reduced transmission losses in order to make the total effects of changing the windows visible. The solar energy transmittance is assumed to be 3 kWh/m^{2}K for the window in the last renovation package. Thermal bridges are not considered in these calculations, as their effects would be difficult to measure.

The greatest contribution to the energy reduction is clearly the change of windows, and this renovation measure will be kept for all packages. Insulation of walls is the second most efficient renovation strategy, by applying the wool thicknesses defined in the refurbishment packages. However, renovation of walls has the smallest effect per added thermal resistance value, as shown in the third group with the experimental values. If the purpose of the refurbishment is to use a certain amount of mineral wool most efficiently, the graphs suggest that it would be better to place this in the ceiling or floor. However, there are certain limitations for the insulation thicknesses that can be placed here. Insulating the floor can be very expensive, as all flooring will have to be removed, and it will also lead to a lower ceiling height. This insulation measurement might be better if the building contains an unheated basement, as the insulation can be added to the ceiling of the basement. Adding insulation to the roof is easier, but this will also make the ceiling height lower (this will not matter as much if the building has an attic), but it is less complicated than adding insulation to the floor. Changing the doors also has a rather low effect on the energy use, unless the door is very thick.

Based on the above discussion on insulation, doors and floors will be kept unchanged for the standard renovation projects, as they are not of great influence to the energy reduction. Nor will there be applied extra insulation in the roof for the standard renovation of the newest buildings, as the suggested thickness of the insulation is so small (22 mm). It does not seem likely that one would go through with an insulation process with a layer as thin as this. The walls are probably still in good condition for the newest buildings, and it is therefore not likely that insulation is added to the walls (as this is usually done by tearing off the outer parts of the wall, this is normally done when the walls are old and ready to be renovated anyway.) The building constructed between 1991 and 2000 might also be too new for renovation of the walls. Mjønes et al. (2012) present values for historical upgrades of the wall, which means that refurbishment like this is being done, but this will be viewed as too extensive for the final standard refurbishment.

The thermal bridge breakers are assumed to be unchanged unless the walls are insulated. This is because the thermal bridge barriers are added to the walls in the renovation process.

Although the extensive renovation package produces some funny results, especially on room heating energy need, the renovation values must be followed in order to satisfy the criterias for a passive house (the calculated energy use is less than a third of the maximum). The results indicate that it is possible to upgrade newer apartment blocks to passive house standard. However, the energy balance model does not seem to be advanced enough for evaluating the energy use in passive houses, as this requires a more dynamic model. A good model would have to take certain factors into account, such as turning off the heat recovery in summer, the effect of solar shading, and controlling that the inside temperature does not exceed the maximum values. Additionally, a passive house might include more energy efficient equipment, thus providing less heat leaks to the indoor air. The newest buildings will probably not be renovated right now, but they will in the future, and it is reasonable to expect that the TEK standard will be updated to include stricter values – possibly identical to that of a present day passive house. If one is to pick an extensive renovation package for newer buildings, it makes sense to use the passive house standard as a basis. In conclusion, the extensive renovation package will not be changed in this project. It is important to note that the energy use calculated probably are too optimistic, but this is from here on assumed to be caused by the model being unsuited for the calculations, rather than the renovation package being unsuited for the building typology.

Deciding the most influential building envelope parts could be done in a more accurate way by calculating the values in Figure 11 for the two newer building types. In order to save time, this was not done in this project, but it should be included when deciding renovation packages for a potential MSc thesis. More details on sources for errors will be treated in chapter 4.2.3.

4.2 Revised renovation projects

4.2.1 Calculation values

Table 19: Final values for calculations of effects of renovation packages for buildings constructed between 1981 and 1990

TABULA abbreviation	Original state 1981-1990	Standard renovation	Extensive renovation
$g_{gl,n}$	0.63	0.5	0.5
ϑ_{int}	20.7	22	22
$n_{air,use}$	0.3	0.4	0.45
$n_{air,infiltr}$	0.1	Unchanged	0.05
$\eta_{ve,rec}$	0	0.8	0.8
$q_{s,w,h}$	2.4	Unchanged	Unchanged
$q_{d,w,h}$	3	Unchanged	Unchanged
$q_{s,w}$	3.6	Unchanged	Unchanged
$q_{d,w}$	4.6	Unchanged	Unchanged
$R_{0,wall}$	3.45	5.56	9.09
$R_{0,window}$	0.45	0.83	1.25
$R_{0,floor}$	5.00	Unchanged	12.50
$R_{0,door}$	0.50	Unchanged	1.25
$R_{0,roof}$	5.00	7.69	11.76
ΔU_{thr}	0.12	0.06	0.03

Table 20: Final values for calculations of effects of renovation packages for buildings constructed between 1991 and 2000

TABULA abbreviation	Original state 1991-2000	Standard renovation	Extensive renovation
$g_{gl,n}$	0.63	0.5	0.5
ϑ_{int}	22	Unchanged	Unchanged
$n_{air,use}$	0.3	0.4	0.45
$n_{air,infiltr}$	0.1	Unchanged	0.05
$\eta_{ve,rec}$	0	0.8	0.8
$q_{s,w,h}$	1,9	Unchanged	Unchanged
$q_{d,w,h}$	0.8	Unchanged	Unchanged
$q_{s,w}$	2.9	Unchanged	Unchanged
$q_{d,w}$	1.4	Unchanged	Unchanged
$R_{0,wall}$	3.45	Unchanged	9.09
$R_{0,window}$	0.50	0.83	1.25
$R_{0,floor}$	5.00	Unchanged	12.50
$R_{0,door}$	0.50	Unchanged	1.25
$R_{0,roof}$	5.00	7.69	11.76
ΔU_{thr}	0.12	Unchanged	0.03

Table 21: Final values for calculations of effects of renovation packages for buildings constructed in 2001 or later

TABULA abbreviation	Original state 2001-	Standard renovation	Extensive renovation
$g_{gl,n}$	0.5	Unchanged	Unchanged
ϑ_{int}	22	Unchanged	Unchanged
$n_{air,use}$	0.4	Unchanged	0.45
$n_{air,infiltr}$	0.1	Unchanged	0.05
$\eta_{ve,rec}$	0.5	0.8	0.8
$q_{s,w,h}$	1,9	Unchanged	Unchanged
$q_{d,w,h}$	0.8	Unchanged	Unchanged
$q_{s,w}$	2.9	Unchanged	Unchanged
$q_{d,w}$	1.4	Unchanged	Unchanged
$R_{0,wall}$	3.70	Unchanged	9.09
$R_{0,window}$	0.63	0.83	1.25
$R_{0,floor}$	7.14	Unchanged	12.50
$R_{0,door}$	0.63	Unchanged	1.25
$R_{0,roof}$	7,14	Unchanged	11.76
ΔU_{thr}	0.06	Unchanged	0.03

4.2.2 Results

The results are given in the Excel document in the same way as in Table 17, with the refurbishment package notation “Standard 2”.

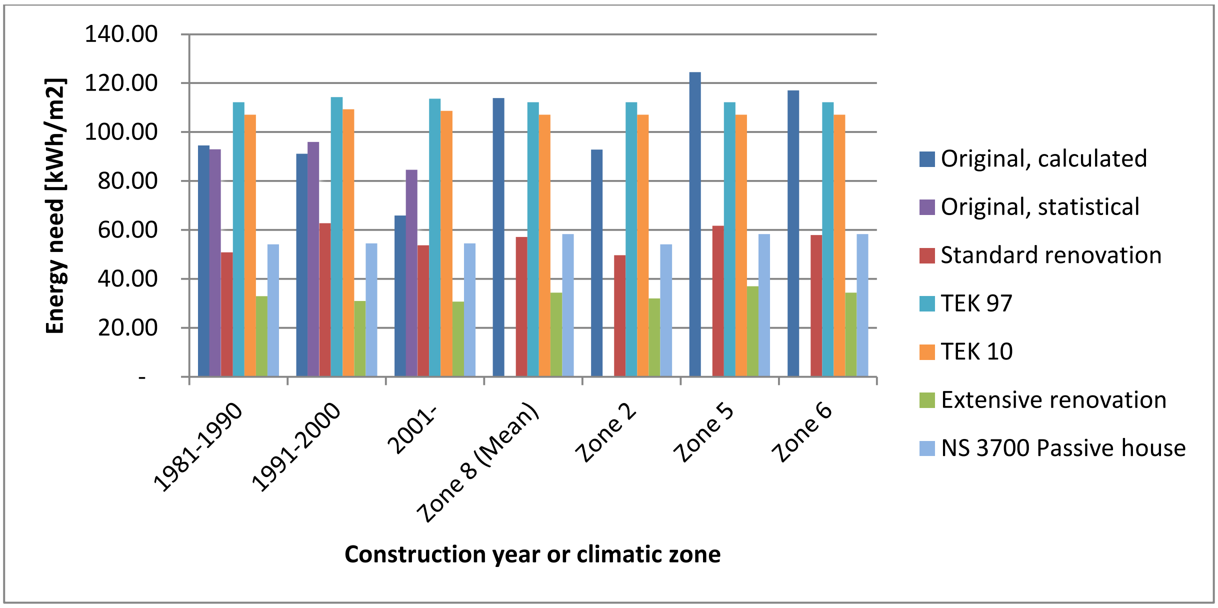


Figure 12: Comparison of annual energy use for heating for the original and rehabilitated buildings (calculated from revised rehabilitation measurements), statistical values from Mjønes et al. (2012) (assuming space heating and DHW heating consisting of 23 % and 25 % of total energy need), and TEK 10 and TEK 97 (assuming standardized energy need for other sources as given in Table 8). The three first buildings are based on Oslo climate, and buildings in different climate zones calculated for buildings constructed between 1981 and 1990, based on climate zones from Table 13.

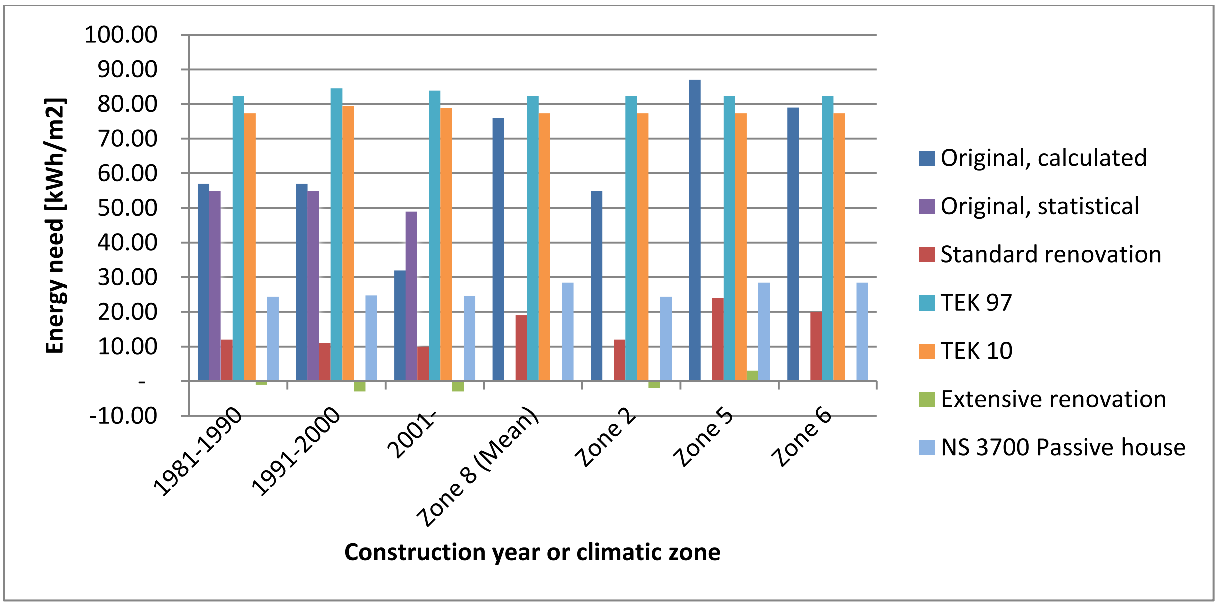


Figure 13: Comparison of annual energy use for space heating equipment in the original and rehabilitated buildings (calculated from revised rehabilitation measurements), statistical values from Mjønes et al. (2012), and TEK 10 and TEK 97 (using standardized values given in Table 8). The first three buildings are calculate from standard (Oslo) climate, while the four last are calculated for different climatic zones, but for buildings constructed between 1981 and 1990. Some statistical values are left out, as they have not been found.

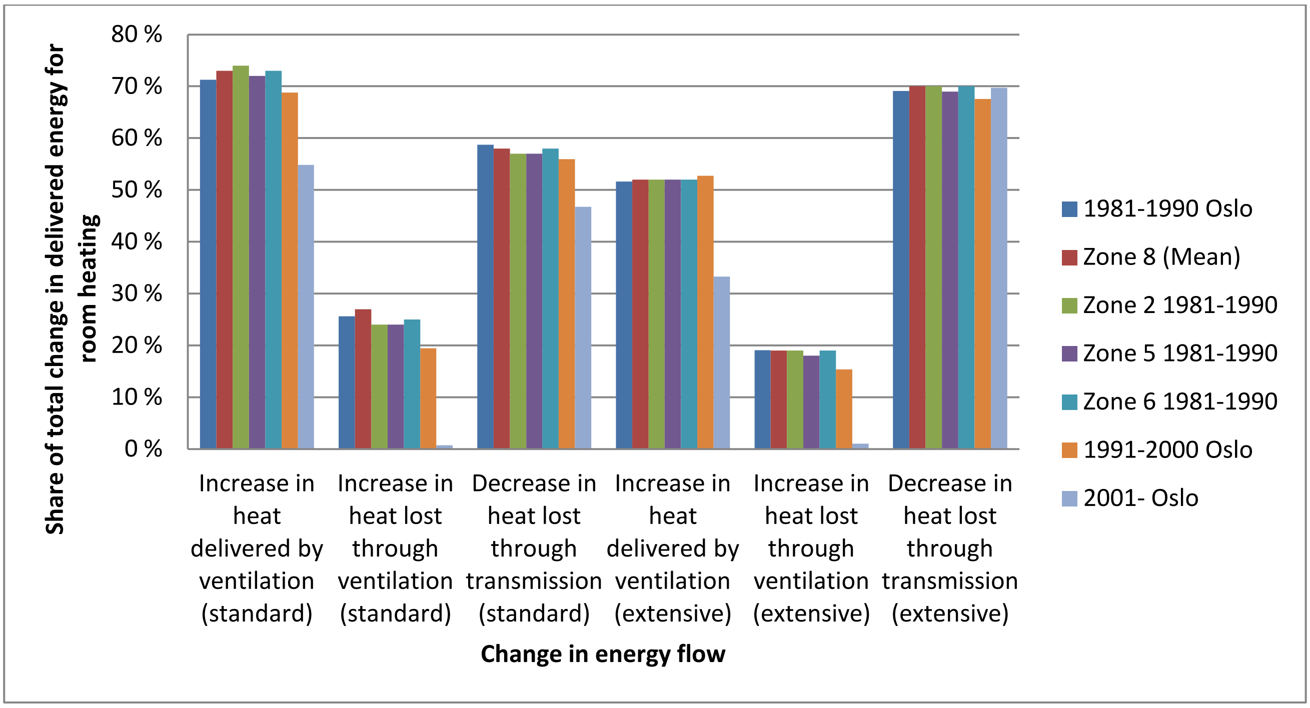


Figure 14: Contribution to change in total energy savings for heating, sorted by parts of refurbishment packages, climate zones, and construction year.

Table 22: Yearly energy savings from applying the renovation packages to all Norwegian buildings within the project definition, calculated for Oslo climate and mean climate values

Construction year	**Energy saving potential, standard renovation [GWh/year]**		**Energy saving potential, extensive renovation [GWh/year]**	
	Oslo climate	**Mean values**	**Oslo climate**	**Mean values**
1981-1990	188.39	244.62	265.61	342.55
1991-2000	136.87	213.57	290.86	373.05
2001-2010	99.33	185.94	285.82	369.03
Total	424.59	644.13	842.30	1 084.63

4.2.3 Discussion

4.2.3.1 Analysis of the results

The effects of changing the standard refurbishment package can be found by comparing Figure 8 and Figure 12. The standard renovation package used to lead to a building that used increasingly less total energy than the passive house requirements. After adjusting the renovation package, making it more realistic and presumably cost efficient, the energy used in the oldest building type has not changed much. The other two renovation packages now lead to an energy grade of B, and contribute to a great reduction in energy needed for the space heaters (Figure 13). The reduction in total energy use is less significant for the newest building type, but this is expected from the redefinition of the renovation package. A standard renovation on a newer building is not likely to include a large number of renovation measures. The energy use for space heating is, however, reduced substantially.

Due to the limited amount of time for this project, only the oldest building type was chosen for analysing differences between climatic zones. The building type was chosen, because it is the one with the largest potential for improvement, and because the statistical and calculated energy flows are a good match, making the results from the calculations more applicable for estimating the real energy saving potential.

Figure 12 and Figure 13 both demonstrate that the variations in energy use between climatic zones in Norway is substantial. Calculated energy use for climatic zones 5 and 6 (inland Trøndelag and coastal Northern Norway) both exceed the limits set for TEK 97 and TEK 10, but they still achieve an energy grade of C. As almost all the climatic zones are colder than the standard (Oslo), the energy use calculated from the mean value is 16 % higher than the standard values, and the specific energy use for space heating is 33 % higher. The calculations based on mean values do not represent Norway as a whole, as the building area is not evenly distributed among the climatic zones. In further analysis, the building area in the different climatic zones should be taken into account in order to calculate values for an average Norwegian apartment block. This would lead to a better estimate of the potential energy savings in the sector.

The energy use for heating in buildings that have undergone extensive rehabilitation is still very low for the buildings in climatic zone 5 and none for those in climatic zone 6. However, the buildings do not achieve a theoretical energy surplus, such as the buildings in Oslo or climatic zone 2 (coastal Southern Norway). They are all still well within the limitation for passive houses, although, as previously discussed, this does not prove that the renovation will lead to a fulfilment of the passive house criteria.

Figure 14 demonstrates that although the amount of delivered energy is different, the distribution of the influence of changes in energy flows on the total energy use is rather similar for different climatic zones within the same construction time, and especially so for the buildings that have undergone the extensive rehabilitation process. There are some variations in the impacts between different climatic zones, but as they do not seem to follow a clear pattern or contribute significantly to the changes in energy use, an analysis of these variations has not been conducted in this project. Based on this figure, the conclusion is therefore that the energy flow has nearly the same impacts on the energy use, regardless of climatic zone.

The variations are clearer between the construction years, as the rehabilitation strategies are no longer similar. The clearest example is for the newest building type, where there is no increase of heat loss through ventilation (because of the already satisfactory amount of air exchanges) and the change in heat delivered by ventilation has a smaller effect, as the heat recovery is not as altered as for the older buildings.

Another interesting aspect of Figure 14 is the difference between the standard and extensive rehabilitation packages. The decrease in energy use following the decrease in insulation losses is more dominant than that caused by increased heat from ventilation. An explanation for this is that the thickness of added mineral wool is substantially different between the two renovation packages, while the difference is less for the ventilation heat recovery. The efficiency of the ventilation heat recovery does, however, undergo a major change from the original to the standard upgraded building, giving a larger energy impact here.

4.2.3.2 Comparison to literature

An overview of the potential aggregated energy savings is given in Table 22. These numbers are calculated by multiplying the energy per floor area with the total area of buildings from the specific construction period. Because of the recent change of the Norwegian government, there are no current goals for energy saving in buildings in Norway, but the former government aimed for a 15 TWh reduction in energy within 2020. If the share of total energy use for the typologies defined in this project remains at 5.6 % and the energy saving is to be distributed evenly, apartment blocks built between 1981 and 2010 need to save 840 GWh of energy. Table 22 shows that this is possible to achieve by applying the advanced renovation to all buildings. The energy saved by standard renovation is about 50 – 75 % of what is needed. It is important not to attach too much importance to these numbers. In addition to the inaccuracies of the model, these values have been calculated without researching the predicted development of the building stock and its energy use or building type distribution. There is also reason to believe that the potential energy savings is greater for older buildings and maybe other building types (including non-residental buildings), and also, savings from energy efficient lighting and appliances has not been considered, so 5.6 % is only a crude estimate, and the number should probably be much lower. However, as there is little literature on this subject, and research on future building stocks was defined outside of the scope of this project, this serves as the most reliable suggestion as to whether the renovation strategies provide a sufficient energy reduction.

According to the calculations by Mjønes et al. (2012), the total Norwegian energy reduction by renovating all pre-2010 buildings to TEK 10 standard is 13.4 TWh. However, this number has been calculated assuming no change in the delivered energy for the building typology defined in this project. The report suggests some renovation strategies, but the report concludes that there is no energy reduction potential for TEK 10 upgrading of these buildings[†]. The report also calculates the technical energy savings potential, which is the theoretical energy savings that can be achieved from a full renovation of the buildings with present technology when costs are not taken into consideration. If these renovation strategies were applied, the energy decrease could be 1.8 TWh, which is more than twice the potential calculated in this project.

[†] The TEK 10 renovation strategies defined in the report will give an increase in delivered energy to the building stock defined in this project of 50 GWh. The report concludes that no upgrades should be done to the insulation, but that there needs to be a larger air change rate. The report does not explain in detail why no insulation has been added, but this decision has probably been based on economical aspects.

4.2.3.3 Evaluation of methodology

Most of the final results found from calculations for the energy use in original buildings were similar to those found by SSB. This implies that the energy balance model, and therefore also the equations from TABULA produces realistic results. The energy demand for the newest buildings did not match the statistics as well as the others, and suggests that the energy use should be lower. This might be caused by the U-values for the buildings being different than the TEK 10 requirements (as discussed in chapter 0), or that the TABULA model is better suited for older buildings. It has been difficult to find literature to compare the renovation results with, and it is therefore not possible to give an evaluation on the results for the renovated buildings based on the results from the calculations. The buildings seem to have a very low energy demand compared to the standards, and this should be investigated further.

The main weaknesses of the TABULA method is that it is not dynamic and that it does not take overheating into account. Only a minimum inside temperature is defined, but no maximum temperature. Cooling needs can be large for tightly insulated buildings, and measures such as sun screening need to be applied. The method does not take these types of technologies into account.

There is little literature on recommended renovation strategies specifically for apartment blocks in different time periods. Mjønes et al. (2012) is the most relevant report, and is the main source for values in this project. However, the strategies in this report is heavily based on economic aspects, and suggests renovation strategies connected to changing of the energy sources – both of these are outside the scope of this project. The report is also confusing in many levels, as values are often given without denomination, and the reasoning behind them often is lacking. It has therefore been difficult to select the correct values both for calculations and comparisons. The report also included some values on historically upgraded buildings, and it was not always clear if these buildings or the original ones were used as a basis when calculating renovation effects. For new buildings, this will affect the results to a small degree, but this would have been significant for calculations involving older buildings.

The values needed for the energy balance model could not be found through one single source, and they are therefore of varying quality. The TABULA method suggests many standard values that can be used for the equations. These values have been avoided when possible, as they are based on average European buildings and energy systems, and they have been found to match the statistical Norwegian values poorly when comparison has been possible. An example of this is the suggested air tightness values in TABULA; even the value suggested for very tight buildings is less than a standard Norwegian building. In the cases where the correct values have not been found in other literature, TABULA variables from Sweden, Denmark or Germany has been used. Sweden is the country most alike Norway in regards to building technologies and climate, but the TABULA values are defined more accurately for the Danish buildings. Neither of these countries provided values on decentralised DHW system, which is why German values had to be used.

Other sources for errors are assumption when describing the standard building (such as assuming no attic and flat roof) and differences in energy demand between standard values in NS 3031and statistical values from SSB and Mjønes et al. (2012). There are also uncertainties about change in indoor temperature after the renovation measurements. The decision to increase the air exchanges in order to achieve a good air quality, decreases the energy reduction potential for the renovation packages, and the energy flows might be very different if the air exchange values had been maintained or less altered.

In order to select the values with the largest influence on the final energy results, a sensitivity analysis should have been carried out for this method. In such an analysis, the input values should each be slightly altered in order to reveal their effect on the calculated energy flows, and thus identifying the values that need to be researched most thoroughly.

The benefits of the energy balance method created in this exercise is that it is simple and quick, and that the input values are easy to change. It also seems to be accurate for buildings constructed before year 2000. The method is based on the TABULA model, which has the benefit of being a standardized tool for other European countries, making it easy to compare the building stocks of different countries.

4.2.3.4 Implications and future work

Judging from Figure 14 and the general calculations from the energy system analysis given in the worksheet, heat recovery upgrades have larger energy savings potentials than the insulation upgrades in standard renovation projects. This is the opposite for extensive renovation projects. This implies that when renovating a building, the ventilation heat recovery system might be the most vital part to change. Figure 11 indicates that windows should be prioritized when upgrading the building envelope and that insulation to roof and walls should be carried through rather than to floor and doors. These recommendations are not given based on economical aspects, which should be researched further before drawing any conclusions.

When carrying on the work of this project, effort should be made in order to find more accurate values for the buildings and the renovation strategies. As this has not yet been obtained from literature in this project, this might have to be developed through a new study. An economical analysis has been mentioned several times, but the environmental aspects might also be looked at, for instance through a life cycle assessment. User behaviour, predicted future developments of the building stock (such as energy used by appliances), and analysis of other building types should be taken into account as well when calculating the potential energy savings and comparing them to the goals set for Norway.

Final energy demand has not been calculated with a basis of an average climatic zone for the building stock, and this needs to be done. Also, more buildings and climatic zones should be analyzed in order to make specific recommendations for the different buildings. An analysis such as the one used to find the values in Figure 11 should be carried through with more of the buildings to see if the figure gives a good representation of the other buildings, or if the requirements need to be altered for other building types.

The energy balance method itself should be analyzed for mistakes using a sensitivity analysis and perhaps also by analyzing the different equations in order to improve them for Norwegian conditions if the goal is to make more accurate predictions and recommendations for Norwegian buildings.

5 Conclusion

Based on the results from this project, Norwegian apartment blocks built after 1980 have an energy reduction potential of between 425 and 644 GWh for the standard renovation package, while the extensive renovation package can reduce the total energy use of about twice this number. Comparing these results to the former Norwegian goal of a 15 TWh reduction, combined with the fact that this building stock only makes up 5.6 % of the total residential area, and that the energy savings potential is largest for the oldest buildings, it seems like this specific building stock should not be the main priority when deciding on renovation policies.

The original buildings are already of a very high standard, and all qualify for an energy grade of A or B, making them all pass the TEK 10 requirements. The most efficient energy saving measures are upgrading of the heat recovery system (for standard upgrades) and changing the windows (for extensive upgrades). The air exchanges in older buildings are too low for satisfying the requirements in TEK 10. Therefore, the air exchanges through the ventilation system must be increased, thus resulting in great energy losses through ventilation. Additional layers of insulation are most efficient when applied to the roof.

The energy demand varies greatly among the different climatic zones, but the distribution of energy losses seem to be more stable. This suggests that the same recommendations will fit buildings in different geographical areas.

All in all, the energy balance model in this project seems to produce reliable estimations for the building stock, but the input values need to be researched further, as well as economical aspects and effects of changing energy carriers. The energy balance is too simple for passive house calculations, and should be avoided in these cases.

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7 Appendix

7.1 Basic energy transmittance calculations

The calculation of thermal losses through a defined part of the building part can be done using equation 5. The U-value of a building element consisting of several layers can be calculated from equation 6 (Aschehoug et al., 2007).

$$Q = U \cdot A \cdot (\vartheta_{int} - \vartheta_e) \tag{5}$$

$$U = \frac{1}{R_{tot}} = \frac{1}{R_1 + R_2 + \cdots + R_n} = \frac{1}{\frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + \cdots + \frac{d_n}{\lambda_n}} \tag{6}$$

Q = Heat transfer by transmission through a certain building element [W]
U = Coefficient of thermal transmittance (U-value) [W/m^{2}K]
A = Area of building element [m^2]
ϑ_{int} = Internal temperature [°C]
ϑ_e = External temperature [°C]
R_n = Thermal resistance of building element n [m^{2}K/W]
d_n = Thickness of building element layer n [m]
λ_n = Heat conductivity of building element n [W/mK]

Building heat is also transmitted by infiltration and radiation.

7.2 Energy Grading from “Energimerkeordningen”

(NVE, 2013)

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]

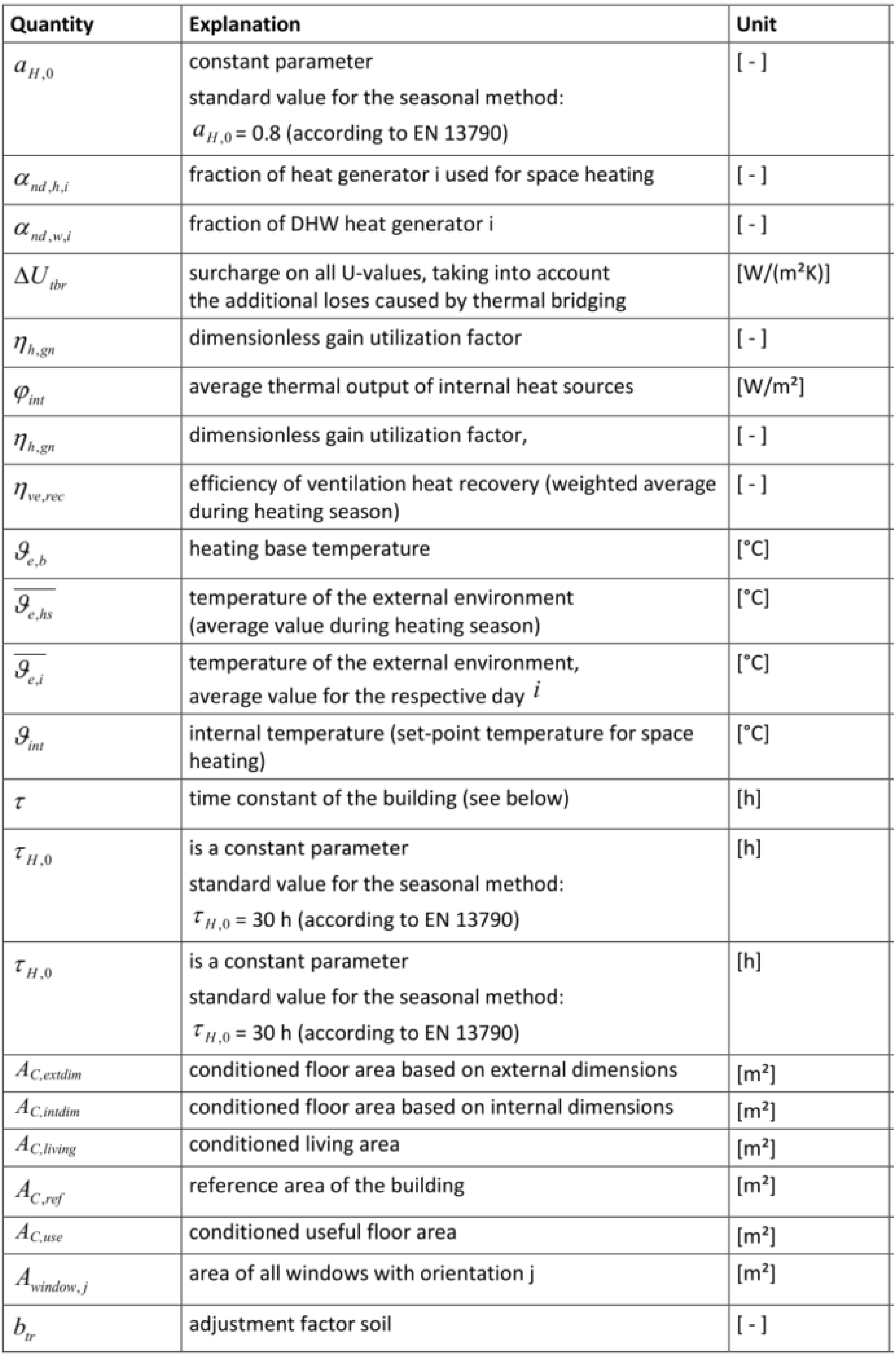
Upper limit for grade C is based on level for TEK 2010.

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

EMS	Version 6.73
Valid from	01.07.2013
Changes	See assumptions on next page

Assumptions	A	B	C	D	E	F	G
Upper limit	”Passive house”	(A+C)/2	”TEK10”	(2C+F)/3	(2F+C)/3	”TEK 69”+7%	> F
Reference	NS 3700 pr NS 3701		Heat recovery 80 %			Heat recovery 70 %	
Yearly heating efficiency	0.88	0.77					
Cooling factor	2.4	2.2					
Air changes, inside of operation time	NS 3031 tab A6	NS 3031 table B1					
Air changes, outside operation time	NS 3031 tab A7	NS 3031 table A6					
SFP and lighting	NS 3701 / NS 3700	NS 3031					
Equipment and DWH	NS 3031	NS 3031					
Adjustable sun screening	”On” all year						
Building models	As for TEK 2010, except for nurseries, where passive house model is used						
Area correction	Adjusted for level, dependant on level in scale						
Calculation standard EMS	NS 3031:2007 / A1:2010						

7.3 TABULA abbreviations

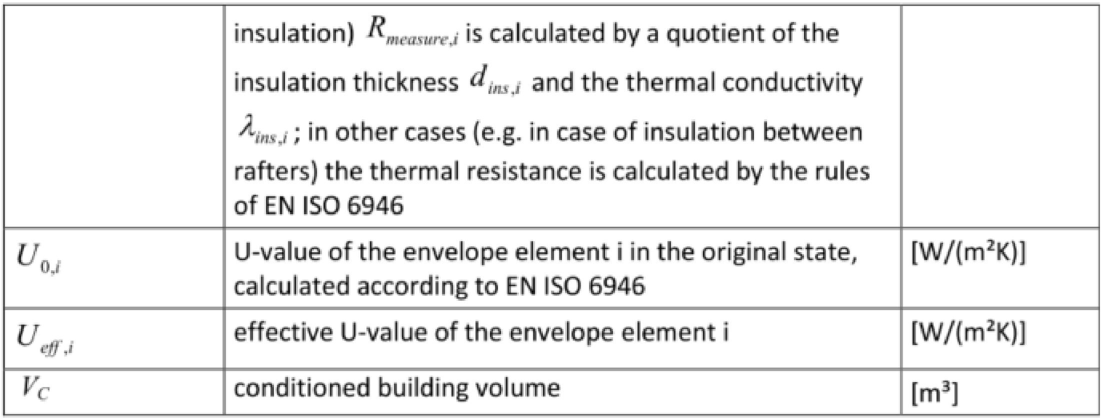


Quantity	Explanation	Unit
$a_{H,0}$	constant parameter standard value for the seasonal method: $a_{H,0}$ = 0.8 (according to EN 13790)	[-]
$\alpha_{nd,h,i}$	fraction of heat generator i used for space heating	[-]
$\alpha_{nd,w,i}$	fraction of DHW heat generator i	[-]
ΔU_{tbr}	surcharge on all U-values, 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 m² reference floor area	[W/(m²K)]
h_A, h_B	are constants, depending on the building type	[W/(m²K)]
H_{ve}	total heat transfer by ventilation	[W/K]
$I_{Sol,j}$	average global irradiation on surfaces with orientation j during the heating season	[m²]
$I_{sol,k,hs}$	global solar radiation on 1 m² surface of orientation k during the heating season	[kWh/(m²a)]
$I_{sol,k,i}$	global solar radiation on 1 m² surface of orientation k during day i	[kWh/(m²d)]
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/(m²a)]
$q_{del,h,adapt,i}$ $q_{del,w,adapt,j}$	annual energy use of heat generator i of the heating system and of heat generator j of the hot water system per m² reference floor area, adapted to the typical level of measured consumption	[kWh/(m²a)]
$q_{del,h,aux}$ $q_{del,w,aux}$	annual auxiliary energy use of heat generator i of the heating system and of heat generator j of the hot water system per m² reference floor area	[kWh/(m²a)]
$q_{del,h,i}$ $q_{del,w,j}$	annual energy use (delivered energy) of heat generator i of the heating system and of heat generator j of the hot water system per m² reference floor area, calculated by applying the standard boundary conditions	[kWh/(m²a)]
$q_{d,h}$	annual effective heat loss of the space heating distribution system per m² reference floor area	[kWh/(m²a)]
$q_{d,w}$	annual heat loss of the DHW distribution system per m² reference floor area	[kWh/(m²a)]
$q_{d,w,h}$	recoverable heat loss of the DHW distribution system per m² reference floor area	[kWh/(m²a)]

$q_{g,h,out}$	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]

Source: Loga and Diefenbach (2012a)

7.4 Equations in the Worksheet

These are the equations used for all calculations in the Excel sheet in order to calculate the energy use according to the TABULA method. The equations are based on the original equations by Loga and Diefenbach (2012a).

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

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

$Q_{g.w} = Q_{del.w} - Q_{nd.w} - Q_{s.w} - Q_{d.w}$

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

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

$Q_{int} = 0.024\ \text{kh/day} \cdot \varphi_{int} \cdot d_{hs} \cdot A_{C.ref}$

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

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

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

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

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

$Q_{del,h} = Q_{del.h.1} + Q_{del.h.2} + Q_{del.h.3}$

$Q_{ve,h,rec} = n_{ve.rec} \cdot Q_{ht.ve}$

$Q\_{}_{w,h} = (q_{g.w.h} + q_{s.w.h} + q_{d.w.h}) \cdot A_{C.ref}$

$Q_{s,h} = q_{s.h} \cdot A_{C.ref}$

$Q_{d,h} = q_{d.h} \cdot A_{C.ref}$

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

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

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

$Q_{del,w} = Q_{del.w.1} + Q_{del.w.2} + Q_{del.w.3}$

$Q_{nd,w} = q_{nd.w} \cdot A_{C.ref}$

$Q_{s,w} = q_{s.w} \cdot A_{C.ref}$

$Q_{d,w} = q_{d.w} \cdot A_{C.ref}$

7.5 Energy balance model

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