Analysis of promising sustainable renovation concepts

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Successful Sustainable Renovation Business for Single-Family Houses - SuccessFamilies

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Deliverable 1.2
Analysis of promising sustainable renovation concepts

WP Leader: **DTU Technical University of Denmark**

Nordic Innovation Centre

Deliverable Administration & Summary

No & name	**D1.2 Analysis of promising sustainable renovation concepts**				
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Comments					

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Disclaimer

Table of contents

1 EXECUTIVE SUMMARY

This report focuses on analyses of the most promising existing sustainable renovation concepts, i.e. full-service concepts and technical concepts, for single-family houses. As a basis for the analyses a detailed building stock analysis was carried out. Furthermore, as a basis a general working method for proposals on package solutions for sustainable renovation was described. The method consists of four steps, going from investigation of the house to proposal for sustainable renovation, detailed planning and commissioning after renovation. It could be used by teams of consultants and contractors and the idea is to help the homeowner with design and decision making process.

The building stock analysis shows that detached single-family houses account for large share of the total number of dwellings in all Nordic countries. Final energy use for space heating and hot water is in the range of 135 to 200 kWh/m^2. Electric heating (and oil heating) of single-family houses is very common in the Nordic countries, except for Denmark where oil/gas boiler and district heating is mostly used. Natural ventilation is widespread in Denmark and there is tradition for mechanical ventilation in Norway, Sweden and Finland. Houses in Norway, Sweden and Finland are typically built with wood as a main construction material, but the insulation and/or finishing materials differ. In Denmark bricks are used as a dominant construction material for cavity walls.

The typical single-family houses identified to have large primary energy saving potential almost descend from the same time period in each Nordic country. The first segment is houses built in large numbers in the 1960 and 1970 before tightening of the insulation standards in the building codes in the late 1970’s due to the oil crisis. The second segment is houses built before 1940 pre-war (except for Finland) where a large part of them has been renovated, but energy renovation of those houses today would still account for a large energy saving. The third segment is houses from the post-war period in Finland, houses that are all individual but built in the same way, using the same materials.

Existing full-service renovation concepts in the Nordic countries have just recently entered the market and are not well established and their success is yet to be evaluated. The success is strongly influenced by the current renovation market that is dominated by a craftsman based approach with individual solutions, traditional warehouses ”do-it-yourself-shops” and some actors marketing single products. Companies may improve concepts by a more integrated approach and application of the full range of technical solutions to ensure the homeowner a sustainable renovation to a reasonable price.

Energy efficiency calculations for individual measures for each of the typical single-family houses in the Nordic countries have been made, and also some examples of cost analysis based on the criterion of cost of conserved energy (CCE) that takes into account the investment and running cost and savings during a defined relevant reference period, e.g. 30 years. Another method that could be used to illustrate the economic implications is “annual economic balance”, i.e. savings minus repayments on a mortgage credit loan, which may be relevant for homeowners who want to utilize cheap long-term financing based on equity.

Different technical renovation scenarios consisting of energy efficiency measures have been tested for the typical single-family houses with large energy saving potential in each of the Nordic countries. Energy efficiency measures in connection with renovation of single-family houses have the potential for very large energy savings. In general the analyses show that typical single-family houses can be renovated to the level of energy performance required for new houses today or in some cases to low-energy level. Reaching passive house level may be challenging in old houses. Passive house level was not reached in any of the analysed cases.

The potential is particularly high for houses with electric heating where installation of a heat pump and water-based heat supply system will reduce primary energy use and heating cost with about 70%. When an efficient heat supply system is in place, then mechanical ventilation with heat recovery (VHR) can result in small energy savings and the quality of indoor environment will usually improve. The primary energy efficiency effectiveness of VHR depends very much on energy supply system, the air tightness of the building envelope and the electricity required to run the system.

Positive impact on the indoor environment can be expected. Thermal comfort will be improved by insulation and air-tightness measures that will increase surface temperatures and reduce draught from e.g. badly insulated windows. A ventilation system with heat recovery will also contribute to a good thermal comfort by draught-free supply of fresh air and assure an excellent air quality. Overheating can effectively be avoided by external movable solar shadings and/or higher venting rate by use of e.g. automatically controlled windows.

2 INTRODUCTION

2.1 Purpose and target group

In this report, the purpose is to analyse the most promising existing sustainable renovation concepts described in D1.1, i.e. full-service concepts and technical concepts, for single-family houses.

In all participating Nordic countries, some typical houses can be found for different time periods. However, since it is not evident that a certain renovation concept can be applied to all the typical houses because they vary in size, age, technical standards and location, first an overview of the existing building stock including typical single-family houses, their energy use and energy savings potential has been given in this report. With this particular knowledge, the renovation concepts can be evaluated, taking into account the characteristics of the different typical single-family houses.

A closer look has also been given to the different evaluation criteria, including an overview of the building codes and regulations in the participating countries, a discussion about different economical criteria and an overview of different calculation tools to be used for detailed calculations of the typical single-family houses.

As for the results from D1.1, the results presented in this report are useful for everyone involved in sustainable renovation of residential buildings and especially single-family houses which is the focus area of this project.

2.2 Contributions of partners

All partners have contributed with descriptions on their existing building stock, the typical single-family houses, energy use and potential energy savings. Furthermore, partners also contributed with descriptions of typical renovation measures for the renovation of the typical single-family houses using a template provided by DTU. Parallel to this, the input and description the participants provided for D1.1 could be further used for the analysis of the most promising renovation concepts.

2.3 Relations to other activities in the project

As mentioned, this report D1.2 will report on the analysis of the most promising existing sustainable renovation concepts described in and selected from D1.1. These concepts will be evaluated with regard to energy saving potential, plans for implementation of energy renovation, durability issues, user needs and total life cycle cost. Based upon this analysis, better sustainable renovation concepts suitable for each of the different typical single-family houses will be proposed in D1.3.

3 BUILDING STOCK ANALYSIS

Building stock analyses have been conducted in all participating countries and in all these countries, some typical houses can be found for different construction periods. This information has been gathered and the relevant results regarding single-family houses are reported.

Information about the Norwegian and Finnish building stock has been collected mainly based on the work carried out for IEA SHC Task 37 “Advanced Housing Renovation by Solar and Conservation” [1] and [2]. Information for the Danish building stock has been collected from the Danish Building Research Institute [3] and Technical University of Denmark [4] and input for the Swedish building stock analysis is based on data from Statistics Sweden, Swedish Energy Agency [5] and [6], and a household survey by Nair et al. [7]

3.1 Denmark

3.1.1 Building stock statistics

3.1.1.1 Number of houses and floor area

There are about 2.5 millions (2.459) dwellings in Denmark of which about 1.14 millions are permanently used detached houses and farmhouses, which corresponds to about 46% of the housing stock (2008 numbers). Number of single-family houses and heated floor area stated by year of construction is shown in Table 1(based on a survey from 2004).

Table 1. Number of single-family houses, gross floor areas and average floor areas [4].

	1850-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	Total
Farmhouses							
Number of houses ($x10^3$)	93	13	5	5	3	5	124
Heated floor area ($x10^3$)	16,484	2,153	742	797	634	951	21,761
Average heated floor area	177	163	158	175	200	195	176
Detached houses							
Number of houses ($x10^3$)	216	120	100	345	139	117	1,037
Heated floor area ($x10^3$)	31,104	15,437	12,373	50,424	21,858	17,340	148,535
Average heated floor area	144	129	124	146	157	148	143
Row houses							
Number of houses ($x10^3$)	29	13	15	28	22	67	174
Heated floor area ($x10^3$)	3,619	1,827	2,114	4,482	3,679	12,747	28,467
Average heated floor area	126	136	141	161	170	190	164

The Danish detached single-family houses can be subdivided into different groups of dwellings according to their year of construction, based on commonly used thermal insulation levels according to the requirements at that time. Approximately half of the houses has been built before 1961 when the first requirements for insulation standards have been laid out. Approximately one quarter has been built during the period 1961 to 1979 and the last quarter has been built after 1979 when the first significant tightening of the thermal insulation requirements was introduced.

In a 20 year period from 1960-80 approximately 500,000 detached single-family houses were built, which corresponds to approximately 45% of the total stock of detached houses, and it is almost as many as were built in the previous 100 years. The vast majority are so-called type houses. In the same construction period, also the average floor area per single-family house increased. The total heated floor area of these 60's and 70's houses is 67 million m^2.

3.1.1.2 Energy use

The building stock in Denmark accounts for a heating use of 216 PJ/a, of which 96 PJ/a is related to single-family houses including detached houses, farmhouses and row houses. Figure 1 shows the energy use for heating in single-family houses.

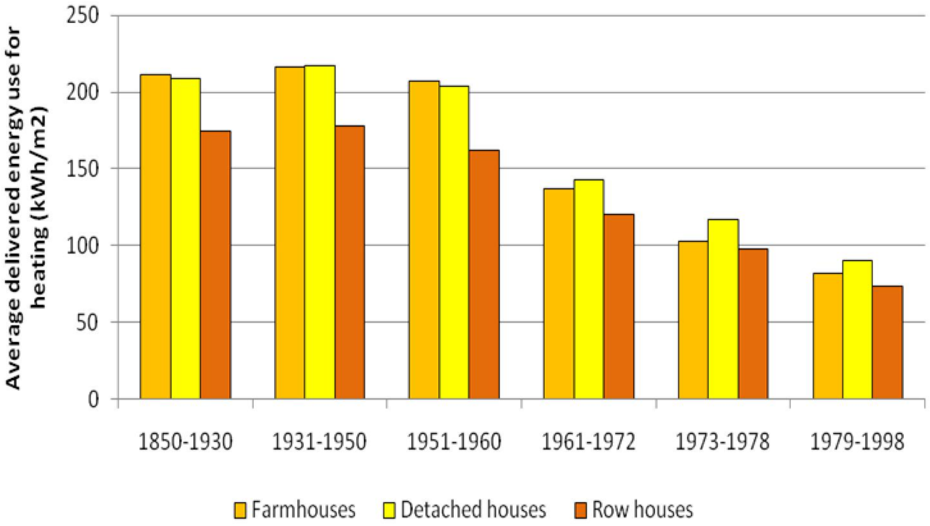

Figure 1. The average delivered energy use for heating (space and hot water), dependent on the type of dwelling and the year of construction [8].

3.1.1.3 Heating systems

The types of heating systems used in Danish single-family house are shown in Table 2 . Danish single-family houses are mainly heated by district heating (38%) or oil/gas-fired burner (48%).

Table 2. Distribution of heating source of the about 1,1 mill. Danish detached single-family houses (2008 numbers).

Heating source	**Number of houses ($x10^3$)**	**Percentage of total (%)**
District heating	432	38
Central, oil	305	27
Central, gas	239	21
Electricity	86	8
Other	77	7
Total	1,141	100

The heating systems used dependent on year of construction are shown in Figure 2.

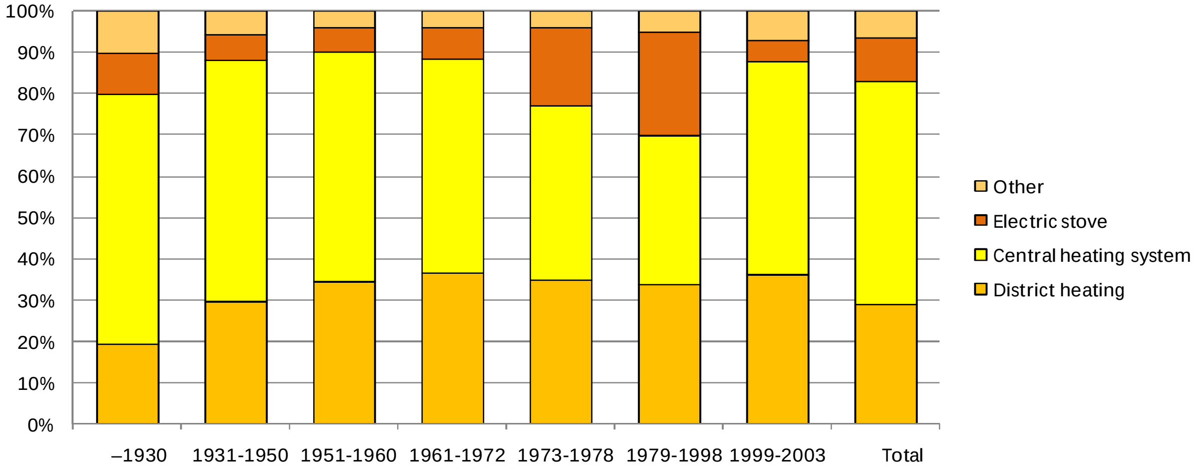

Figure 2. Heating systems used in the Danish single-family houses, dependent on the year of construction (2004 numbers) [4].

3.1.1.4 Ventilation systems

The typical ventilation principle in older Danish single-family houses is natural ventilation – a combination of opening of windows and doors, intended ventilation openings and unintended air leakage through the building envelope.

3.1.2 Typical single-family houses with great energy savings potential

Looking at the average delivered energy use for space heating for the different types of single-family houses for each construction period (Figure 1) together with the number of single-family houses and their gross area (Table 1), three types of typical single-family houses with great energy savings potential can be distinguished for different construction periods in the

Danish building stock: farmhouses built before 1930, master builder houses built before 1930 and standard detached houses built between 1961-1978. These three typical single-family houses account altogether for approximately 60% of the building stock. They are described below. Furthermore, also row houses can be seen as typical in Denmark from the 1980´s on. They will, however, not be considered for analysis in this report since they account for less transmission heat losses and renovation measures usually concern the replacement of windows, the installation of a ventilation system with heat recovery or the installation of a large scale solar heating system.

3.1.2.1 Farmhouse (-1930)

Figure 3 shows a typical old farmhouse, built before 1930. Many of these farmhouses are in a bad condition because they are badly insulated and have many thermal bridges which result in mould problems and damaged structures. In order to improve the condition and the living comfort of these buildings, better insulating windows need to be used, the floors and foundation need to be insulated and more insulation needs to be added on the loft and the space under the roof slope. Many of the farmhouses typically use an oil-fired central heating system, or they use (cheap) heat from a larger heating system for the stables and production buildings. However, many of the stables and production buildings have been abandoned today and the existing heating systems will have to be replaced by new more efficient heating systems. By replacing the heating system and improving the building envelope of these buildings, a lot of energy can be saved.

Figure 3. Typical old farmhouse - typically a big house with around 175 m^2 in average floor area.

Average U-values for old farmhouses are presented in Table 3.

Table 3. U-values for building components of old farmhouses [3].

Building component	**Walls**	**Floors**	**Roof**	**Windows**
U-value (W/ m^{2}K)	0.85	0.41	0.34	2.59

3.1.2.2 Master builder house (-1930)

Old master builder houses (e.g. Figure 4) originally have a full basement (not heated) and a floor area of around 150m². Exterior walls are constructed as non-insulated cavity walls (110-80-110mm) with massive brick ties in the wall at window sill and corners. The effect of insulation in the cavity wall is therefore limited. In order to improve the effect of insulation, the walls can be post-insulated with internal or preferably external insulation. However, this has a large influence on the image of the building and might cause architectural problems.

Old master builder houses are commonly also characterized by old, but high quality wooden windows. Renovation of the windows by adding energy efficient secondary windows is therefore an obvious measure. They almost all have natural ventilation and therefore ventilation system with heat recovery could be implemented in order to improve the indoor climate and lower the ventilation heat loss. However, ventilation with heat recovery should be analyzed carefully; The primary energy saving potential depends on the heat supply system, air-tightness of the house, and electricity use for running the ventilation system. Many of this type of houses have an old boiler and old cast iron heaters in need of replacement.

Figure 4. Typical old master builder houses built in 1927, having a full basement.

Average U-values are for old master builder houses are presented in Table 4.

Table 4. U-values for building components of old master builder houses [3].

Building component	**Walls**	**Floors**	**Roof**	**Windows**
U-value (W/ m^{2}K)	0.86	0.37	0.39	2.56

3.1.2.3 Standard detached house (1961-1978)

Typical standard detached houses in Denmark, see Figure 5, are built between 1961 and 1978, have a heated floor area of around 150 m² and constitute almost 50% of all Danish single-family houses. Since they have been erected before real energy requirements were introduced, they are generally poorly insulated although some improvements have been carried out (mainly roof insulation). The external walls are constructed as cavity or framed walls with an insulation thickness of 75-100mm, an outer leaf of 110mm masonry and an inner leaf of 100mm of light-weight concrete or 110mm of masonry. The windows are mainly wooden (coupled) windows which need a replacement. Most of the times, this is eventually done by only replacing the glazing. The roofs are mostly constructed with elevated roofing, however, some roofs are constructed as flat (built-up-roofs) and both types were originally built with a horizontal insulation thickness of about 100mm. Standard detached house are also characterized by extensions, typically carried out in the 1970´s.

Figure 5. Typical standard detached house built in 1972 - having a slab on ground construction

Average U-values for standard detached houses from 1961-1978 are presented in Table 5.

Table 5. U-values for building components of standard detached houses [3].

Building component	**Walls**	**Floors**	**Roof**	**Windows**
U-value (W/ m^2K)	0.50-0.65	0.28-0.30	0.26	2.48-2.52

3.1.3 Renovation scenarios - energy savings potential

The most recent and thorough Danish investigation of the savings potential in existing buildings was conducted early 2009 by the Aalborg University, Danish Building Research Institute [4]. This investigation is based on information from public building data files and most recent issued building energy certificates (2005 to late 2008). Different scenarios were investigated, called “obvious”, “healthy” and “extreme” measures respectively. The results of the scenario calculations are shown in Table 6.

Table 6. Energy savings potential in TJ/a by implementation of building envelope measures in Danish single-family houses [3].

	1850-1930	**1931-1950**	**1951-1960**	**1961-1972**	**1973-1978**	**1979-1998**	**Total**
Scenario: “Obvious”							**4,537**
Farm houses	770	113	20	29	4	7	943
Detached house	1,123	477	417	874	152	56	3,099
Row houses	163	124	65	93	43	7	495
Scenario: “healthy”							**21,940**
Farm houses	2,974	422	116	82	43	78	3,715
Detached house	4,802	2,273	1,987	3,840	1,638	872	15,412
Row houses	710	392	320	385	314	692	2,813
Scenario: “extreme”							**36,100**
Farm houses	5,085	729	230	101	87	120	6,352
Detached house	8,412	4,328	3,738	4,667	3,144	1,252	25,541

	1850-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	Total
Row houses	1,142	647	558	475	557	828	4,207

Table 6 shows a savings potential of energy for space heating of about 22 PJ/a for the "healthy investment" scenario and a lot less or more for the other two scenarios. The savings potential regarding better efficiency of heating systems including boilers, hot water etc. is estimated at 16 PJ/a, of which 0.4 PJ/a is electricity use. If the "obvious" scenario is disregarded, the total savings potential of energy for heating is in the range of 40-60 %.

Wide spread implementation of ventilation with heat recovery in connection with renovation of single-family house was not taken into account in the study. Ventilation with heat recovery can significantly reduce the ventilation heat loss assuming an air-tight house, and low electricity use for running the ventilation system. A 40-60% reduction in the energy use for heating is therefore a conservative estimation of the potential.

Based on the above, it can be confirmed that the greatest energy savings potential in single-family houses is indeed in old farmhouses and especially in detached master builder houses built before 1930 and small detached standard houses from the 1960's and 70's. The great potential of 60/70's houses is due to a mixture of a poor energy standard and a large number of houses.

3.2 Sweden

3.2.1 Building stock statistics

3.2.1.1 Number of houses and floor area

There are about 4.5 million dwellings in Sweden of which about 1.36 million are permanently used detached houses, which corresponds to about 30% of the housing stock (see Table 6).

Table 7. Number and average floor area of various types of single-family houses (with a value of at least SEK 50000 in 2006, but excluding houses in agricultural property), by year of construction [9]

	-1940	1941-1960	1961-1970	1971-1980	1981-1990	1991-2000	2000 -	Total
Permanent used *detached* houses								
Number of houses (x10^3)	314	294	210	287	145	63	43	1360
Average floor area	122	112	116	133	131	134	141	123
Permanent used *row* houses								
Number of houses (x10^3)	2	12	28	61	20	5	2	130
Average floor area	116	98	115	120	116	105	122	116
Permanent used *linked* houses								
Number of houses (x10^3)	6	7	32	69	21	13	3	152

	-1940	1941-1960	1961-1970	1971-1980	1981-1990	1991-2000	2000 -	Total
Average floor area	113	105	118	131	123	109	123	123
***Seasonal* and secondary use**								
Number of houses (x10^3)	85	64	83	93	46	25	15	417
Average floor area	77	61	57	62	66	68	72	65

Note: The dwelling stock is based upon the census of population and housing in 1990 and updated yearly with reported new construction, conversion and demolition of multi-dwelling buildings. Changes which are not considered are when dwellings for seasonal and secondary use have been transformed to permanent use and vice versa. Most demolitions of one- or two-dwelling buildings are also not considered.

3.2.1.2 Energy use

In Sweden, the total final energy used in 2008 was 397 TWh. About 141 TWh was used in the residential and services sector, 61% of which was used for space heating and hot water production. Single-family houses (includes detached houses, row houses and farm houses) accounted for about 42%, apartment buildings 32% and commercial premises and public buildings for about 26% of the energy used for space heating and hot water production in the residential and services sector [5].

The average final energy use for heating and hot water production decreases with decreasing age of the houses (Table 8). The Swedish building code with higher energy standards was introduced in January 01, 1977. However, the final energy use of houses built during 1970-80 is the same as those built during 1980-2000.

Table 8. Average energy use for space heating and hot water (kWh/m^2) in 2008 in one- and two-dwelling buildings (including agricultural property), by size of non-residential floor area and year of completion [6]

	-1940	1941-1960	1961-1970	1971-1976	1977-1980	1981-1990	1991-2000	2000-	Average of all houses in 2008
Energy use (kWh/m^2)	172	165	141	130	129	132	128	111	148

Note: For houses having biomass or oil-based heating systems the estimated energy use in Table 2 is based on energy content of the fuel input, while for electric or district heating system the estimation is based on actual use of electricity or district heat excluding conversion and distribution losses. Hence, the primary energy use may be different depending on the energy supply system.

3.2.1.3 Heating systems

The types of heating systems used in single-family house has varied a lot over the past century in Sweden (Figure 6). In houses built during 1970-80 electric heating is mostly used, while biofuel use is common in houses built before 1941. Recently, also heat pumps (both air and water-based) have been widely installed and nowadays 10% of the single-family houses are connected to district heating. In multi-family dwellings district heating is dominant.

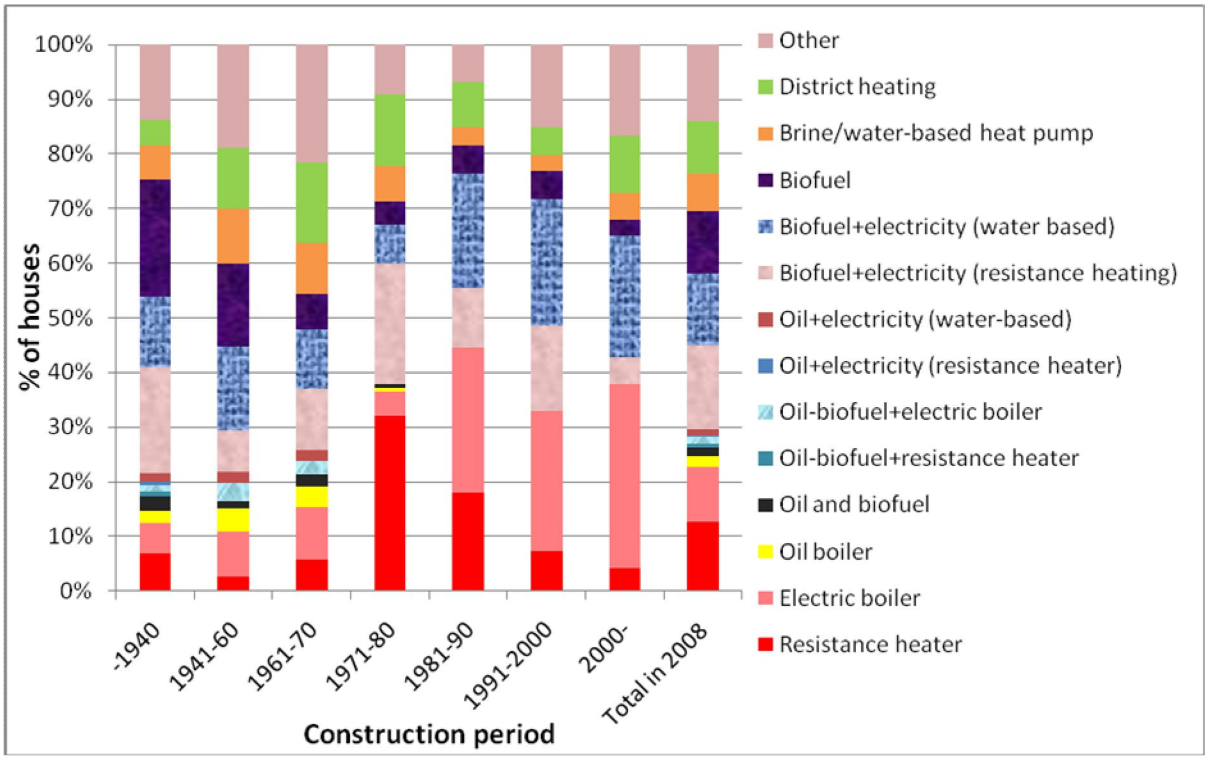

Figure 6. Percentage of one- and two-dwelling buildings (including in agricultural property) in 2008, by main heating equipment and year of completion [6]

3.2.1.4 Ventilation system

As well as different heating systems, also different ventilation systems are being used. Figure 7 presents the different ventilation systems for single-family houses for each construction period. As can be seen from the figure, more than 80% of the houses built before 1970 use natural ventilation. From 1971 onwards, the use of mechanical ventilation increased and most of the houses built during 1981-90 have mechanical ventilation system with heat recovery.

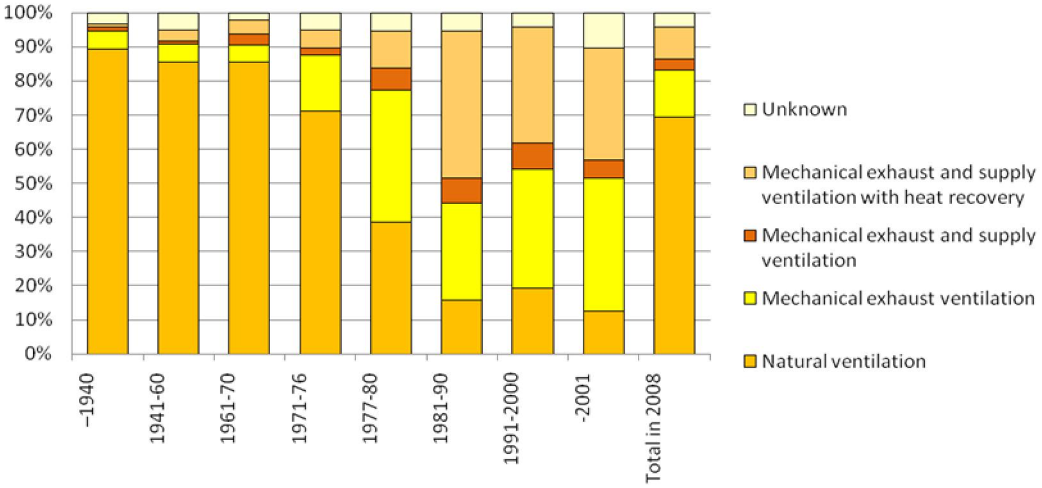

Figure 7. Percentage of single-family houses from different construction periods with various types of ventilation systems, as of summer 2008 [6]

3.2.2 Typical single-family houses with great energy savings potential

In order to determine the segments of single-family houses with the highest energy savings potential in the Swedish building stock, knowledge about the number of single-family houses in each construction period, their heating systems and information about building envelope components is required. Of the investigated single-family houses in the mail-in questionnaire survey by Nair et al. (2009) [7], about 20% of the houses built till 1970 have attic insulation thicknesses up to 100 mm, and about 50% of the houses built before 1977 have attic insulation thickness of not more than 200 mm. More than 80% of houses built before 1977 also have a wall insulation thickness of less than 200mm and a significant proportion of houses built before 1971 even have wall insulation thicknesses of less than 100 mm. However, it seems that wall insulation is being improved in some of the houses built before 1961 as about 7% of such houses have insulation thickness of more than 300mm, while only 2% of the houses built during 1961-76 have such an insulation thickness.

Houses built until 1970 usually have a basement. More than 80% of the houses built before 1960 and 70% of the houses built during 1961-76 have a basement insulation thickness of up to 100m. Houses built after 1980 have a higher insulation thickness. About 55% of the houses built before 1977 have double glazed windows without insulation. Triple glazed windows with insulation are common in houses built after 2000.

The reported data in Table 9 may not truly reflect the conditions in typical detached houses since the survey included permanently used leisure houses or cottages which usually have lower energy standards than a typical detached house. Moreover, respondents might have reported the building component specific information even if they did not know the same. Also, the data excluded about 30-35% respondents who did not know about attic or basement insulation and about 75% who did not know about wall insulation. However, assuming that the awareness about building component specific information was similar among the respondent groups, the data give some indication of scope of energy efficiency improvement in houses from different construction periods.

Table 9. Percentage of houses from different construction periods with various attic insulation thicknesses, as of summer 2008 [7]

	-1940	1941-1960	1961-1970	1971-1976	1977-1980	1981-1990	1991-2000	2000 -	All houses in 2008
***Attic* insulation thickness (%)**									
Up to 100mm	18	23	20	9	8	7	4	4	12
101-200 mm	26	26	30	43	35	16	9	7	24
201-300 mm	31	29	25	26	47	30	22	22	28
301-400mm	18	18	20	14	10	20	29	39	21
>400 mm	6	4	6	8	0	27	35	29	15
***Wall* insulation thickness (%)**									
Up to 100 mm	34	49	34	21	14	9	7	1	21
101-200 mm	47	32	51	64	63	41	37	38	46
201-300 mm	12	12	12	13	24	38	39	47	24
>300 mm	7	7	2	2	0	12	17	14	8
***Basement* insulation thickness (%)**									
Up to 100 mm	79	88	71	70	60	46	36	46	69
101-200 mm	11	7	20	22	40	27	29	27	18
201-300 mm	6	5	4	5	0	24	29	18	10
>300 mm	3	0	4	3	0	3	7	9	3
Type of *window* (%)									
2-glass	59	53	54	58	32	19	14	9	40
3-glass	18	25	22	24	45	52	47	28	32
Energy efficient 2-glass	6	9	9	7	9	6	13	14	8
Energy efficient 3-glass	11	13	12	10	13	23	24	48	17
Others	6	0	3	1	1	0	2	2	2

From a first glance at Table 8, which shows energy use in single-family houses from different construction periods, it seems that the largest potential to reduce the final energy use lies in houses built before 1960. These houses constitute about 50% of the single-family houses and they have the highest energy use per floor area. However, from the data on building envelope components in Table 8, no significant difference in insulation thickness or type of windows could be found among these houses and those built during 1961-76. Hence, there might be similar energy saving potential through building envelope renovation measures in all types of houses built till the end of 1976. However, if consideration is given to reduce primary energy use, then the potential could be in the 400.000 houses built during 1970-80, of which the majority has electric heating systems.

3.2.3 Renovation scenarios - energy savings potential

A public investigation conducted by SOU in 2008 [10] of energy efficiency potential in the Swedish building sector reported that the final energy demand for heating and electricity could be reduced by about 40 TWh under the period 2005-2020. In the single-family house segment the potential was estimated to be about 14 TWh. However, the actual realization of this techno-economic potential depends on adoption of the energy efficiency measures by the end-users.

Joelsson (2008) [11] analyzed the primary energy use efficiency potential associated with conversion of heating systems and implementation of various building envelop measures in typical single-family houses from the 1970´s. The energy supply system was found to strongly influence the energy efficiency of houses. Primary energy use could be reduced by up to 75% if building envelope measures (attic and basement insulation and energy efficient windows) were implemented and resistance heaters were replaced with brine/water-based heat pumps or co-generated district heating system. Installation of energy efficient windows and additional insulation in the attic or basement may reduce primary energy use by up to 25%.

3.3 Norway

3.3.1 Building stock statistics

3.3.1.1 Number of houses and floor area

Approximately 90% of the current Norwegian dwelling stock is built after the Second World War. During the period 1982 to 2005 the number of dwelling units increased by 40 % and in 2005, the total number of dwellings in Norway was around 2.2 million. 57% of the total number of dwellings are categorized as single-family houses, 21% of the dwellings are located in the group “divided small houses”, which includes vertically and horizontally divided small houses, row houses and smaller terraced houses, and the remaining 22% of the dwellings are considered to be part of the group named apartments, which includes detached blocks of flats and combined buildings.

During the period 1982 to 2005 also the total heated floor area in the dwelling stock changed. The total heated floor area increased by 16%, reaching nearly 70 m² per inhabitant in 2005. The distribution of the total heated area, estimated to be 230 million m², is shown for the different types of buildings and different construction periods in Figure 8.

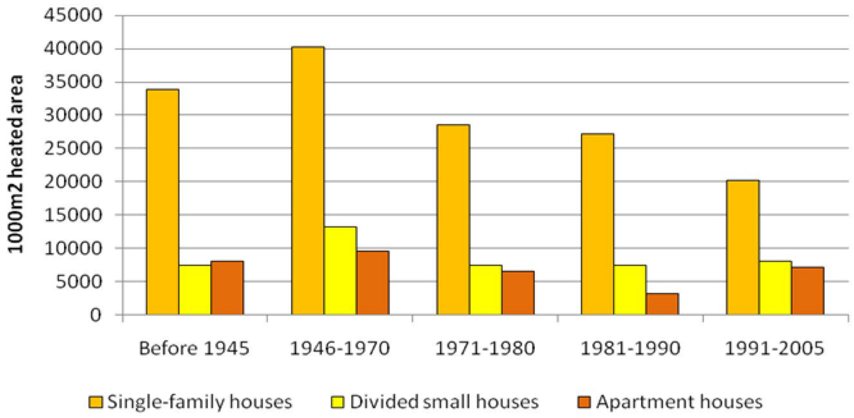

Figure 8. The total heated area, dependent on the type of dwelling and the year of construction [1].

3.3.1.2 Energy use

Single-family houses and divided small houses use approximately 85 % of the total energy use, while only 15% is used in apartment buildings. The total useful energy use (final energy use minus the conversion losses in the house) for the existing building stock is estimated to be 44 TWh and single-family houses count for roughly 30 TWh. About 78 % of this energy use was supplied by electricity in 2005. In Figure 9, the total useful energy use is shown for the different types of buildings and construction periods. From the figure one can read that the main energy use in the building stock lies in single-family houses built after the Second World War up until today.

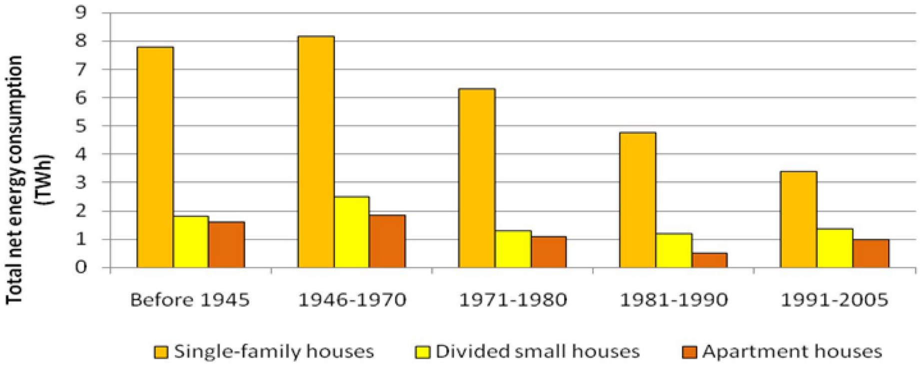

Figure 9. Total useful energy use, dependent on the type of dwelling and the year of construction [1].

3.3.1.3 Heating systems

As in Sweden, the use of different types of heating systems has varied a lot over the past century in Norway. An overview is given in Figure 10. In about 70% of the buildings, electric heating is used, either as the only heating system or in combination with other types of heating systems, whereas only in 12% of the buildings, hydronic heating systems are being used. However, a large share of the hydronic heating systems in new dwellings is based on electricity.

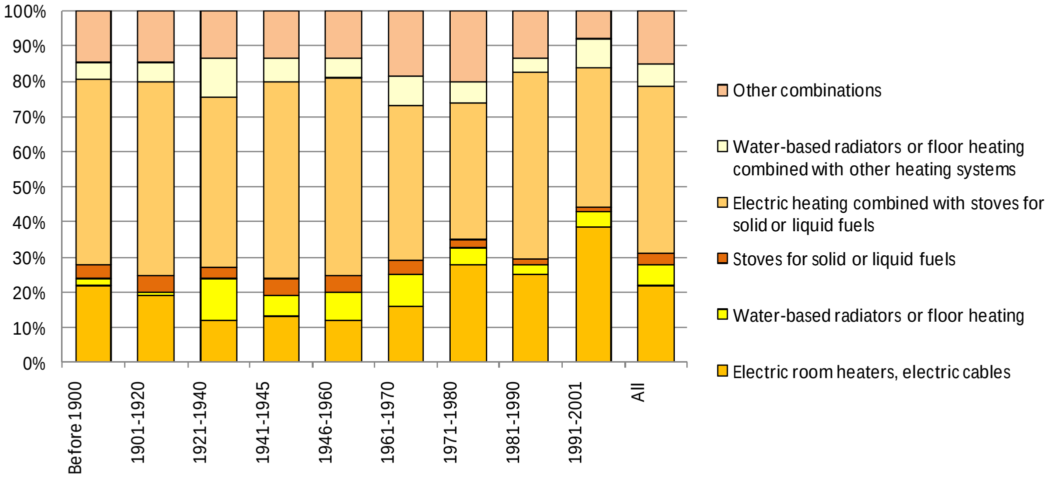

Figure 10. Heating systems, dependent on the year of construction [1].

3.3.1.4 Ventilation systems

It was not possible to find specific data on type of ventilation system in single-family houses in Norway. A situation like in Sweden is assumed where originally natural ventilation was used and from around 1970 and onwards mechanical ventilation increased.

3.3.2 Typical single-family houses with great energy savings potential

For each construction period, one stereotype of a single-family house can be distinguished in the Norwegian building stock. The different stereotypes are presented in Figure 11, all of them have wood as a main construction material. Since the construction of the Ekeberg house in 1948, single-family houses with slimmer wooden structures were introduced. From around 1955 onwards, light timber framed constructions with mineral wool have been the dominating construction principle of single-family houses. Initially, 100 mm studs were used in the walls. In the early 1980s, there was a shift towards 150 mm studs and 150 mm thermal insulation. The thermal insulation level of floors and roofs was also improved during the same period due to the increasing oil prices and the tightening of the Building regulations. New Building Regulations were enforced 1 July 1997, involving tightened requirements for the energy demand for space heating and ventilation of new buildings. The regulations may therefore be expected to have contributed to a new shift in the thermal insulation level.

Figure 11. Stereotypes of single-family houses, dependent on the year of construction [1]

The number of single-family houses for each of the construction periods is presented in Figure 12 below. From the figure, one can read that single-family houses before 1945 up until 1980 have a big share in the total number of single-family houses. Many of these single-family houses have been partially renovated today. Only 5% of the houses before 1945 have not been renovated whereas this is respectively 20 and 70% for houses built between 1945-1970 and 1971-1980. In single-family houses built between 1971-1980, only window improvements have been implemented, in the other two construction periods, insulation has been added to the walls, floor and ceilings.

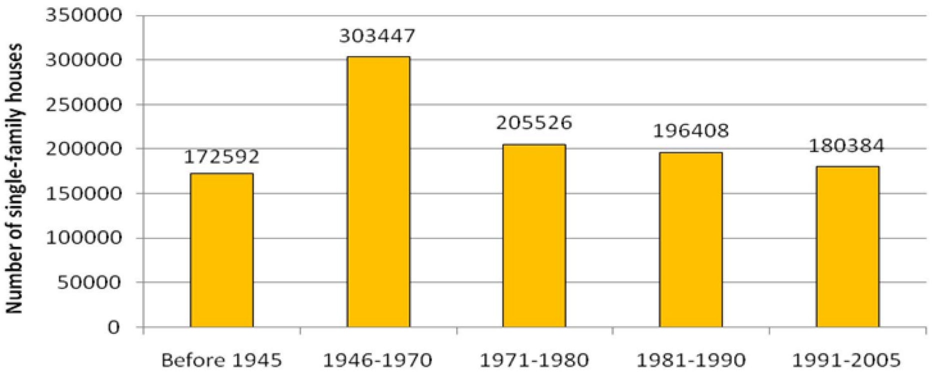

Figure 12. Number of dwellings and dwelling area, dependent on the year of construction [1].

In the table below, an overview of the different U-values, both the original and the U-values after adding insulation, for the different stereotypes of single-family houses is given. From the table can be seen that although a large share of the buildings has been renovated in the construction periods discussed above, their U-values are still worse than these for the non-renovated single-family houses. A large amount of energy can be saved in future renovations of all the stereotypes of single-family houses.

Table 10. U-values (W/ m^2K) for different stereotypes of single-family houses [1].

U-value (Original/ additionally insulated)	**Before 1945**	**1945-1970**	**1971-1980**	**1981-1990**	**1991-2005**
Walls	0.9/ 0.4	0.4/ 0.3	0.38/ -	0.26/ -	0.26/ -
Floors	0.69/ 0.34	0.27/ 0.17	0.36/ -	0.20/ -	0.20/ -
Ceilings	0.6/ 0.3	0.36/ 0.20	0.20/ -	0.18/ -	0.18/ -
Windows	2.8/ 2.0	2.8/ 2.0	2.8/ 2.0	2.0/ -	1.8/ -

3.3.3 Renovation scenarios - energy savings potential

Two investigations of the savings potential in the Norwegian building stock have recently been carried out, each of them taking into account a different energy scenario [1]. For the first energy scenario the energy saving potential is estimated for the existing Norwegian building stock in 2005. The second energy scenario is based on an assumed future development of the building stock towards 2035, and is thus less relevant for this report.

In the first energy scenario, two packages of energy saving measures have been investigated, referred to as a “moderate” package and an “ambitious” package [1]. These packages have been applied for all buildings before 1945 up until 1990 (buildings after 1990 are considered to have a fairly good condition). The results of the calculated energy savings by implementing the two packages are shown in Figure 13.

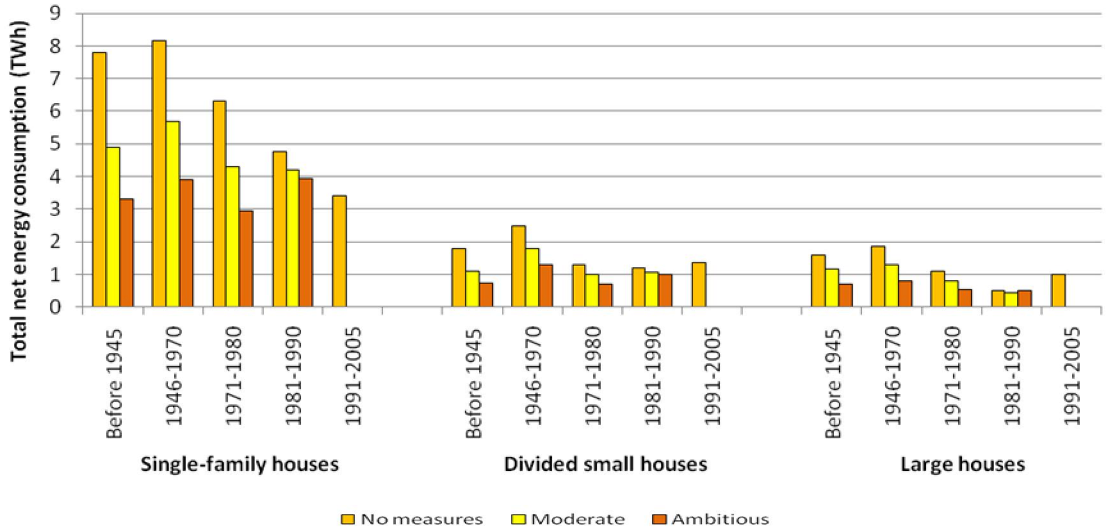

Figure 13. Total useful energy use, dependent on the type of dwelling and the year of construction. *[1]*

Calculating the theoretical reduction in energy use, approximately 12 TWh or 25 % can be saved by applying the “moderate” package on the Norwegian 2005 existing building stock. Similarly, the implementation of an `ambitious´ package would result in about 17 TWh or 40% reduction of the energy use.

Based on the figure above and taking into account the number of dwellings in each of the main groups, and the specific energy saving potential, the largest reduction potential is found in single-family houses. They account for 70% of the total reduction potential in the existing building stock.

Within the group of single-family houses, the largest reduction potential lies in renovation of single-family houses built before 1945. Their saving potential is nearly 2.9 TWh and 4.5 TWh for respectively the two energy saving measure packages. This implies that the largest saving potential is in the building stock that is already renovated to some degree. Also in fairly "new" houses from the 1970's, a lot of energy can be saved because of the large number of such houses.

3.4 Finland

3.4.1 Building stock statistics

3.4.1.1 Number of houses and floor area

According to Statistics Finland (2010) the total number of dwellings is 2.768.000 of which 1.083.000 are detached single-family houses with a heated area of roughly 150 mill. m^2 (house average of 139 m^2). The age distribution, number of houses and their total heated floor area is shown in Figure 14 (2008 numbers). Finnish single-family houses are mainly after-war houses. About 60 % is built before 1980.

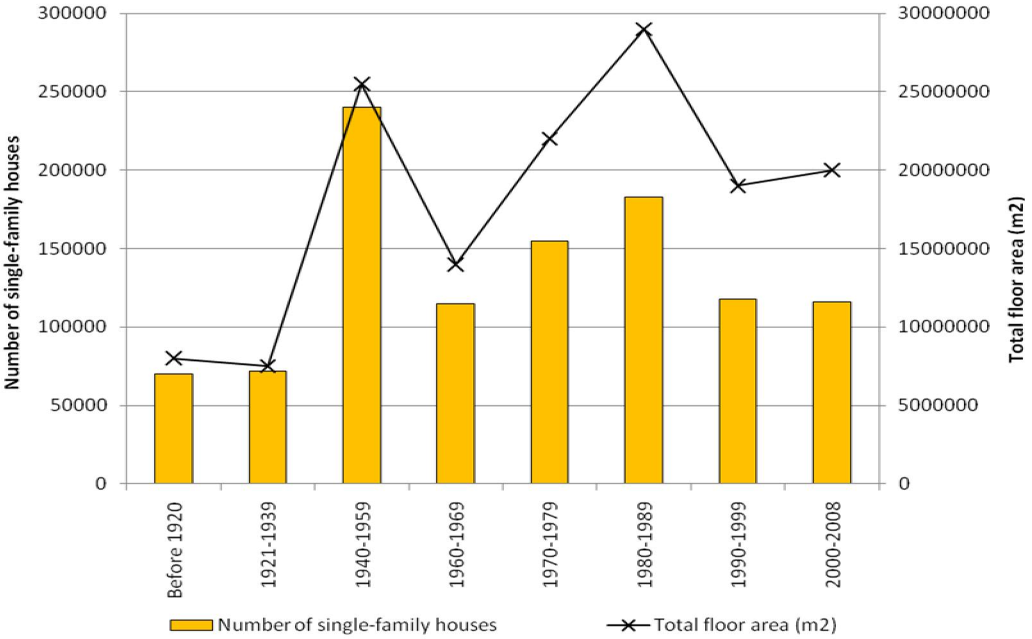

Figure 14. Age distribution, number of single-family houses in *the Finnish dwelling stock and their total floor area.*

3.4.1.2 Energy use

Energy use in buildings counts for approximately 40 % of the total end-user energy use (389 TWh). Of this, 56 % was used for heating and the remaining 44 % was used for electricity. More than 60 % of the building related energy use is consumed in residential buildings.

In Table 11, the total energy use and the contribution of space heating, electricity for fans, pumps, lighting, etc., hot water and household electricity to this total energy use can be seen for Finnish single-family houses of different ages.

Table 11. Energy use in Finnish single-family houses of different ages [12].

kWh/m^2/year	-> 1960	1960 ->	1970 ->	1980 ->	2003 ->	2010 ->
Space heating	160-180	160-200	120-160	100-140	80-120	40-60
Electricity for fans, pumps, lighting etc.	20-30	20-30	20-40	20-40	10-30	10-30
Hot water	20-60	20-60	20-60	20-60	20-50	20-40
Household electricity	20-40	20-40	20-40	20-40	20-40	20-30
Total energy use	220-310	220-330	180-300	160-280	130-240	90-160

3.4.1.3 Heating systems

Direct electrical heating is used in 42% of all Finnish detached single-family houses and wood and oil heating count each for 24%. For an overview of other typical heating sources, see Table 12.

Table 12. Typical heating source of the about 1.1 mill. Finnish detached single-family houses (Statistics Finland 2010)

Heating source	Number of houses (x10^3)	Percentage of total (%)
Electricity	462	42
Wood	263	24
Oil	258	24
District heating	54	5
Others (coal, ground heat, unknown)	54	5
Total	1,100	100

The heating source dependent on year of construction is shown in Figure 15. Oil-heating is very common in houses built in the 1970's. Electricity is common in newer houses and ground heating is becoming even more popular.

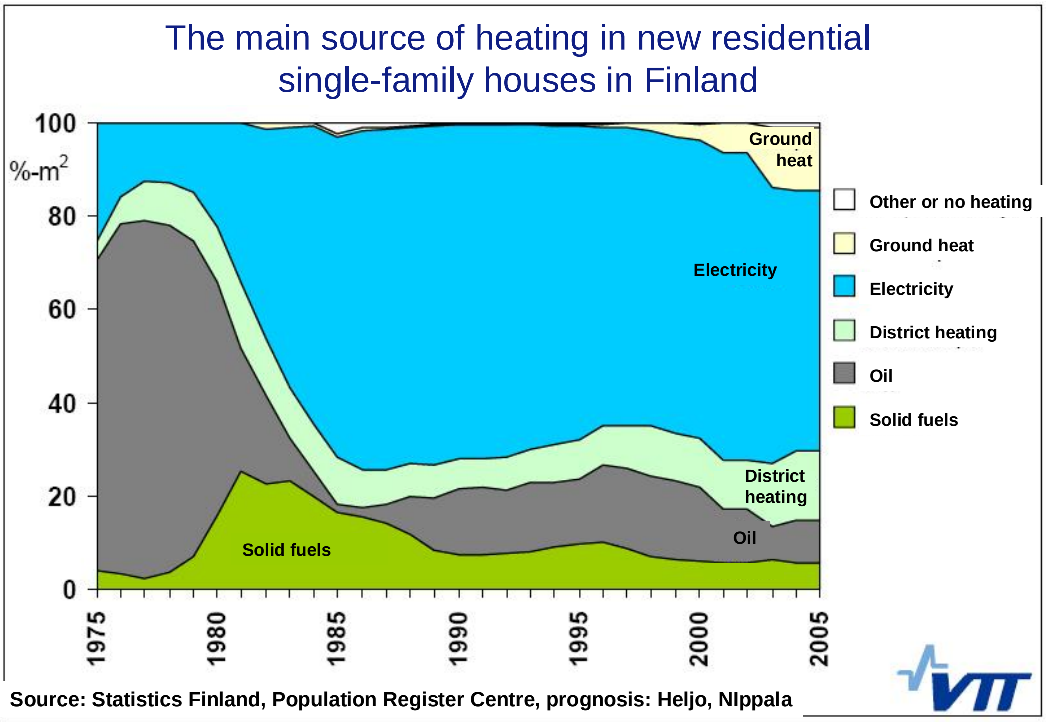

Figure 15. Heating sources in single-family houses dependent on year of construction [2].

3.4.1.4 Ventilation systems

As well as different heating systems, also different ventilation systems are being used. Figure 16 presents the different ventilation systems for single- and multi-family houses in 2007.

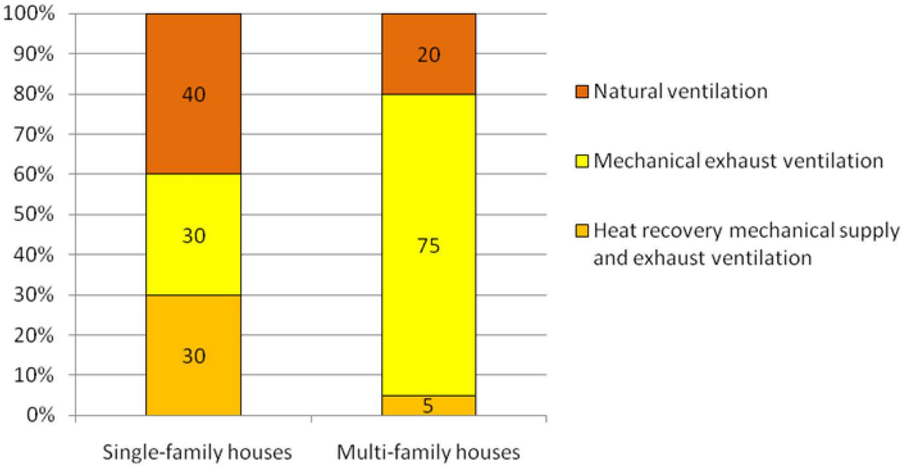

Figure 16. Estimate on ventilation systems in single- and multi-family houses in 2007 [2].

The trend in new buildings is to install heat recovery mechanical supply and exhaust ventilation systems (in 90% of new single-family dwellings and 30% of multi-family dwellings) or mechanical exhaust ventilation (in 10% of new single-family dwellings and 70% of multi-family dwellings).

3.4.2 Typical single-family houses with great energy savings potential

Since the largest amount of single-family houses in Finland are built between 1940 and 1990, the biggest energy savings potential is most likely in that part of the building stock. If only the total floor areas of the single-family houses are considered (Figure 14), the conclusion is not that obvious due to the fact that during the years the average floor area of a new-built single-family house has increased all the time. However, also the building codes have tightened, so the newer houses are better insulated and the average energy use by floor area is smaller. So, the biggest energy saving potential is actually in the single-family houses built between 1940 and 1990.

Some very typical Finnish single-family houses with large energy savings potential within this time period are described below. External walls in these houses are solid or based on a wooden frame construction (Figure 17). In all these houses, a lot of heat losses occur through the building envelope and especially the windows are significant conductors of these heat losses. Simulations and measurements done by VTT show that the energy use in these standard houses is almost ten-fold compared to new energy efficient houses, so there is definitely room for improvement.

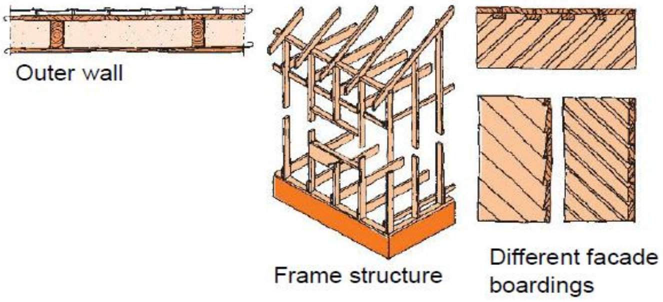

Figure 17. Main construction principle of typical Finnish single-family houses. [12]

3.4.2.1 Veteran houses (1940-1960)

Veteran houses from 1940’s and 1950’s have typically 1,5 stories, a cellar and a characteristic steep roof. The floor area is typically below100 m^2, about 60-80 m^2. A typical Veteran house is presented in Figure 18 below. As insulation between the wooden frame construction of the external walls in Veteran houses, sawdust and/or cutter chips or sometimes even moss or peat are used. As a finish, different facade boardings are used. Veteran houses are mostly finished with a light painted board or nature-coloured parget.

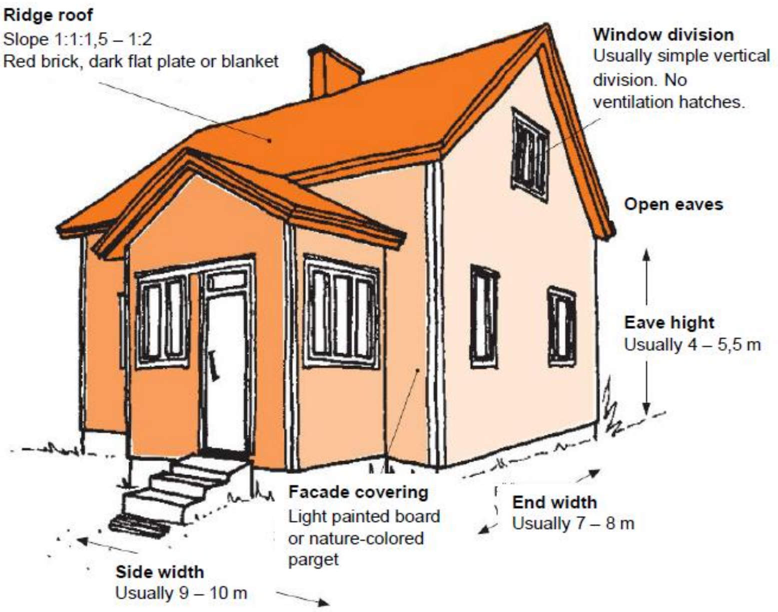

Figure 18. Typical house from 1940's and 1950's, so called Veteran house. [2]

Typical U-values for Veteran houses are presented in Table 13.

Table 13. U-values for building components of Veteran houses [2]

Building component	**Walls**	**Floors**	**Roof**	**Windows**
U-value (W/ m^{2}K)	0.55-0.7	0.35-0.45	0.3-0.4	3.5-4

3.4.2.2 Single-family house from 1960´s

The typical single-family houses from 1960's have a floor area about 60-80 m^2 and instead of a steep roof as for Veteran houses, they are characterised by a more gently sloped roof. A typical single-family house from the 1960´s is presented in Figure 19 and the typical U-values are presented in Table 14. The wooden frame construction of the external wall is usually finished with horizontal panelling.

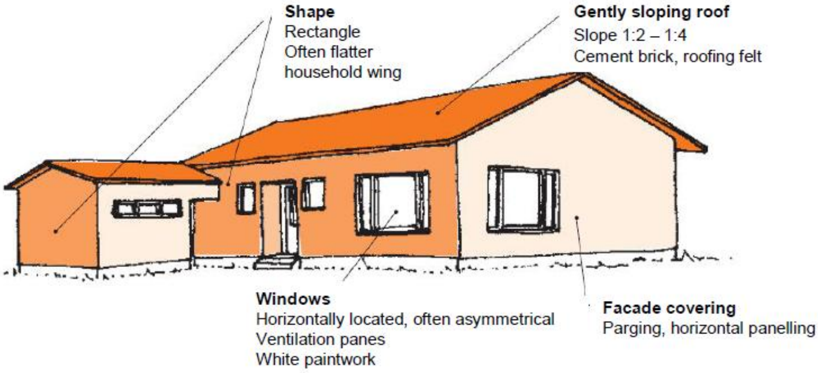

Figure 19. Typical single-family houses from 1960's. [13]

Table 14. U-values for building components of single-family houses from the 1960´s [2]

Building component	**Walls**	**Floors**	**Roof**	**Windows**
U-value (W/ m^2K)	0.35-0.45	0.3-0.4	0.25-0.35	2.9-3.5

3.4.2.3 Single-family house from 1970´s

The typical single-family houses from 1970's usually have a floor area about 100 m^2 and have windows with triple glazing. Two variants for this type of typical single-family house can be distinguished (see Figure 20). A first variant, in L-shape or rectangular, with a flat roof, has usually one story but can be build with 2 stories for hillside solutions. The second variant has a rectangular shape, is 1,5 stories high and sometimes has a part cellar. However, the two variants both have large windows, a covered balcony and are finished similarly by use of fair-faced brick or dark staining.

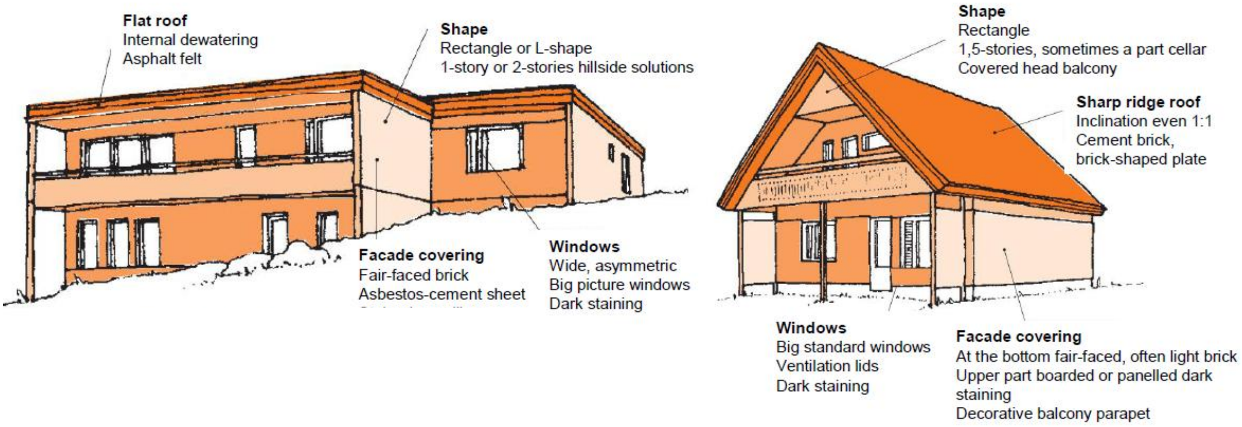

Figure 20. Typical single-family houses from 1970's [13].

Typical U-values for single-family houses from the 1970´s are presented in Table 15.

Table 15. U-values for building components of single-family houses from the 1970´s [2].

Building component	**Walls**	**Floors**	**Roof**	**Windows**
U-value (W/ m^2K)	0.24-0.28	0.2-0.3	0.18-0.22	1.8-2.1

3.4.3 Renovation scenarios - energy savings potential

3.4.3.1 Whole building stock

Residential buildings in Finland are responsible for more than 60 % of the building related energy use, and about 50 % of the building stock of 2050 is already built. Therefore the biggest potential to affect the energy saving in short term is through retrofits, but the significance of new buildings will grow in long run.

Apartment buildings are older than single-family houses. However, since they are mostly heated with CHP based district heating, it is most likely that the energy efficiency improvements in single-family houses would result in more energy savings and reduction in emissions.

The effect of different renovation measures on the heating energy use in Finnish building stock was studied by Tuominen in 2008 [13]. The overall result is presented in Figure 21.

The "Minimum" level line in Figure 21 describes the situation, where all the building stock would be on passive house level in energy demand. The renovation rate in this scenario is 3,5 % per year. With more emphasis on energy efficient renovation and higher renovation rate the energy demand would go down even quicker.

Even in the business as usual (BAU) scenario the energy demand will go down after 2020, because part of the old building stock is demolished, and new buildings are built according to new, tighter building regulations.

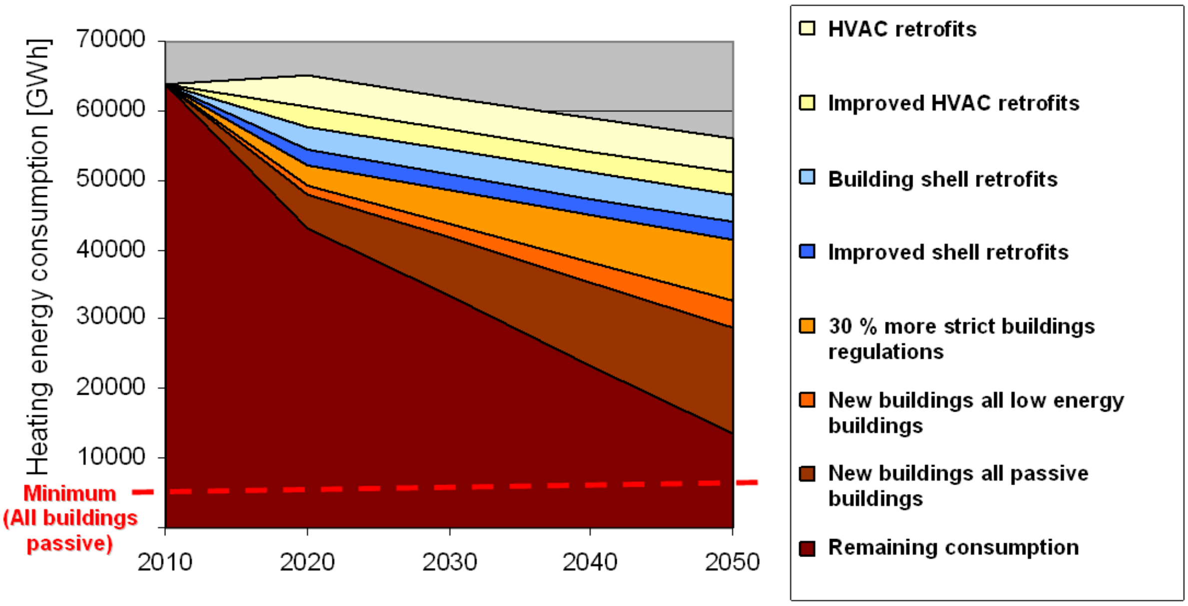

Figure 21. The effect of renovation actions to heating energy use [14].

3.4.3.2 Case Pakila

The objective with this case was to evaluate the energy saving potential of single-family houses built between 1940-1990 in the Pakila district in Helsinki. The estimates are based on calculations and experimental data and information on typical houses. In Table 16, the amount of single-family houses based on the year of construction in the Pakila area is shown.

Table 16. Number of single-family houses in the Pakila district (Statistics Finland 2009).

Construction year	**1940-1949**	**1950-1959**	**1960-1969**	**1970-1979**	**1980-1989**	**1940-1989**
Number	173	420	158	132	274	1157

Hekkanen et al. (1993) [15] describe typical structures and building services in single-family houses built in 1940-1980 and corresponding U-values, which are used in the calculations (see Table 15). In addition, one case where new U-value requirements from the 2010 building code were used was calculated for comparison.

Table 15. U-values for building components (W/m^2K) in houses of different age. House40 refers to a single-family house built in the 1940's. The other codes respectively.

Structure	**House ´40**	**House ´50**	**House ´60**	**House ´70**	**House ´80**	**House 2010**
External wall	0.9	0.65	0.4	0.26	0.26	0.17
Roof	0.35	0.35	0.3	0.26	0.2	0.09
Floor	0.35	0.4	0.35	0.25	0.25	0.16
Windows	3.5	3.5	3.2	2.0	2.0	1.0

Hekkanen et al. (1993) [15] also express typical living areas. However, especially the older houses may nowadays contain more space due to later enlargements or change of usage or quality. In Table 16, the utilized living areas are shown.

Table 16. The average living areas (m^2).

	House ´40	**House ´50**	**House ´60**	**House ´70**	**House ´80**	**House 2010**
Area	70	70	70	100	140	160

Halme et al. (2005) [13] have stated typical annual energy use values for single-family houses. All the houses built before 1960 are divided in the same category. In Table 17, the total annual heating energy use including both space heating and water heating is summarized.

Table 17. Annual energy use for heating in kWh/m^2 (space heating + hot water) in single-family houses based on the construction year.

Construction year	**-> 1960**	**1960 ->**	**1970 ->**	**1980 ->**	**2003 ->**	**2010 ->**
Energy use for heating	180-240	180-260	140-220	120-200	100-170	60-100

The calculations were done using the WinEtana software developed by VTT. For the older houses built in the 1940's, 1950's and 1960's, WinEtana results in higher energy use than empirically known. Perhaps there are already some energy renovations done in these houses during the years. In addition, there might be inefficient ventilation compared to a good quality. So, the average experimental level of energy use was selected as the reference level.

For the single-family houses built in and after the 1970's, the WinEtana calculations are in line with the empirical data, so the calculation results were selected as the reference data. So, it is easier in the future for example to evaluate saving potential of a certain energy renovation measure.

Table 18 shows an estimate of the total energy use for heating of the Pakila single-family houses built between 1940-1990 and a corresponding value if all of them were renovated to the level of the 2010 building code (83 kWh/m^2). In addition, the savings potential for the whole area was calculated. This corresponds to savings of 58 % of the total energy use for heating.

Table 18. Energy use for heating before and after renovation of the single-family houses in Pakila built between 1940-1990 and the corresponding savings potential.

	House ´40	**House ´50**	**House ´60**	**House ´70**	**House ´80**	**Total**
Energy use for heating, current, kWh/m^2	210	210	220	197	175	-
Energy use for heating, current, MWh	2,543	6,174	2,433	2,598	6,721	20,469
Energy use for heating, renovated, kWh/m^2	83	83	83	83	83	-
Energy use for heating, renovated, MWh	1,006	2,443	919	1,097	3,188	8,653
Savings potential, MWh	1,537	3,731	1,514	1,501	3,533	11,816

3.5 Summary

Residential building stock analyses have been conducted in all participating countries and some general conclusions can be drawn. In Table 19, a summary of the building stock statistics can be found.

Table 19. Summary of building stock statistics; Number of dwellings and single family houses, heated floor areas, energy use for heating and existing heating and ventilation system.

	Denmark	**Sweden**	**Norway**	**Finland**
Total number of dwelling (x 10^3)	2,459	4,500	2,300	2,768
Number of detached single-family houses (x10^3)	1,141 (46%)	1,360[1] (30%)	1,200 (52%)	1,083 (39%)
Heated floor area (mill. m^2) – in brackets the average area per house	170 (149m^2)	167 (123 m^2)	150 (125 m^2)	150 (139 m^2)
Average yearly energy use for heating (kWh/m^2)	135	148	200	180
Existing heating system	Mostly oil/gas boilers + district heating	Direct electric heaters + wood + heat pumps	Mostly electric heating (70%)	-1980: Mostly oil 1980-: Mostly electric heating
Existing ventilation system	Natural ventilation	Originally natural ventilation, Later mechanical ventilation	Originally natural ventilation, Later mechanical ventilation	Originally natural ventilation, today mechanical ventilation

[1] Not including detached farmhouses. Included for the other countries.

First of all, it shows numbers for the total housing stock and permanently used single-family houses, with numbers in percentage for the single-family house share of the total housing stock. Row houses are not included. In general, detached single-family houses account for an average of 40% of the total number of dwellings in the Nordic countries, varying from 30% in Sweden (excluding farmhouses) to 57% in Norway.

The average yearly final energy use for space heating and hot water is ranging from 135 kWh/m^2 in Denmark to 200 kWh/m^2 in Norway. The energy use is highest in Norway/Finland, which are also the countries situated farthest to the north. The average energy use for a single-family house in Denmark is 135 kWh/m^2. More for old houses and less for newer houses. The requirement for heating demand in the new Danish building code (BR10) is a maximum of roughly 60 kWh/m^2 for a typical house. This indicates that existing houses therefore need to be significantly upgraded just to comply with the minimum energy requirements in the building code.

As is shown in Table 19, the heating systems and sources used in the Nordic countries differ. In Denmark, 55% of the single-family houses are centrally heated with oil fired boilers or gas boilers and 35% of the detached single-family houses are connected to a district heating system. District heating has only a minor share in heating of the single-family houses in the other countries. In Sweden, electric heating (resistance heaters, electric boilers and combinations of these with other heating system) is mostly used. Electric heating is also used in about 70% of the buildings in Norway. Older existing buildings in Finland are mostly heated with oil fired boilers, although electrical heating gained popularity after 1980.

Natural ventilation is used in most single-family houses built before 1970. Onwards, the use of mechanical ventilation increased and e.g. most of the single-family houses in Norway, Sweden and Finland built in the 1980’s have a mechanical ventilation system.

Like heating systems and ventilation systems used in single-family houses in the Nordic countries differ, also the use of construction material might differ. Single-family houses in Norway, Sweden and Finland are typically built with wood as a main construction material, but the insulation and/or finishing materials differ. In Denmark, however, bricks are used as a dominant construction material for cavity walls.

The typical single-family houses identified to have large energy saving potential descend from the same time period in each Nordic country. Although a large part of the single-family houses built before 1945 has been renovated, energy renovation of those houses today would still account for a large energy savings, even if they would only be upgraded to meet the current building code requirements. Single-family houses from the 1960´s and 1970´s also have a large energy saving potential since they were built in large numbers and built right before the tightening of the insulation standards in the late 1970’s due to the oil crisis, and because electric heating is prevalent (except for Denmark and Finland).

Since each of these identified single-family houses with large energy saving potential have a different composition and characteristics, their potential for energy savings will differ mutually. Some of the full service renovation packages and technical renovation solutions described in D1.1 will accordingly only be relevant to apply on certain types of typical single-family houses. This will be further investigated later by detailed analysis of individual typical single-family houses.

4 METHOD FOR PROPOSALS ON SUSTAINABLE RENOVATION CONCEPTS

Given the knowledge about the existing building stock in the Nordic countries, the renovation concepts described in the D1.1 report need to be evaluated and their potential for full-service solutions needs to be investigated.

In order to propose new sustainable renovation concepts suitable for different categories of single-family houses with regard to type and age (deliverable D1.3), a general (ideal) working method for sustainable renovation of single-family houses will be described. The method consists of four steps, going from investigation of the house to planning and commissioning after renovation.

- Step 1: Initial evaluation of house condition and energy use
- Step 2: Pre-project – proposal for sustainable renovation
- Step 3: Detailed planning and contract work
- Step 4: Quality assurance and continuous commissioning

The steps will be described in more detail below.

4.1 Step 1: Initial evaluation of house condition and energy use

Mandatory energy evaluation (certification/labelling) of new buildings or at sale and renting of existing buildings, in accordance with the requirements of the Energy Performance of Buildings Directive (EPBD), should help the implementation of energy saving measures and renewable energy applications. Energy labels are designed to give house buyers and house owners a picture of the energy use (on a scale from A to G) even before the signature to purchase or lease and at the same time, the label should give an overview of cost-effective renovation measures to enhance the energy efficiency. The idea is that receiving such proposals will raise awareness and will make building owners more inclined to carry out the investments involved in energy efficient renovation. In Denmark, an evaluation report showed that the effect of the labelling scheme is, however, very limited, so a major revision is going on and a new scheme is expected to be put into force in autumn 2010.

In order to enhance the quality of the energy label and increase its usability, more focus should be put on the registration of the existing single-family house. Hence, it could be useful to integrate a report with an analysis of the condition of the existing house dealing with e.g. the craftsman like qualities, appearance and functionality of the house. This integration is not expected to be part of the new scheme.

The initial house condition and energy evaluation should be carried out by a trained and independent energy consultant (could be a carpenter that have received supplementary training) as a thorough but simplified examination that could form a basis for the homeowners consideration of future renovation work, i.e. repair and maintenance work and also improvements to the house (e.g. a new kitchen).

It may be relevant to include the following in the examination:

- Rough estimation of energy savings for different energy renovation measures and priority using e.g. the criterion of cost of conserved energy (CCE method) or annual economic balance (savings minus repayments on e.g. a mortgage credit loan).
- Focus on the many non-energy benefits related to the energy benefits
- Advice on how to use the house more efficiently
- Clarification of needed repair work (= damages and defects that need to be fixed for upgrade to normal condition) and order of priority.
- Clarification of needed maintenance work (= work that needs to be carried out to upkeep the house in normal condition, so that damage is avoided) and order of priority.
- Homeowners needs and wishes for improvements to the house
- Estimated remaining life time of building components and general quality of the house
- Estimated expenses for repair, maintenance and improvements over a period of e.g. 10 years and divided into labour and material cost for each measure/activity.
- Maybe as a supplementary service an elaboration of the activities pointed out by the consultant as needed to be carried out (repair and maintenance).

It would be useful if the evaluation report included some estimates on the economic implications of:

- Normal step-wise renovation
- Thorough energy renovation
- Demolition of existing house and building of a new house

The goal for energy performance could be minimum requirements in the building code or low-energy house. Reaching passive house level in renovation is very demanding. For old houses that tend towards a demolition and building of a new house the main argument not to demolish it is that even though renovation is labour intensive and costly it is possible to achieve a new comfortable house with low-energy costs in an old house. Renovation is also attractive if price of new land is expensive.

4.1.1 Case REEP – energy evaluation of private homes in Canada

REEP (Residential Energy Efficiency Project) is a Canadian example on third-party expert advice on energy savings and renewable energy applications. A certified energy advisor will assess the house and give recommendations on how to improve the energy performance of the house. REEP is a ”success story” and a project of Waterloo Region Green Solutions, a community-based non-profit environmental organization that is funded by a combination of local partners, provincial contracts, grants and client fees. The local university is involved. A part of the success is that the advisor prints a report on site with his portable PC and printer. It is therefore a practical tool and report which the homeowner receives immediately and can discuss it with the advisor.

In 2010, Canadian home owners could obtain grants of up to $5000 (approx. € 3700) per household and get an up to 50% rebate on the initial home energy evaluation. After renovation, a follow-up evaluation is required to qualify for all government grants. Get more information on REEP on http://www.reepwaterlooregion.ca. REEP is described and used as a case in a Marketing Guide that was written as part of IEA project task 28 [16].

4.2 Step 2: Pre-project – proposal for sustainable renovation

Based on the "extended energy certification", the initial house condition and energy evaluation report (step 1), the purpose of the pre-project stage is to put together relevant proposals for sustainable renovation for the homeowner to choose from - including quotation for the work, financing and management of the renovation process. The main point is that homeowners need help in the design and decision making process to be carried out by groups of consultants (e.g. engineers and architects) and contractors.

The starting point for the pre-project phase may be determined by the budget of the homeowner. Then detailed analysis of possible technical energy renovation measures with parameter/product variations should be performed in order to result in trustworthy proposals for sustainable renovation including energy and non-energy benefits, economy/financing, plan for renovation, durability issues and fulfilment of user needs and wishes. The effect on energy use and indoor environment should be analysed with detailed but easy-to-use calculation tools. A low energy use should not be obtained at the expense of overheating and bad air quality and use of daylight.

The ability to visualize/document the effect of proposals for sustainable renovation with emphasis on non-energy benefits and aesthetics may be the most important aspects of the pre-project phase. Handling of the "Twofold benefit" of energy efficiency measures; energy savings and rehabilitation of the building components physical condition is also important.

In some cases, a major sustainable renovation is not relevant and therefore the facilitator should offer to make a detailed long term plan for renovation and modernization which optimize the economy in relation to the homeowner's wishes and needs.

4.3 Step 3: Detailed planning and contract work

After signing of contract for the renovation work and approval of a possible loan and/or governmental subsidy, a detailed planning process is carried out. This includes fine-tuning the contract details considering the specific situation including detailed drawings. Some extra work or/and better products might be included.

The price model could be a fixed priced contract work carried out on the risk of the facilitator of the full-service package solution or it could be energy performance contracting (EPC) utilized and redeveloped to match the single-family house renovation market.

The sustainable renovation is carried out, managed and quality assured by the facilitator and the affiliated professional group of consultants and contractors. Sustainable renovation of a single-family house is demanding for the typical homeowner who needs help from professionals. However, as the traditional market for renovation is very much a do-it-yourself-culture, service packages should be flexible to handle a customer wish for contributing more or less to the process of carrying out the work.

4.4 Step 4: Quality assurance and continuous commissioning

It is important to check the quality of the contract work. This could be done by an independent consultant, e.g. a certified energy consultant, in connection with a follow-up evaluation after the renovation. The consultant can also check if the commissioning of heating and ventilation systems etc. have been done correctly. This is an important issue which needs to be carried out not only once but on a continuous basis to optimize system operation and control schedules.

To ensure that the house owner continuously obtains the promised energy savings and improvements to the indoor environment, the detailed model for energy and indoor environment performance, used in the previous stages of the renovation process, could be used. This is feasible by measurements of weather data and the actual use of the house, e.g. indoor temperature, opening of windows and adjustment of thermostat. These data are implemented in the model, and the expected energy use is calculated and compared with the measured energy use for a validation of the model. The measurements and the model can be used to correct technical or behavioural problems and to illustrate the implications of e.g. a higher indoor temperature than assumed before renovation.

User behaviour can have an enormous impact on energy use. To ensure a low energy use, user guidelines should be presented and explained for the homeowner. The homeowner is of course master in his own house so he should be able to override the systems, e.g. opening of windows in winter time even though there is a mechanical ventilation system with heat recovery. But it should be based on informed decisions based on information on the consequences for energy use.

In the future the detailed model of the house could be the basis for the development of intelligent control of active and passive systems for heating, cooling, ventilation, solar shading etc. in single-family houses, based on measurement of actual and forecasted weather data and use of the building.

The Energy Saving Trust in Denmark (Elsparefonden) is offering a new program to homeowners (My E-Home) where they can build up a model of their house to investigate potential energy savings. The idea is also to link it to measurements on energy use before and after energy savings have been realized. By installation of (e.g. wireless) units for measurement and control of energy use for heating and electricity the homeowner can keep a watchful eye on the energy use online and with the right equipment it’s possible to control the house, i.e. to switch on, turn off or adjust the heating and ventilation system etc. It is probably too optimistic to expect that homeowners in general would take the effort to build up the model of their house. Energy saving specialists could offer to help to build up “My E-home” as part of their selling of the service they are offering.

Links to “My E-Home”:

http://www.savingtrust.dk/consumer/tools-and-calculators/my-home

http://www.elsparefonden.dk/forbruger/vaerktoejer-og-beregnere/om-minbolig

5 PRE-PROJECT - EVALUATION OF TECHNICAL RENOVATION CONCEPTS

Focus in this report is on the evaluation of the promising sustainable renovation concepts from D1.1, including both full service renovation concepts and technical renovation concepts. Whereas the full service renovation concepts will be analysed according to all steps in the general method for proposals on new better sustainable renovation concepts proposed in previous chapter, the technical renovation concepts will mainly be analysed according to step 2 in the general method in order to result in proposals for energy renovation including energy savings, economy, plan for renovation, durability issues and fulfilment of user needs and wishes. Each of these criteria will be described in more detail below. Furthermore, an overview of possible dynamic but easy-to-use calculation programs will be given, as they can be used for analysis of parameter/product variations for possible technical energy renovation measures with regard to the criteria mentioned above.

5.1 Suitability to result in extensive energy savings

Renovation of typical single-family houses in the Nordic countries offers large energy saving potential. In order to renovate these houses to a very high energy standard, simple insulation measures on the building envelope to reduce the transmission, air infiltration, and heating system heat losses should be combined with more ambitious renovation measures, such as external facade renovation with added insulation, the installation of an energy efficient ventilation system and the use of renewable technologies such as solar heating and low temperature based heat pumps. A combination of insulation and air tightness measures and minimized ventilation losses can significantly result in extensive energy savings and reduce the final energy demand for heating to a very low level. Reaching passive house level will however be very demanding in renovation. Thermal energy from possible sources, e.g. solar, waste incineration, low temperature heating in combination with heat pumps, and biomass is then used to reduce the primary energy demand of the building even more. It should be noticed that a new heating system e.g. a change from oil boiler to district heating may not reduce the final energy demand, but improves primary energy efficiency. Biomass heating may not reduce primary energy use compared to e.g. oil/gas heating, but will contribute to reducing the CO2 emissions on a global level.

In order to evaluate whether the full-service and technical renovation concepts described in D1.1 can result in extensive energy savings, it is useful to situate the current energy requirements in the participating countries building codes and regulations. Moreover, in some of the building codes and regulations, requirements to extensive renovations are listed under certain conditions. An overview of the requirements in the building codes and regulations in the Nordic countries is given in Appendix 1.

5.2 Implementation plans for renovation

Carrying out a comprehensive low energy renovation means a relatively large investment. In order to deal with the large investment costs, it is important that there is a need for a thorough renovation not only based on energy savings. Thorough renovation of the house so to speak "shall be made anyway" as a result of physical degradation of main building components, bad indoor environment, health problems, practical issues, architecture and use of the house etc.

The crucial point is thus to link the extensive energy savings to the normal renovation measures, in that way reducing the price of implementing the savings.

In order to deal with the large investment, a thorough renovation of a building requires the set-up of a good planning. Homeowners usually carry out renovation measures according to their available budget, in which they often focus on the costs of renovation right away and therefore prefer step-wise renovation. However, a higher level of energy-efficiency and cost-effectiveness can be reached by combining several renovation measures at the same time. For example, it is better to replace windows as well when deciding to insulate the walls with external insulation than to do both separately.

Homeowners may not see the most important things to be improved in order to ensure the condition of the building and forget about the technical issues when implementing certain renovation measures [17]. Therefore, homeowners might need the help of a professional.

Additional insulation of roof and ceiling constructions is relatively easy to carry out. However, insulation improvements of slab-on-ground floors, foundations, basement, and crawl space structures, are significantly constrained by technical conditions relating to moisture, long life spans, and relatively large initial construction costs. One obviously inexpensive and efficient possibility for insulation improvement is to place the insulation between the flooring joists when replacing existing floors, especially in connection with non-insulated foundations.

5.3 Durability and energy characteristics

Durability is defined in ISO 15686-2 (2000) [18] as “the capability of a building or its parts to perform its required function over a specified period of time under the influence of the agents anticipated in service”. Because the basic need of a renovation usually involves the functionality of the building and its components, a good appearance and aesthetics inside and outside the building and a long life, durability is an important aspect after renovation.

Factors that influence the durability of a building and its components in its specific environment are for example poor design and detailing. Poor workmanship and lack of knowledge of properties of materials, their energy characteristics and their performance in use are also important factors. If these factors are not paid attention to, durability of buildings and components will be affected. For example, external insulation is in many cases preferred above internal insulation. This because when applying external insulation, the surface temperature of the existing walls is close to the indoor air temperature and therefore the construction is protected from internal condensation and lasts longer. Applying external insulation also minimizes thermal bridges which in turn also reduce the risk of structural damages. Applying internal insulation not only results in more thermal bridges (e.g. internal dividing walls), and increasing risk of structural damage, but also decreases the useful indoor surface area of a building. Sometimes, however, practical or aesthetic reasons inhibit the use of external insulation.

Another example is related to the energy characteristics of materials influencing the durability of a building. The energy characteristics of materials can be influenced by the in-use conditions and the execution of the detailing of the building. An example can be made considering the thermal conductivity of insulation materials. Moisture and wind can influence the thermal conductivity of mineral wool. In order to ensure the durability of a building insulated with mineral wool, the mineral wool needs to be protected against external weather influences. In case of a building insulated with vacuum insulated panels (VIP), a careful execution and detailing is needed in order to avoid puncturing of the panels and thereby a decrease of its thermal conductivity. However, the thermal conductivity of VIP decreases with time. For the application of VIP and other compact insulation materials, the benefits, such as less reduction of useful floor area when using VIP for internal insulation in comparison with traditional insulation materials, should be weighed against the decrease in thermal performance and influence on the durability of a building. However, if a VIP is punctured, it will still have a lower thermal conductivity than e.g. mineral wool.

5.4 User needs and wishes

Homeowners could have various needs, including non-energy reasons, behind energy efficient renovation of a house. As mentioned, physical degradation of main building components, bad indoor environment, health problems, practical issues, architecture and usability of the house can trigger the start of a renovation. Some homeowners may want to have a warmer house in winter and a colder house in summer or a better indoor climate with regard to moisture issues and a reduction of draft. Improvement of the draft issues also leads to less energy use for heating, which is an additional advantage.

Some homeowners might want to improve the architectural quality of their house when renovating, whereas others might want to ensure some aspect of their house for the future (such as a facade worth preserving) or reduce the care for maintenance. In that way, the market value of the house will also increase and will hereby have a positive impact on the economy of the house owner. Another non-energy related reason for renovation is a reduction of noise from the outdoor environment after renovation. This can be done by installing new windows, which at the same time can reduce the need for heating. When installing new windows (and/or doors), homeowners might also consider the security aspect of their house.

In some cases, homeowners opt for an energy renovation of their houses out of concern about energy supply difficulties and rise in energy prices. When energy prices rise, homeowners usually install new heating systems to reduce their annual energy cost. An additional benefit might be a better indoor environment. Some people may undertake energy efficiency improvements for the sake of environment and/or to improve their status in the society.

5.4.1 Indoor thermal environment

The European standard EN 15251 [19] defines different indoor environment categories and corresponding criteria. The different categories are explained in the following way:

I: High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons.

II: Normal level of expectation and should be used for new buildings and renovations.

III: An acceptable, moderate level of expectation and may be used for existing buildings

IV: Values outside the criteria for the above categories. This category should only be accepted for a limited part of the year.

Table 20 shows the temperature ranges for winter and summer conditions for each category specified above.

Table 20. Indoor environment classification based on criteria for energy calculations. Living spaces in residential buildings [19].

Category	**Thermal conditions in winter**	**Thermal conditions in summer**
I	21.0-25.0˚C	23.5-25.5˚C
II	20.0-25.0˚C	23.0-26.0˚C
III	18.0-25.0˚C	22.0-27.0˚C

*Corresponds to a ceiling height of 2.5 m.

The standard states that thermal conditions meet the criteria of a specific category when a maximum of 3 % of occupied hours a year are outside the limits of the specified category, corresponding to 259 hours a year.

In summer typical existing and renovated single-family houses will be free-running with no mechanical cooling system and the criteria for the categories are based on indoor temperature. To avoid overheating in summer passive thermal controls can be used, e.g. roof overhang, sensible orientation and opening of windows and solar shading.

In general the indoor environment can be classified by doing whole year computer simulations of the indoor environment and energy performance, choosing a heating setpoint equal to the lowest winter temperature and a setpoint for overheating hours equal to the highest summer temperature - for the category in question (typically #II).

5.5 Total life cycle costs

There exist different criteria to assess cost effectiveness of energy saving measures, such as simple payback time, cost of conserved energy (CCE) and net present value (NPV), to assess cost effectiveness of energy saving measures.

5.5.1 Simple payback time

The simple payback time is one of the most popular criteria used because it is readily comprehensible for non-economists. The simple payback time is a fairly good tool for comparing different energy-saving measures with a short lifespan (up to 15 years), but is less well suited as a basis for decisions that have consequences running 50–100 years into the future, since it does not take into account the lifetime of renovation measures [20].

5.5.2 Net present value (NPV)

What is needed instead is a criterion that gives an indication about the net benefit of a long-term investment, such as net present value (NPV). The NPV of a renovation measure is determined as the difference between the present value of the cost savings due to the application of the renovation measures (e.g. operating cost, maintenance cost and replacement cost) and the present value of the investment costs. By calculating the NPV, all future costs are discounted to the time of investment and are being added up to the investor’s net benefit. Differences in the lifetime of measures should be taken into consideration by introducing the necessary reinvestments and the residual value of investments into the calculations at the end of the chosen calculation period [21]. The application of a renovation measure is profitable when NPV is a positive quantity. Considering different renovation measures with various investment costs, it is the investment with the largest NPV that is the most favourable.

5.5.3 Cost of conserved energy (CCE)

To evaluate economic efficiency of energy saving measures, the criterion of so-called cost of conserved energy (CCE) can also be applied. As in the case of the NPV, this criterion takes into consideration both the lifetime of measures and the cost of borrowing money.

The CCE method can be used for economically optimised design of renovation of existing buildings and new buildings. It takes into consideration both the lifetime of measures and the cost of borrowing money. A measure is considered economically efficient if the CCE is lower than the price of primary energy from the energy supply system. CCE simply indicates if it is cheaper to save energy or to consume it. CCE does not depend on present or future energy prices. For example, if the CCE of a measure is higher than the present energy price, but lower than the forecasted energy price, then one could conclude that it is wise to implement this measure.

The basic definition of CCE is according to ref. [21]:

Equation 1. Basic formula for calculation of cost of conserved energy (CCE)

$$CCE = \frac{I}{S} \cdot \frac{d}{1-(1+d)^{-n}}$$

With I the investment cost of a measure, *S* the annual energy savings, *n* the lifetime of a measure and *d* the discount rate.

A more complete definition of CCE is proposed in ref. [22]:

Equation 2. Complete formula for calculation of cost of conserved energy (CCE)

$$CCE = \frac{t \cdot a(n_r, d) \cdot I_{measure} + \Delta M_{year}}{p_1 \Delta E_{year} - p_2 \Delta E_{operation,year}}$$

Where:

$t = n_r/n_u$	Time-factor t, where n_r is the reference period (in years) and n_u is the useful life time (in years). This means that only the proportion of the investment cost equal to the ratio between the reference period and useful life time is depreciated in the reference period. The useful lifetime of energy-conserving measures may vary from a few years to the entire lifetime of the building. A reference period is therefore introduced to ensure a fair frame of reference for comparison of energy-conserving measures with various useful lifetimes.
$a(n_r,d)$	Capital recovery rate, *d* is the discount rate (in shares of unit) and *n* is useful life time of the measure (in years).
$I_{measure}$	Investment cost, or additional cost, of an energy-conserving measure (in a monetary unit)
ΔM_{year}	Increase in annual maintenance cost (in a monetary unit). Some energy-conserving measures require a certain rate of maintenance with an associated cost. The increase in annual maintenance cost, ΔM_{year}, is added to the annualised investment cost. If the maintenance cost is expected to occur in an interval smaller or greater than one year, this maintenance cost should be distributed as an annual maintenance cost.
ΔE_{year}	Annual final energy conserved by the measure (in a physical unit, e.g. kWh).
$\Delta E_{operation,\,year}$	Energy use in operation, e.g. VHR saves energy for heating, but uses

electricity to do so.

P_1 and P_2	Primary energy factors related to the conserved and consumed energy of the energy-conserving measure, respectively. If $\Delta E_{operation,\ year}$ and/or ΔE_{year} are in units of electricity, the difference between energy content in one unit of heating and in one unit of electricity should be taken into account. This is done by multiplying $\Delta E_{operation,\ year}$ and ΔE_{year} by a primary energy factor which is the ratio between the energy content of secondary energy source (electricity) and the energy content of a primary energy source (heating). Some of the secondary energy might be converted into a heat gain for the building. This gain could be reflected by reducing the primary energy factor.

5.5.4 Discussion

Usually, results of the CCE coincide with results of the NPV calculations. However the calculation of the CCE is slightly simpler and its interpretation is more readily comprehensible since the CCE simply indicates if it is cheaper to save energy or to consume it. Another advantage of the CCE is that it does not depend on present or future energy prices. [21].

However, whichever of these criteria will be used for the calculation of the cost-effectiveness of energy saving measures, one should be aware that energy saving renovation measures not only save energy but also improve the condition of a building and in turn increase the value of a building. Considering only the reduction of energy cost from implementing energy saving measures, their implementation is usually hard to prove through cost-effectiveness. In ref. [21] the benefit of the renewal of building components is taken into account by means of introducing a coefficient of the building component´s rehabilitation into the cost calculations. If the deterioration level of an individual building component is very high, the whole investment cost of the measure will be attributed to the rehabilitation of the component´s condition; and the cost-effectiveness of the measure will be the highest. This aspect of the so called “two-fold benefit” of renovation is dealt with by considering the cost for energy saving measures only as an incremental cost better than normal measures (i.e. according to the minimum requirements) [23].

Another important matter in the calculation of the cost-effectiveness of energy saving measures is the lifetime of the investment in a renovation measure, i.e. the period over which the cost savings and the costs are of interest to the investor. This period is commonly set equal to the lifetime of the building component with the longest expected lifetime, i.e. the building structure. However, as a major renovation combines several components that have different lifetimes and most building components have a shorter lifetime than the building structure, it is suggested for simplification purposes an average lifetime for the whole renovation of 30 years [24]. This period correspond to the normal loan period for real estate investments.

5.6 Calculation tools

In order to calculate the effect on the energy performance and/or indoor environment and to evaluate the energy savings potential of different renovation measures, today, a lot of different calculation tools exist and can be used. This can go from internationally known tools such as TRNSYS, DOE-2, IES <Virtual Environment> and BSim, which rely on a sophisticated approach and are not applicable to simple calculations, to more locally and user-friendly calculation programs such as Be06. Some tools, such as EPIQR and TOBUS, are developed for use in the decision process to see the effect of different solutions in retrofitting of specific building types (respectively apartment buildings and office buildings).

In Table 21, an overview of the principles and features of **relatively easy to use dynamic calculation tools** that are being used in the participating countries and that can be used to see the effect of different retrofit solutions on the energy performance and/or indoor environment is given. All of these calculation tools, except Be06, rely on hourly calculations of energy performance and/or indoor environment. A more detailed description of the calculation tools can be found in Appendix 2

Table 21. Overview of calculation tools.

Calculation tool	**Country**	**Purpose**	**Strengths (+) /Weaknesses (-)**
WinDesign	Denmark	Program to optimize selection of building components both regarding energy performance and thermal comfort in the design process.	+ Calculations based on requirements in ISO 13790 + Indication of thermal comfort (hours of overheating) + Calculation of electricity needed for lighting + Easy to use and extend (Microsoft Excel and VBA) + free utility but - beta version
Be06	Denmark	The Be06 calculation program has been developed for the calculation of the energy balance in buildings.	+ Used to document that buildings comply with the energy requirements in the Danish Building Code - Monthly calculation - No indication of thermal comfort and daylight
EnergiKoncept	Denmark	Energikoncept.dk is a digital tool that is designed to give a rough calculation of energy use and advice on energy optimal renovation.	+ free utility + quick introductory overview of possible energy saving measures + shows influence of energy saving measures on architectural quality, economy and indoor environment +/- few entries →estimates of energy savings may differ from more detailed calculations

Calculation tool	**Country**	**Purpose**	**Strengths (+) /Weaknesses (-)**
Enorm	Sweden	Enorm is a calculation tool designed to determine the energy use of a building and verify if the regulation requirements regarding energy use are met.	+ short computing time with reasonable requests for input. + calculations based on the Swedish building regulations + separate module to calculate transmission heat losses + Including module for economical calculations - Does not include thermal calculations
VIP+	Sweden Norway	VIP+ is used to calculate the energy balance in buildings according to known and measurable energy flows.	+ Function for 2D and 3D heat flow calculations integrated in the program + Building part catalogue and data catalogue +/- Very detailed input possible
WinEtana	Finland	WinEtana is an easy to use calculation tool for energy balance calculations that uses a knowledge database for generating input values for calculations.	+ Only few input needed and input data can be specified step by step according to the information known - Knowledge database limited to Finish buildings - Reliable results only in Nordic climate
RIUSKA	Finland Norway	RIUSKA is a tool for the dynamic simulation of comfort and energy balance in building services design and facilities management in everyday design processes.	+ Includes default data libraries to help the user to choose input values. + Including 3D visualization and allowing import from IFC-compliant architect software + Stand-alone result viewing application - Engineering background needed to analyze calculation results.
Simien	Norway	Simien is a dynamic building simulation program for calculating the annual energy, power demand and indoor climate in buildings.	+ Results are compared against the requirements in the Norwegian Building Code -Only Oslo-climate data used -No output for temperatures

As has been pointed out, each of the calculation tools described above could be used for the calculation of the energy performance of existing buildings. However, not all programs can be used for calculations of the thermal indoor environment, daylight conditions etc. Additional stand-alone calculation tools can be used if these calculations are of importance. Some of the calculation tools described above include modules to calculate U-values and heat loss transmissions. This is a big advantage since with the other calculation tools, those calculations need to be made by the user in advance.

In order to choose a particular program for calculations, matters discussed above should be taken into account but one should also look if the program can be used from the very beginning of the renovation process since most important decisions regarding the energy usage are already made in that stage. Some of the calculation tools mentioned above require very detailed input data. Where this can be an advantage for experienced users, this is a disadvantage for inexperienced users and makes it hard to use the program early in the renovation process. Early in the renovation process, focus should mainly be on the differences between different renovation measures. Calculation tools requiring only little input in the beginning, and thus only giving an estimation of energy use, can perfectly be used in this stage of the renovation process. However, in order to obtain reliable results after renovation and to be able to be used throughout the whole renovation process, calculation tools should at the same time be flexible, allowing more detailed input depending on the information available through the renovation process.

6 ANALYSIS OF TECHNICAL RENOVATION CONCEPTS

Different technical energy renovation measures that can be applied in existing single-family houses on component level will be combined into technical renovation concepts which will be analysed according to step 2 in the general method for proposals on sustainable renovation concepts (step 2 is described in detail in chapter 5). The technical renovation concepts will be analysed for each of the typical single-family houses in the Nordic countries.

In order to analyse the technical renovation concepts, first of all an overview of the individual energy renovation measures that can be applied will be given. In this overview in part 7.1, technical energy renovation measures have been combined with the technical principles (minimized transmission losses etc.) into technical renovation concepts.

In part 7.2, energy savings for typical individual renovation measures are stated. Also, an example of cost analysis of energy efficiency measures in connection with renovation is included.

In part 7.3, the effect of the application of the technical renovation concepts on the typical single-family houses will be investigated in different renovation scenarios, using the simple calculation tool WinDesign.

6.1 Overview of technical renovation concepts

6.1.1 Minimized transmission and infiltration heat losses

- Internal insulation of exterior walls
- Exterior insulation of exterior walls
- Insulation of cavity walls
- Insulation of thermal bridges, especially foundations
- New energy efficient glazing
- New energy efficient windows and doors
- New removable (secondary) windows
- Insulation of slab on ground construction (inside, outside or cavity)
- Insulation of roofs (flat roof, loft, sloped walls, under roof slope, dormers)
- Insulation of crawl spaces (cold or warm) or conversion to slab on ground construction
- Insulation of dividing floor to cold basement including lowering of basement temperature
- Insulation of basement (walls and floor)
- Air tightness measures (based on combined blower door test and thermography)

6.1.2 Minimized ventilation heat losses

- Ground pre-heating of ventilation, also cooling.
- Ventilation with heat recovery: natural, hybrid, mechanical
- Change to more efficient ventilation unit including more efficient fans/motors (if there is already mechanical ventilation)
- Utilization of “free” ventilation / night cooling

6.1.3 Passive solar energy

- New roof windows for better daylight conditions and solar heat gains, less use of artificial light etc.
- Sun pipes / light ducts for better daylight conditions and solar heat gains and less use of artificial light.

6.1.4 Utilization of internal and solar heat gains

- Utilization of thermal mass with conventional materials and PCM (phase change materials)

6.1.5 Heating system and hot water demand

- Change to low temperature heating, heaters
- Change to low temperature heating, floor heating (increases heat transmission losses but reduces heat losses from distribution pipe system and solar collectors. Added insulation to the ground and perimeter of the floor is needed. May improve the efficiency of heat pump or solar heating system).
- Insulation of heating pipes etc.
- Better (intelligent) control of water based heating and cooling systems, e.g. supplement thermostatic valves with control of supply temperature based on the actual weather.
- Water efficient tap ware (to reduce hot water use).

6.1.6 Sustainable sources of energy and efficient energy supply

- Biomass-based combined heat and power production system
- Change/insulation of district heating unit
- Change/insulation of boiler (gas, oil, wood pellet etc.)
- Change of circulating pump
- Solar heating for hot water
- Solar heating for hot water and space heating
- Photovoltaics (building integrated)
- Heat pumps (water/water, air/water, air/air)
- A possibility in the future: Micro CHP systems; hydrogen or natural gas (not renewable) based as alternative to individual boilers

6.1.7 Measures for overheating control

- Mechanical devices for solar shading
- Roof overhangs
- Solar control glazing

6.1.8 Appliances

- New A- labelled white goods or better
- More efficient lighting (fittings, light source, control and regulation equipment)
- More efficient IT equipment
- Change / more efficient other appliances
- Avoid use of electrically heated rails to dry towels
- Wash and dish machines that may directly use hot water produced efficiently by a heating system

6.2 Individual renovation measures

Since the typical houses identified for each country differ from each other regarding construction principle and age, the technical renovation measures that can be applied to these houses will differ.

Energy efficiency calculations for individual measures for each of the typical single-family houses in the Nordic countries have been made. These individual measures will be combined in different renovation scenarios and their combined effect on energy savings and indoor environment will be investigated in chapter 6.3.

An example of cost analysis of individual measures is also included below.

6.2.1 Denmark

The calculation of the stated annual primary energy use is explained in chapter 6.3.1.

Table 17. Annual primary energy use and saving (in kWh/m^2 per year) for typical technical renovation measures in a typical Danish standard detached house from the 1960/70's and old master builder house (-1930).

Technical renovation measure	Primary energy use	Savings
Existing old master builder house, 161 m^2 (heated by an oil boiler)		
Existing house	385	-
80mm insulation in cavity wall (U = 0.60 W/m2K)	331	53
Internal wall insulation, 95mm (U = 0.29 W/m2K)	290	95
External wall insulation, 95mm (U = 0.22 W/m2K)	283	102
75-200mm insulation in roof (U = 0.19 W/m2K)	343	41
70mm extra insulation in floor (U = 0.40 W/m2K)	322	63
Storm windows, 4 mm energy glass (Uw = 1.6 W/m2K)	363	22
Low-energy windows (U_w = 0.80 W/m^{2}K)	353	32
VHR, efficiency 80%, SFP 1 kJ/m3	361	24
VHR, efficiency 85%, SFP 0.6 kJ/m3	346	38
Replacement of existing circul. pump (60W) with low energy pump (25W)	380	5
Replacement of old oil fired boiler with new condensation oil boiler	252	132
Replacement of old oil fired boiler with a new heat pump, COP 3.6	177	207
Existing standard detached house, 155 m^2 (heated by a gas boiler)		
Existing house	246	-
External wall insulation, 100-150mm (U = 0.19 W/m2K)	225	20
External wall insulation, 200-250 mm (U = 0.13 W/m2K)	222	24
345 mm insulation in roof (U = 0.10 W/m2K)	230	16
150 mm extra insulation in floor (U = 0.15 W/m2K)	232	14
New low energy glazing/windows (Ug = 0.52/1.16 W/m²K)	200	46
VHR, efficiency 85%, SFP: 0.6 kJ/m3, air infiltration rate: 0.13 h^{-1}	196	49
Replacement of existing circul. pump (60W) with low energy pump (25W)	231	15
Replacement of existing gas boiler with new condensing gas boiler	218	27
Solar panels for domestic hot water	240	5

Since old master builder houses in Denmark normally use oil-fired boilers for heating, these houses are not connected to any gas or district heating network. Instead of replacing the old oil-fired boilers with new condensation boilers, a heat pump could be installed. As can be seen from Table 15, an extra reduction of 75 kWh/m^2 per year can be obtained when installing a heat pump instead of replacing the old oil-fired boilers with new condensation boilers. However, the investment in the installation of a heat pump is twice the investment in a replacement of the old boiler with a new one with better efficiency.

6.2.2 Sweden

Table 18. Annual primary energy use and saving (kWh/m^2 per year) for typical technical renovation measures in a typical Swedish detached single-family house.

Technical renovation measure	Primary energy use	Energy savings	Primary energy use	Energy savings	Primary energy use	Energy savings
	Kiruna		Ostersund		Stockholm	
Existing house with resistance heaters	581	-	413	-	328	-
External “basement” wall insul, 100mm (U=0.32 W/m2K)	552	29	391	22	310	18
Extra external wall insulation, 200mm (U = 0.18 W/m2K)	497	83	350	63	278	50
200mm insulation added to roof (U = 0.11 W/m2K)	552	28	392	22	311	17
Insulation in floor (U = 0.27 W/m2K)	543	38	384	29	305	23
200mm extra insulation in floor (U = 0.15 W/m2K)	519	62	366	47	290	37
Low-energy windows (U = 0.8 W/m^{2}K)	491	90	347	66	276	52
VHR, efficiency 70%, SFP 1 kJ/m3, infilt.rate: 0.10 h^{-1}	444	137	313	100	252	76
VHR, efficiency 85%, SFP 1 kJ/m3, infilt.rate: 0.10 h^{-1}	404	176	282	131	226	102
Replacement of electric heaters with heat pump, COP 3.3	170	411	121	292	96	232
VHR, effic. 85%, SFP: 1 kJ/m3, infilt.rate: 0.10 h^{-1} (heat supply: heat pump)	125	45	89	32	72	24
VHR, effic. 85%, SFP 1 kJ/m3, infilt.rate: 0.20 h^{-1} (heat supply: heat pump)	136	34	98	23	80	16

In Swedish standard detached single-family houses built during 1970-80 electric heating is mostly used. The houses are thus not connected to any gas or district heating network, when a replacement of the electric heaters is needed, heat pumps are widely installed. The replacement of the electric heaters with a heat pump reduces the primary energy use by as much as 411 kWh/m^2 in Kiruna or about 70% (the same for the other locations).

When the existing house uses electrical heaters for heating, the installation of a VHR with efficiency 85% reduces the primary energy use with 176 kWh/m^2 in Kiruna. However, usually when an efficient heat supply system is in place (in this case the heat pump), the reduction in primary energy use by installation of VHR is smaller. Having a heat pump based heat supply system instead of electrical resistance heaters the primary energy use is reduced with only 45 kWh/m^2 in Kiruna. If the air tightness of the building envelope has not been improved and is twice as leaky (0.20 instead of 0.10 h^{-1}), the reduction of primary energy use is even smaller, 34 kWh/m^2.

6.2.3 Norway

Table 19. Annual primary energy use and saving (kWh/m^2 per year) for typical technical renovation measures in a typical Norwegian pre-war detached single-family house and a house from 1970's.

Technical renovation measure	Primary energy use	Energy Savings
Single-family house -1945, 124 m^2 (electric heating)		
Existing building	398	-
External wall insulation (U = 0.25 W/m2K)	323	76
Extra external wall insulation (U = 0.2 W/m2K)	311	87
Extra roof insulation (U = 0.2 W/m2K)	380	19
Extra roof insulation (U = 0.15 W/m2K)	376	23
Extra floor insulation (U = 0.2 W/m2K)	367	32
New windows (Uw = 1.6 W/m2K)	375	24
Low-energy windows (U_w = 1.2 W/m^{2}K)	365	34
Low-energy windows (U_w = 1 W/m^{2}K)	356	43
VHR, efficiency 70%, SFP 1 kJ/m3	312	86
VHR, efficiency 85%, SFP1 kJ/m3	293	106
Replacement of electric heaters with heat pump, COP 3	133	266
Single-family house 1971-1980, 137 m^2 (electric heating)		
Existing building	312	-
External wall insulation (U = 0.22 W/m2K)	286	26
Extra external wall insulation (U = 0.18 W/m2K)	281	31
Extra roof insulation (U = 0.15 W/m2K)	301	11
Extra floor insulation (U = 0.2 W/m2K)	278	34
New windows (Uw = 1.6 W/m2K)	298	14
Low-energy windows (U_w = 1.2 W/m^{2}K)	293	19
Low-energy windows (U_w = 1 W/m^{2}K)	284	28
VHR, efficiency 70%, SFP 1 kJ/m3	243	69
VHR, efficiency 85%, SFP1 kJ/m3	227	85
Replacement of electric heaters with heat pump, COP 3	104	208

As for Swedish standard detached single-family houses, most Norwegian standard detached single-family houses use electric heating. The houses are thus not connected to any gas or district heating network, when a replacement of the electric heaters is needed. Heat pumps are widely installed. The replacement of the electric heaters with a heat pump reduces the primary energy use by, respectively, 266 kWh/m^2 and 208 kWh/m^2 for a pre-war detached single-family house and a house from the 1970´s. This corresponds to a 67% reduction in primary energy use for both types of houses.

6.2.4 Finland

Table 20. Annual primary energy use and saving (kWh/m^2 per year) for typical technical renovation measures in a typical Finnish so-called veteran houses, single-family house from the 1960's and house from the 1970's.

Technical renovation measure	Primary energy use	Energy Savings
Veteran house 1940-1960, 70 m^2 (heated by an oil boiler)	395	-
External wall insulation (U = 0.24 W/m2K)	329	65
Extra external wall insulation (U = 0.17 W/m2K)	320	74
Extra roof insulation (U = 0.15 W/m2K)	366	29
Extra roof insulation (U = 0.09 W/m2K)	360	34
Extra floor insulation (U = 0.16 W/m2K)	367	28
new windows (Uw = 1.4 W/m2K)	358	36
low-energy windows (U_w = 0.8W/m^{2}K)	351	44
VHR, efficiency 60%, SFP 1 kJ/m3	369	25
VHR, efficiency 85%, SFP1 kJ/m3	350	45
Replacement of oil fired boiler with heat pump, COP 3	335	60
Replacem. of existing circul. pump (60W) with low energy pump (25W)	381	14
Single family house 1960´s, 147 m^2 (heated by an oil boiler)	275	-
External wall insulation (U = 0.25 W/m2K)	257	18
Extra external wall insulation (U = 0.17 W/m2K)	250	25
Extra roof insulation (U = 0.16 W/m2K)	251	24
Extra roof insulation (U = 0.09 W/m2K)	241	34
Extra floor insulation (U = 0.2 W/m2K)	253	22
Extra floor insulation (U = 0.16 W/m2K)	249	26
new windows (Uw = 1.4 W/m2K)	237	38
low-energy windows (U_w = 0.8W/m^{2}K)	230	45
VHR, efficiency 60%, SFP 1 kJ/m3	262	13
VHR, efficiency 85%, SFP1 kJ/m3	248	27
Replacement of old oil fired boiler with heat pump, COP 3	232	43
Replacem. of existing circul. pump (60W) with low energy pump (25W)	268	7
Single family house 1970´s, 100 m^2 (electric heating)	526	-
External wall insulation (U = 0.24 W/m2K)	518	8
Extra external wall insulation (U = 0.17 W/m2K)	501	25
Extra roof insulation (U = 0.15 W/m2K)	481	45
Extra roof insulation (U = 0.09 W/m2K)	461	65
Extra floor insulation (U = 0.19 W/m2K)	522	4
Extra floor insulation (U = 0.16 W/m2K)	517	9
New windows (Uw = 1.4 W/m2K)	490	36
Low-energy windows (U_w = 0.8W/m^{2}K)	477	49
VHR, efficiency 60%, SFP 1 kJ/m3	447	79
VHR, efficiency 85%, SFP1 kJ/m3	406	120
Replacement of electric heaters with heat pump, COP 3	184	342
Replacem. of existing circul. pump (60W) with low energy pump (25W)	516	10

Finish standard detached single-family houses built before 1970 are usually heated by use of an oil-fired boiler, whereas houses built from 1970 on use electric heating. Table 20 shows that replacement of electrical heating with a heat pump saves more energy (reduction of 65% in primary energy use) than replacement of the oil-fired boilers with a heat pump (reduction of 15% in primary energy use). In Finnish standard detached single-family houses built before

1970, a replacement of the oil-fired boilers with a new condensation boiler could instead be considered.

6.2.5 Cost analysis

Information about the costs of the above mentioned typical individual energy renovation measures would be interesting. But the main point is to illustrate how cost analysis can be carried out. Therefore only some examples of cost analysis will be shown in the report.

Focus will be on the Cost of Conserved Energy (CCE) method for economically optimised design of renovation of existing buildings and new buildings. A measure is considered economically efficient if the CCE is lower than the price of primary energy from the energy supply system. The method is described and discussed in detail in section 5.5.

In the calculation of Investment cost or additional cost of an energy-conserving measure ($I_{measure}$ in Equation 1) it could be relevant to operate with an energy renovation factor to take into account not only the sole benefit of energy saving but also the e.g. the rehabilitation of building envelope condition which is much related with the overall durability and the value of the house.

Building envelop energy efficiency measures are often implemented not from energy cost savings point of view, but because the building components need renovation; e.g. improved wall insulation along with façade renovation and energy efficient windows to replace existing old windows. The energy renovation factor states the share of the renovation work or investment that could be ascribed to the energy efficient measures. A factor of 1 indicates that the measure is only implemented in order to achieve energy cost savings. An example of calculating the factor is replacement of worn-out windows by windows that have better energy performance than normal energy windows as required e.g. by the building code and therefore is 20 % more expensive. In this case the energy renovation factor is only 0.2.

The evaluation of the energy renovation factor must be done for each measure by the homeowner and is highly a question of opinion and therefore hard to determine exactly.

Example of cost analysis

The case house is the Danish standard detached single-family house from 1960/70's with a heated floor area of 155 m^2. The heat supply system is based on a gas-fired burner with an average yearly efficiency of 85%.

Renovation needs/wishes of the homeowner:

- Façade renovation with new brickwork mortar joints
- Replacement of worn-out windows/punctured glazing and
- Better thermal comfort and indoor air quality

Proposed energy efficiency measures (energy renovation factor in brackets):

- External wall insulation including foundations (50%). The total cost of external wall insulation is reduced by the cost for needed brickwork renovation work (50% of total).
- Extra roof insulation (100%). Extra roof insulation is only carried out to achieve energy cost savings
- Windows with triple low-energy glazing (20%). Such windows are about 20% more expensive than standard windows with double low-energy glazing as required by the building code.

- Implementation of a mechanical ventilation system with heat recovery, VHR (75%) - the homeowner is willing to invest 25% of the total cost of VHR in air quality improvements (window valves, exhaust fans etc.).

The energy savings are calculated one by one with the existing house as a reference. The case house has a fairly energy efficient heat supply system. If that was not the case, by implementing an efficient heat supply system prior to building envelope energy efficient measures and VHR, the energy and cost efficiency of these measures will be smaller, resulting in lower energy savings and higher CCE.

Results of the CCE calculation for different energy efficiency measures are shown in Table 21.

Table 21. Cost of Conserved Energy (CCE) for some energy efficiency measures in a typical Danish single-family house. CCE is calculated based on a reference period n_r = 30 years, a discount rate d = 2.5 % p.a, primary energy factor for conserved energy of 1 and a factor of 2.5 for consumed energy (only relevant for VHR)

Energy efficiency measure	$I_{total,}$ incl VAT	$I_{total,}$ incl VAT	Energy renovation factor	$I_{measure}$	ΔM_{year}	n_u	ΔE_{year}	$\Delta E_{operation, year}$	CCE
	EUR/m^2	EUR	-	EUR	EUR/a	Years	kWh/m^2/a	kWh/m^2/a	EUR/kWh
External wall insulation[1]	200	21,560	0.50	10,780	0	40	24	0	0.10
Extra roof insulation[2]	65	5,909	1.00	5,909	0	40	16	0	0.09
Better low-energy windows[3]	400	17,280	0.20	3,456	0	30	11	0	0.10
VHR[4]	50	7,750	0.75	5,813	50	30	31	2	0.08

[1] External wall insulation of 200-250 mm (U = 0.13 W/m2K)

[2] Extra roof insulation of 345 mm (U = 0.10 W/m2K)

[3] Replacement of existing windows with new windows with triple low-energy glazing instead of standard windows with double low-energy glazing.

[4] Mechanical ventilation with heat recovery; 0.5 h^{-1} (air change per hour), 85% heat recovery, electricity use (SFP): 0.6 kJ/m^3 and air-infiltration of 0.13 h^{-1}

The calculated CCE for energy efficiency measures in connection with renovation is in the range of 0.08 to 0.10 EUR/kWh. The CCE may be compared with the current price of energy or an expected higher average price during the reference period. In this example the CCE is compared with the current energy price of gas in Denmark which is roughly 0.10 EUR/kWh. Calculations show that all measures actually are economically efficient to implement (CCE < energy price). Assumptions regarding useful lifetime and energy price may be determined conservatively and the cost analysis then be regarded as on the safe side.

There are major non-energy benefits of the measures that should be taken into account, e.g. thermal comfort improvements due to insulation of the building envelope and ventilation system. The overall conclusion is that a package solution consisting of the investigated individual energy efficiency measures seems to be attractive for the homeowner.

6.3 Renovation scenarios

In order to coherently analyze the renovation of the different types of single-family houses, five scenarios have been defined in which different technical renovation concepts will be investigated. These concepts consist of a combination of the individual technical energy renovation measures investigated previous.

Scenario 1: Existing house

This scenario consists of a simulation of the existing house.

Scenario 2: Easy-to-carry-out insulation measures etc.

Since the Nordic countries have a heating dominated climate, it is especially important to reduce heat losses during the heating season. Accordingly, easy-to-carry-out renovation measures, such as replacing or renovating existing windows, adding insulation and improving the air tightness, to reduce the heat losses will be applied to the different typical houses.

Scenario 3: Scenario 2 + efficient heat supply system

Improvements to the heat supply system will be investigated to ensure a low energy use, e.g. change of the heating system to a system based on low temperature heating, change of a boiler or circulation pump and change from oil-boiler/electric heating to a more energy efficient heat supply system such as heat pump or district heating.

Scenario 4: More extensive renovation measures incl. sustainable sources of energy and ventilation system

To ensure a good indoor environment, improvements to ventilation system will be investigated, such as the installation of a ventilation system with heat recovery (VHR). Depending on the type of house and its age, it could be useful in this scenario to compare different solutions with each other. A cheaper standard solution can then be compared with a more advanced or state-of-the-art solution.

In Denmark, the typical single-family houses usually have a quite energy efficient heat supply system as they are connected to a gas or district heating network. Hence, scenario 3 for Danish typical single-family houses already includes the use of a mechanical ventilation with heat recovery (VHR) to ensure a good indoor environment. In scenario 4 for typical Danish single-family houses, the effect of more extensive renovation solutions, such as low-energy windows and use of solar heating on the houses will then be evaluated.

Scenario 5: Extensive measures

The effect of extensive measures that change the appearance of the house (can be inconvenient or not wanted by the building owner) or are far reaching (state-of-the-art), but allow a large reduction in the energy use, will be analysed.

In general, the measures applied in the different scenarios and the resulting energy use etc can be seen in Appendix 3 and Appendix 4, respectively.

6.3.1 Calculation of energy and indoor environment performance

To investigate the scenarios and the technical renovation concepts to be applied to the different typical single-family houses, the calculation tool WinDesign is used. WinDesign allows for an easy comparison of different scenarios in one simulation.

In general, calculations in WinDesign are made with an room temperature of 20°C, internal heat gain (people and household electricity) of 5 W per m^2 gross heated floor area and air change rate per hour of 0.5 h^{-1} for both natural and mechnical ventilation. The setpoint for venting has been 23°C with a rate of 1,5 h^{-1} which is a typical average value for manual controlled windows in dwellings during warm summer periods.

The weather data required for calculations in WinDesign consists of hourly values for external temperature (°C), direct normal solar radiation (W/m^2), horizontal diffuse solar irradiation (W/m^2), and global horizontal solar illuminance (lx). Standard weather data can be found in the IWEC weather data format [24]. However, for Denmark, calculations are performed by using weather data for the Danish Reference Year.

Lighting will not be changed. However, changing glazing properties will influence the electricity use for lighting. Lighting is kept the same throughout the scenarios since an improvement of the lighting is a renovation measure that can be easily applied separately from other renovation measures. Moreover, an improvement of the lighting can be done at any time and is usually a very cost-effective measure to reduce the electricity use.

The results presented for each scenario and house are listed and explained below:

- Annual energy need for space heating: Heat to be delivered to maintain the intended temperature conditions during a year
- Length of heating season and hours of overheating (>26°C)

Total hours of overheating and the length of the heating season is also shown. According to EN13790 [26], heating season for a specific dwelling in WinDesign is defined as all days for which the heat gains, calculated with a conventional utilization factor, $\eta_{gn,1}$, do not balance the heat transfer. The cooling season includes all days for which the heat transfer, calculated with a conventional utilization factor, $\eta_{ls,1}$, does not balance the heat gains. Days where no heating or cooling is needed are indicated as non-heating or non-cooling days and may overlap with days that need heating or cooling. As such, the sum of heating season and cooling season might not add up to 365 days or might exceed this number. However, all hours of overheating occur during the cooling season.

- Non-utilized heat losses
- Contribution from solar heating
- Annual energy need for heating: Energy need for space heating incl. hot water and non-utilized heat losses from heating pipes etc.
- Annual efficiency of the heat supply system (-)
- Annual energy use for heating: Energy input to satisfy the energy need for heating
- Electricity use for heating and ventilation. It is assumed that there is no active cooling.
- Annual primary energy use: Energy used to produce the energy delivered to the house (excluding household appliances and lighting) and calculated using primary energy factors for conserved and consumed energy. For Denmark a primary energy factors of 2.5 for electricity use and 1 for use of oil, natural gas and district heating are applied [27]. For Sweden, Norway and Finland the corresponding factors used are 2.65 [32], 2.5 [35] and 3.0 [36]. The passive house standard uses a primary energy factor for electricity of 2.7.

The energy performance is compared to relevant references in different countries, e.g. building code or energy rating classes. Building regulations and passive house standard are presented in Appendix 1.

Generally, energy renovation is most likely to have a very positive impact on the indoor environment. Thermal comfort will be improved by insulation and air-tightness measures that will increase surface temperatures and reduce draught from e.g. badly insulated windows. Windows with low-energy glazing can be used in the full room height (without need of a heat source below) and will result in a much better utilization of living space area close to the windows. A ventilation system with heat recovery will assure excellent air quality and draught-free supply of fresh air. As mentioned, the negative impact on thermal comfort of energy renovation measures is calculated using the hours of overheating as an indicator. Overheating can be avoided and in this report the effect of more venting and/or moveable external solar shading have been investigated.

6.3.2 Cost analysis

The Cost of Conserved Energy (CCE) method is used for the analysis of the different scenarios.

6.4 Renovation scenarios - Denmark

6.4.1 Master builder house (-1930)

Master builder houses typically have a facade worth preserving. Combined with the fact that they in many cases have non-insulated cavity walls, an old boiler and no ventilation system installed, this will influence the definition of the different renovation scenarios previously described.

Scenario 1:

Existing house.

Scenario 2:

- Cavity walls insulation, injection in roughly 80 mm cavity (λ = 0.044W/mK) and insulation of walls under windows/radiator recesses (75 mm) (λ = 0.037 W/mK)
- Vertical and horizontal insulation of space under the roof slope (250-300 mm), insulation of sloped walls (75 mm) and insulation in loft (300 mm) (λ = 0.037 W/mK)
- Renovation of windows and new air-tight secondary window frames with one layer of energy-saving glass (U = 1,6 W/m^2K)

Scenario 3:

- Replacement of the old oil-fired boiler with a new oil-fired condensation boiler + installation of thinner iron cast heaters under windows + new thermostatic valves + pump + change to low temperature heating (55/40°C).
- Installation of a mechanical ventilation system with heat recovery (VHR). Two cases of systems has been investigated: Heat recovery efficiency of 80/85%, infiltration rate of 0.18/0.13 h^{-1} and SFP factor of 1.0/0.6 kJ/m^3.

Scenario 4:

- Internal insulation of exterior walls (95 mm, λ = 0.037 W/mK). The effect of cavity wall insulation is limited due to considerable thermal bridges from massive brick ties at window sill and corners and sometimes also in the wall. However, when applying internal insulation, internal wall and horizontal floor divisions constitute thermal bridges, and careful and good workmanship is required to avoid moisture problems.
- Replacement of windows with new low-energy windows (U_w = 0.80 W/m^{2}K).
- Insulation of the floor towards the basement (70 mm, λ = 0.044 W/mK)

Scenario 5:

- External insulation of exterior walls (95 mm, λ= 0.037 W/mK). This measures influences the image of the house and might cause architectural problems. Adding external insulation in case of old master builder houses requires an additional adaptation of the roof causing a rise in construction costs.

The scenarios are summarized in Table 22. The specification of Do (=ditto) means the same as the previous value.

Table 22. Renovation measures applied for the different scenarios

Scenario	**1**	**2**	**3**	**4**	**5**[2)]
Building envelope					
U-value walls[1)]	1.26	0.60	Do	0.29	0.22
U-value roof	0.61	0.19	Do	0.19	do
U-value floor	1.12	1.12	Do	0.40	do
Total UA-value	318	198	Do	87	79
U-value window	3.27	1.60	Do	0.80	do
Ventilation system	Natural	do	VHR	do	do
Heat supply system	Old boiler (oil)	do	New condensation Boiler (oil) or heat pump	do	do

1) Includes linear heat losses through thermal bridges

2) The U-values in this scenario are higher than the U-values required for major renovation since master builder houses have a facade worth preserving and are therefore exempt from these requirements

Energy performance

Table 23 shows the results of the calculations for the old Danish master builder house.

Table 23. Energy performance of the different renovation scenarios (kWh/m^2 per year)

Scenario	**1**	**2**	**3a**	**3b**	**3c[1]**	**4**	**5**
Energy need for space heating	**209**	**130**	**110**	**104**	**104**	**37**	**33**
Length heating season	365	365	328	318	318	256	240
Hours of overheating (>26°C)	0	0	0	0	0	24	6
Hot water use	13	13	13	13	13	13	13
Non-utilized heat losses	23	23	21	20	20	25	21
Contribution solar heating	-	-	-	-	-	-	-
Energy need for heating	**246**	**167**	**144**	**137**	**137**	**75**	**68**
Efficiency of heat supply system (-)	0.65	0.65	1.0	1.0	3.6	1.0	1.0
Energy use for heating	**378**	**257**	**144**	**137**	**38**	**75**	**68**
Electric. use for heating and ventilation	3	3	4	2	2.1	2	2
Primary energy use	**385**	**263**	**154**	**142**	**100**	**80**	**73**

[1] Instead of replacing the old oil-fired boilers with new condensation boilers, a ground heat pump (COP 3,6) could be installed since these houses are not connected to any gas or district heating network. The installation of a heat pump is, however, only used in this scenario.

The energy need for space heating can be reduced from 209 to 130 kWh/m^2 through the mentioned easy-to-carry-out building envelope energy efficiency measures in Scenario 2, corresponding to a 38% reduction.

Installation of a VHR system (scenario 3) after building envelope measures reduce the energy need for space heating further from 130 to 110 kWh/m^2 and 104 kWh/m^2 for respectively VHR with an efficiency of 80% and 85%, equivalent to a reduction of 47% and 51%. However, installing VHR results in an increase in electricity use for ventilation and depends on the air tightness of the house (air infiltration), which will influence the energy use. The combined installation of a new more efficient heat supply system (new condensation boiler) and a VHR system in scenario 3a and 3b reduces energy use for heating from 257 to respectively 144 kWh/m^2 and 137 kWh/m^2. Replacing the existing heat supply system with a ground heat pump instead of a new condensation boiler (scenario 3c) will influence the primary energy use.

Applying extra inside and outside insulation of to the external walls, adding extra insulation to the floor and applying low-energy windows in respectively scenario 4 and 5 results in a reduction of the need for space heating with respectively 82% and 84%. The energy use for heating is reduced with 32%, 62% and 64% for respectively renovation scenario 2, scenario 3a and scenario 3b. The large difference with the reduction of the energy need for space heating (38%, 47% and 51% for respectively scenario 2, scenario 3a and scenario 3b) is due to the great improvement in yearly efficiency of the heat supply system due to the replacement of the old oil fired boiler with a new condensing boiler.

The primary energy use has been reduced with 32%, 60% and 63% for respectively renovation scenario 2, scenario 3a and scenario 3b. Using a heat pump in scenario 3c, the primary energy use has been reduced by 74%. In scenario 4 and 5, the reduction has been respectively 79% and 81%, resulting in a factor 6 renovation with an energy use close to the maximum energy use of a building in low energy class II according to the Danish Building Regulations BR 2008 [27].

With the analysed measures, the passive house level cannot be reached.

Thermal indoor environment

From Table 23 can be seen that generally, no problems with overheating occur in the building. However, adding extra insulation and low-energy windows in scenario 4 and 5 significantly reduces the length of the heating season in the building, which in turn results in some hours with overheating. These are, however, very small and largely within limits of the requirements. Using internal insulation for the insulation of the external walls in scenario 4 also results in a lower heat capacity of the house which results in more hours of overheating than for scenario 5.

Cost calculations

For the calculation of the cost-effectiveness of the different renovation scenarios by use of the cost of conserved energy in WinDesign, input data for the costs in scenario 2 has been used from the report: “Energy project Villa – Main Report” [29], input data for the other scenarios has been based on prices from V&S Prisbog 2008 [30]. The results are presented in Table 24 below. Since none of the renovation measures applied in scenario 1 (and the following scenarios) was needed for an improvement of the physical condition of the existing building, the total investment cost for each scenario equals the investment cost in energy efficient measures and only one case for the calculation of the cost of conserved energy is presented.

Table 24. Calculation of cost-effectiveness of the renovation scenarios, using CCE

Scenario	**1**	**2**	**3a**	**3b**	**4**	**5**
Annual primary energy savings (MWh)	0	18.7	36.0	39.0	50.3	51.2
Total investment cost (DKK x10^3)	0	107	182	187	278	258
Cost of conserved energy (DKK/kWh)	**Reference**	**0.29**	**0.26**	**0.24**	**0.28**	**0.26**

Given the fact that the building is heated by using an oil-fired boiler and that the current price for oil is estimated to be 0.90 DKK/kWh, all renovation scenarios turn out to be very cost-effective. From the results can also be concluded that it is even more cost-effective to improve the building envelope, install a new boiler and VHR at once (scenario 3) than only to improve the building envelope (scenario 2).

In Table 24, it can also be seen that the cost-effectiveness of applying extra external insulation to the walls (scenario 5) is comparable to the cost-effectiveness of the improvement of the building envelope and installation of the ventilation system (scenario 3a). It is, however, less cost-effective to apply extra internal insulation to the walls (scenario 4). This because they account for less energy savings than when applying extra external insulation in scenario 5 and the installation costs are more expensive than the installation costs for external insulation. Besides this, more overheating occurs when choosing to apply internal insulation in the building and the risk of structural damage is higher than when using external wall insulation.

6.4.2 Standard detached house (1960/70's)

Standard detached houses in Denmark from the period 1960-1980 can easily be typified as having large roof overhangs. Therefore, when renovating these houses, adding more external insulation to the facade is fairly easy to do.

Scenario 2

- External insulation of exterior walls including foundations (100-150 mm λ= 0.035-0.038W/mK)
- Added (external) insulation to the roof with a ceiling to the ridge (345 mm, λ= 0.034 W/mK)
- Replacement of small windows with normal energy efficient windows and replacement of the large glazing areas with triple glazing filled with krypton gas to obtain a low U-value with a narrow glazing unit for easy installation. Resulting in an average U-value for all windows of 1.34 W/m^{2}K.

Scenario 3

- Mechanical ventilation system with heat recovery (VHR) (same system properties as for the master builder house)
- Installation of a new high-efficiency condensing gas boiler (yearly efficiency 98%) and new thermostatic valves.
- Change to low temperatures in the heat supply system – possible due to the reduced space heating need.

Scenario 4

- Installation of solar panels (4 m^2) for domestic hot water.

Scenario 5

- Extra external wall insulation has been added compared to sc. 2 (+100 mm, λ= 0.037W/mK)
- Replacement of the slab on ground construction with integrated and badly insulated heat distribution pipes with a much better insulated new construction (150 mm, λ= 0.044W/mK)
- New low energy windows (U-value = 0.80 W/m^{2}K).

An overview of the properties for building envelope and services for the different scenarios can be seen in Table 25.

More details can be found in Appendix 3.

Table 25. Renovation measures applied for the different scenarios

Scenario	**1**	**2**	**3**	**4**	**5**
Building envelope					
U-value walls	0.53	0.19	Do	do	0.13
U-value roof	0.27	0.10	Do	do	do
U-value floor	0.36	0.36	Do	do	0.15
Total UA-value	181	106	Do	do	70
U-value window	2.80	1.34	Do	do	0.80
Ventilation system	Natural ventilation	do	VHR	do	do
Heat supply system	Gas boiler	do	New condensing gas boiler	Solar heating	do

Energy performance

Table 26 shows the results for the Danish standard detached single-family house erected in the period 1960-80. To calculate the primary energy use, primary energy factors of 2.5 for electricity use and 1 for use of oil, natural gas and district heating are applied [27].

Table 26. Energy performance of the different renovation scenarios (kWh/m^2 per year)

Scenario	**1**	**2**	**3a**	**3b**	**4**	**5**
Energy need for space heating	**160**	**81**	**61**	**55**	**55**	**35**
Length heating season (days)	287	241	225	219	219	201
Hours of overheating (>26°C)	217	397	346	363	363	270
Hot water use	13	13	13	13	13	13
Non-utilized heat losses	30	31	29	29	30	16
Contribution solar heating	-	-	-	-	5	5
Energy need for heating	**203**	**125**	**104**	**97**	**92**	**58**
Efficiency of heat supply system (-)	0.85	0.85	0.98	0.98	0.98	0.98
Energy use for heating	**239**	**148**	**106**	**99**	**94**	**60**
Electric. use for heating and ventilation	2.7	2.7	3.7	2.1	2.4	2.4
Primary energy use	**246**	**154**	**115**	**104**	**100**	**66**

Energy need for heating can be reduced from 160 to 81 kWh/m^2 through the mentioned easy-to-carry-out building envelope energy efficiency measures in Scenario 2, corresponding to a 49% reduction. This large reduction is much due to the fact that it is easy to add more external insulation to the walls of this type house and therefore to reduce the building envelope heat loss significantly.

Assuming the installation of VHR in scenario 3 (and a new more energy efficient condensing gas-boiler), the energy need for space heating is reduced further from 81 to 61 kWh/m^2 and 55 kWh/m^2 for respectively a “standard” VHR system and a state-of-the-art system, equivalent to a reduction of 62% and 66%. The installation of a VHR system will increase the electricity use but the new boiler will decrease the electricity use. The new boiler and state-of-the-art ventilation system with low electricity use (scenario 3b) results in an overall lower electricity use compared to scenario 2. The more efficient ventilation system (scenario 3b) results in primary energy savings of 11 kWh/m^2. Solar panels for domestic hot water production in scenario 4 do not reduce energy need for space heating but scenario 5 does result in a total reduction of the energy need for space heating demand of 78%. The use of solar heating in scenario 4 (and scenario 5) does not have influence on the reduction of the space heating need but has, however, influence on the reduction of the energy need/use for heating. Adding extra insulation to the floor in scenario 5 does also not influence the space heating need. However, by adding extra insulation to the floor, the heating pipes in the existing building can be moved inside the house and their non-utilized heat losses can be reduced, which will influence the energy use.

The energy use for heating is reduced with 38%, 56% and 59% for respectively renovation scenario 2, scenario 3a and scenario 3b. Solar heating in scenario 4 reduces the energy use for heating with 61%. This reduction in scenario 4 is quite limited in comparison to the reduction obtained in scenario 3a and 3b. Moreover, the use of solar heating requires the installation of an extra circulation pump, which increases the energy use for electricity.

The primary energy use has been reduced with 37%, 53% and 58% for respectively renovation scenario 2, scenario 3a and scenario 3b. In scenario 4 and 5 the reduction is respectively 59% and 73%. Using extensive renovation measures in scenario 5 results in an almost factor 4 renovation with an energy use close to the maximum energy use of a building in low energy class II.

Looking at the results from the calculation in Table 26, the non-utilized heat losses in scenario 5 have been reduced to almost half of their original value by adding extra insulation to the floor. In general, due to the particular structure and position of pipes in the typical Danish single-family houses from the 1960´s – 1970´s, these non-utilized heat losses contribute for a large part to the energy use. In new buildings, these non-utilized heat losses can easily be reduced from the beginning.

Thermal indoor environment

Table 26 shows that there are problems with overheating. Comparing with requirements for a class II indoor environment in EN 15251 [19] (see part 5.4), only the existing building has a number of hours with overheating below the maximum allowed 259 hours with overheating.

Assuming a homeowner wants to have an indoor environment class I (i.e. heating setpoint at 21°C instead of 20°C and cooling setpoint at 25.5°C instead of 26°C, see part 5.4), the amount of hours with overheating increase but also the space heating demand increases, see Table 27.

Table 27. Length of cooling season and hours of overheating, evaluated according to class I indoor environment in EN15251.

Scenario	**1**	**2**	**3a**	**3b**	**4**	**5**
Energy need for space heating (kWh/m^2), 20°C	160	81	61	55	55	35
Hours of overheating (>26°C)	217	397	346	363	363	270
Energy need for space heating (kWh/m^2), 21°C	175	90	68	60	60	39
Hours of overheating (>25.5°C)	287	500	441	454	454	365

In Denmark, other requirements regarding thermal indoor environment are stated in DS 474 [31]. The standard states that in periods where the outdoor temperature or other conditions are extreme and exceed the design assumptions (winter temperature between 20-24ºC and summer between 23-26ºC, similar to requirements in EN15251), it can be allowed that the requirements for thermal indoor climate are exceeded. As such, it is indicated in the standard that on warm days, the operative temperature cannot exceed 26ºC for more than 100 hours and 27ºC for more than 25 hours during a typical year. In Table 28, the number of hours with overheating above 26ºC and 27ºC are presented.

Table 28. Hours of overheating evaluated according to EN15251 and DS 474.

Scenario	**1**	**2**	**3a**	**3b**	**4**	**5**
Hours of overheating (>26°C)	217	397	346	363	363	270
Hours of overheating (>27°C)	132	250	212	221	221	163

Comparing the number of hours with overheating from Table 28 with the requirements in DS 474, none of the scenarios fulfils the requirements. However, the amount of hours with overheating in scenario 5 is noticeable lower than for scenarios 2 to 4. This is mainly due to the application of new low energy windows in this scenario. The low energy windows have a lower g-value and lower as such the amount of heat gain through the total building envelope, which in turn reduces the risk of overheating.

Results for simulations using a higher venting rate of $3h^{-1}$ for automatically controlled windows with a larger opening area, a good external solar shading with a shading factor of 0.3 (movable, controlled by solar irradiation >300W/m^2) and a combination of both can be seen in comparison with the reference for the different scenarios (i.e. venting rate of $1.5h^{-1}$ for manually controlled windows and no external shading) for different evaluation temperatures in Table 29.

Table 29. Hours of overheating when using higher venting rate, external solar shading and a combination, evaluated according to EN15251 and DS 474.

Scenario		**1**	**2**	**3a**	**3b**	**4**	**5**
Evaluation temperature	**Measure**						
25,5 °C (class I)	Reference[1]	287	500	441	454	454	365
	Venting 3h-1	158	199	190	195	195	138
	External shading	84	157	136	139	139	108
	Venting and shading	57	71	68	69	69	46
26 °C (class II and DS 474)	Reference	217	397	346	363	363	270
	Venting 3h-1	110	155	144	148	148	93
	External shading	58	104	86	90	90	68
	Venting and shading	34	39	39	40	40	30
27 °C (DS 474)	Reference	132	250	212	221	221	163
	Venting 3h-1	63	80	76	76	76	50
	External shading	18	41	35	37	37	19
	Venting and shading	14	14	13	13	13	9

[1] Venting rate of $1.5h^{-1}$ and no external shading

From Table 29 it can be seen that the effect of using good external solar shading or the combination of a good external solar shading and a higher venting rate reduces the number of hours with overheating a lot. Using a higher venting rate alone has a smaller effect but the space heating demand remains unchanged. However, using the external solar shading is not only more expensive, but also increases the space heating demand.

Considering the requirements in EN15251 as an evaluation criterion (maximum 259 hours of overheating), both a class II and class I thermal indoor environment can be obtained, even when only increasing the venting rate. Requirements in DS 474 are only met for the case house when combining an increased venting rate and a good external solar shading.

Cost calculations

For the calculation of the cost-effectiveness of the different renovation scenarios by use of the cost of conserved energy (CCE) in WinDesign, input data for the costs in scenario 2 and 3 is taken from Tommerup [32]. Input data for scenario 4 and 5 has been used from V&S Prisbog 2008 [30]. The results are presented in the Table 30. In contrast to the CCE calculation for the master builder house, two different cost calculations are needed for the standard detached house. The windows of the existing house need a replacement and work has also been done to bathroom and kitchen. Accordingly, these costs are not taken into account as investment cost in energy efficient measures.

Table 30. Calculation of cost-effectiveness of the renovation scenarios, using CCE

Scenario	**1**	**2**	**3a**	**3b**	**4**	**5**
Annual primary energy savings (MWh)	0	14.1	20.2	21.9	22.5	27.8
Total investment cost (DKK x10^3)	0	672	747	752	784	900
Total CCE (DKK/kWh)	**Ref.**	**2.43**	**1.89**	**1.75**	**1.78**	**1.65**
Cost of energy efficiency measures (DKK x10^3)	0	200	275	280	307	391
CCE energy efficient measures (DKK/kWh)	**Ref.**	**0.72**	**0.70**	**0.65**	**0.70**	**0.72**

Note: The cost of energy efficient measures is calculated as the total cost deducted by cost for needed renovation work. The difference between "Total CCE" and "CCE energy efficient measures" is related to whether the total investment or "reduced" investment cost is used.

Given the fact that the building is heated by a gas boiler and that the current price for gas is roughly 0.8 DKK/kWh, previous table shows that from calculation of the total cost of conserved energy, it is better not to renovate the house. However, when calculating the cost of conserved energy based on the investment cost in energy efficient measures, all scenarios are cost-effective to apply and the effect of the two-fold benefit of renovation when only taking into account these investment costs in energy efficient measures is clearly reflected in the results.

6.5 Renovation scenarios - Sweden

6.5.1 Detached house (1961-1976)

Like standard detached houses in Denmark during the 60's and 70's, typical detached houses in Sweden during this period also have large roof overhangs and make it easy to apply external insulation during renovation activities. Most of these houses also have part of their ground floor underground and are considered as a basement. These "basement" walls usually need more insulation.

Scenario 2

- Added roof insulation, ceiling to the ridge (200 mm, λ= 0,042W/mK)
- Since, the drainage system needed renovation, external insulation has been added to the "basement" walls (100 mm, λ= 0,039W/mK).
- New low-energy wooden-framed windows with triple glazing (U = 0,80 W/m^{2}K)

Scenario 3

- Installation of water-heated radiator system and installation of a water to water ground heat pump (COP= 3.3) to replace electric resistance heaters. This type of heat pumps are widely installed in Sweden and will reduce primary energy use and total heating cost significantly.

Scenario 4

- Installation of a mechanical ventilation system with heat recovery (VHR) working partial time - both the case of a heat recovery system with an efficiency of 70% according to the minimum Swedish requirements (Scenario 4a), and the case of a heat recovery system with an efficiency of 85% (Scenario 4b) have been investigated. An air-infiltration rate of 0.1 h^{-1} is used for both scenarios.

Scenario 5

- Improving external wall insulation is advisable when façade is renovated and insulation of the slab-on-ground is advisable when the drainage system or flooring is renovated. 200 mm extra external insulation (λ= 0,039W/mK) has been added to the walls and to the slab-on-ground floor in order to comply with the new building requirements.

Connection to a CHP-based district heating system could be an option or the homeowner could already be connected. In such cases, the cost and energy efficiency of suggested energy efficiency measures is likely to be limited.

The renovation measures applied for the different scenarios are presented in Table 31.

Table 31. Renovation measures applied for the different scenarios

Scenario	**1**	**2**	**3**	**4**	**5**
Building envelope					
U-value walls	0.40	0.32	0.32	0.32	0.18
U-value roof	0.25	0.11	0.11	0.11	0.13
U-value floor	0.45	0.27	0.27	0.27	0.15
Total UA-value	165	113	113	113	71
U-value window	2.7	0.80	do	do	do
Ventilation system	Natural	do	do	VHR	do
Heat supply	Electric resistance heaters	do	Heat pump, COP 3.3	do	do

Energy performance

The results can be found in Table 32. The different measures in the five renovation scenarios have been tested with Stockholm weather data as well as using weather data for Östersund (Mid Sweden) and Kiruna (North Sweden). All other assumptions are the same as assumed for the Danish houses, except that the infiltration rate of 0.1 h^{-1} has been kept the same throughout all scenarios. More details can be found in Appendix 4.

Table 32. Energy performance of the different renovation scenarios for different locations in Sweden; Stockholm, Ostersund and Kiruna (kWh/m^2 per year)

Stockholm, Scenario	**1**	**2**	**3**	**4a**	**4b**	**5**
Energy need for space heating	**103**	**62**	**62**	**33**	**27**	**17**
Length heating season (days)	273	242	242	207	195	150
Hours of overheating (>26°C)	197	169	169	169	169	207
Hot water use	13	13	13	13	13	13
Non-utilized heat losses	4	4	4	4	4	4
Contribution solar heating	-	-	-	-	-	-
Energy need for heating	**120**	**79**	**79**	**50**	**44**	**31**
Efficiency of heat supply system (-)	1	1	3	3	3	3
Energy use for heating	**124**	**81**	**24**	**15**	**13**	**9**
Electric. use for heating and ventilation	0	0	0	3	3	3
Primary energy use	**328**	**216**	**63**	**47**	**42**	**32**
Ostersund, Scenario	**1**	**2**	**3**	**4a**	**4b**	**5**
Energy need for space heating	**135**	**83**	**83**	**46**	**39**	**22**
Length heating season (days)	340	302	246	246	234	168
Hours of overheating (>26°C)	108	93	93	93	94	120
Hot water use	13	13	13	13	13	13
Non-utilized heat losses	3	3	3	3	3	3
Contribution solar heating	-	-	-	-	-	-
Energy need for heating	**151**	**99**	**99**	**62**	**55**	**38**
Efficiency of heat supply system (-)	1	1	3	3	3	3
Energy use for heating	**156**	**102**	**30**	**19**	**17**	**12**
Electric. use for heating and ventilation	0	0	0	3	3	3
Primary energy use	**413**	**271**	**79**	**57**	**51**	**38**

Kiruna, Scenario	**1**	**2**	**3**	**4a**	**4b**	**5**
Energy need for space heating	**197**	**126**	**126**	**74**	**63**	**38**
Length heating season (days)	358	348	348	299	288	252
Hours of overheating (>26°C)	-	-	-	-	-	-
Hot water use	13	13	13	13	13	13
Non-utilized heat losses	3	3	3	3	3	3
Contribution solar heating	-	-	-	-	-	-
Energy need for heating	**213**	**142**	**142**	**90**	**79**	**54**
Efficiency of heat supply system (-)	1	1	3	3	3	3
Energy use for heating	**219**	**146**	**43**	**27**	**24**	**16**
Electric. use for heating and ventilation	0	0	0	3	3	3
Primary energy use	**581**	**388**	**114**	**79**	**70**	**50**

The results of the simulations show, that even in the North of Sweden, the energy need for space heating be reduced to a very low level and that the energy savings for each scenario are the largest for houses located in the north of Sweden. However, the reduction in the three locations is the largest for houses in the south of Sweden and corresponds to 36% (Kiruna)-40% (Stockholm) of the original space heating demand when adding insulation to the building envelope components in scenario 2.

Installation of a heat pump (scenario 3) prior to the installation of a VHR system (scenario 4) does not influence the energy need for space heating but influences the energy use for heating and the primary energy use. Using an average primary energy factor of 2.65 for the electricity use by electric heaters [32], the installation of a heat pump in scenario 3 reduces the primary energy use by about 80% (Kiruna-Stockholm). This already results in a primary energy use in all locations lower than the energy performance requirements for newly-built Swedish residential buildings.

Installation of a VHR system with an efficiency of 70% and 85% and adding extra insulation to the walls and floor, scenario 4a and 4b, reduces the primary energy use with respectively 86% (Kiruna)-86% (Stockholm) and 88% (Kiruna)-and 87% (Stockholm). The difference in reduce of primary energy use between the use of a VHR with an efficiency according to the minimum Swedish requirements and a more efficient VHR system is, however, rather small. As mentioned previously, the installation of a heat pump prior to a VHR system can decrease its effect on primary energy use reduction.

Furthermore, as can be seen in table 31, the installation of a VHR system and adding extra insulation to the walls and floor results in a decrease of the length of the heating season but at the expense of an increase of energy use for electricity due to the installation of a mechanical ventilation system with heat recovery and in a slight increase of hours of overheating by adding extra insulation to the walls and floor. Adding more insulation to the walls and floor in scenario 5 (extensive renovation measures), the hours with overheating increase further while the primary energy use has been reduced by 91% (Kiruna)-90% (Stockholm).

Thermal indoor environment

Table 32 shows that there are problems with overheating. Comparing with requirements for a class II indoor environment in EN 15251, however, only the building located in Stockholm has a number of hours with overheating above the maximum allowed 259 hours with overheating. In order to reduce the number of hours with overheating the use of a higher venting rate, a good external solar shading and a combination has been investigated, see Table 33.

Table 33. Hours of overheating (>26ºC) and space heating demand when using higher venting rate, external solar shading and a combination; house located in Stockholm.

Scenario		**1**	**2**	**3**	**4a**	**4b**	**5**
Reference[1]	Energy need for space heating (kWh/m^2)	103	62	62	33	27	17
	Hours of overheating (>26ºC)	197	169	169	169	169	207
Venting 3h^{-1}	Energy need for space heating (kWh/m^2)	103	63	63	33	28	17
	Hours of overheating (>26ºC)	97	97	71	71	71	83
External shading	Energy need for space heating (kWh/m^2)	120	77	77	43	37	21
	Hours of overheating (>26ºC)	41	41	37	37	37	72
Venting and shading	Energy need for space heating (kWh/m^2)	120	77	77	43	37	21
	Hours of overheating (>26ºC)	21	21	20	20	20	26

[1] Venting rate of 1.5h^{-1} and no external shading

From Table 33 can be seen that the effect of using a good external solar shading or the combination of a good external solar shading and a higher venting rate reduce the number of hours with overheating a lot. Using a higher venting rate alone has a smaller effect and the energy use for heating remains practically unchanged. Using the external solar shading is not only more expensive to install, but also increases the energy use for heating. The energy use increases due to the control strategy used in WinDesign, i.e. shading is activated all year round when solar irradiation is above 300 W/m^2, resulting in reduced solar heat gains in periods with a energy need for space heating and simultaneously solar irradiation above the mentioned limit.

Cost calculations

For the calculation of the cost-effectiveness of the different renovation scenarios for all locations, input data for the costs in scenario 2, 3 and 4 has been provided by Mid Sweden University and input data for scenario 5 has been used from V&S Prisbog 2008 [30]. Below, only the results for the cost calculations for the house located in Stockholm are shown. Calculations for the cost of conserved energy in the other locations will be more favourable since they account for more energy savings.

Two different cost calculations are needed. The windows, walls and roof in scenario 1 are still in good condition. Accordingly, their investment cost can be seen as a cost to obtain a reduction in the energy use of the building. Other costs, such as the installation of a drain around the house are not taken into account as investment cost in energy efficient measures.

Table 34. Calculation of cost-effectiveness of the renovation scenarios; house located in Stockholm

Stockholm, Scenario	**1**	**2**	**3**	**4a**	**4b**	**5**
Annual primary energy savings (MWh)	0	26.5	62.6	66.3	67.4	69.9
Total investment cost (SEK x10^3)	0	175	286	367	377	539
Total CCE (SEK/kWh)	**Ref.**	**0.34**	**0.23**	**0.28**	**0.29**	**0.39**
Cost of energy efficiency measures (SEK x10^3)	0	106	218	299	309	469
CCE energy efficient measures (SEK/kWh)	**Ref.**	**0.20**	**0.18**	**0.23**	**0.23**	**0.34**

Note: The cost of energy efficient measures is calculated as the total cost deducted by cost for needed renovation work. The difference between “Total CCE” and “CCE energy efficient measures” is related to whether the total investment or “reduced” investment cost is used

With the building heated by electrical heaters in the first two scenarios and the use of a heat pump in scenario 3, 4 and 5, the current price for electricity estimated to be 1,1 SEK/kWh, an average primary energy factor of 2,65 for the electricity use by electric heaters, it can be concluded from Table 34 that all renovation scenarios are cost-effective, both when considering only the investment cost in energy efficient measures and when considering the total investment cost. Table 34 also shows that the cost-effectiveness of the installation of a heat pump prior to the installation of a VHR system (scenario 3) is higher than considering the installation of VHR system afterwards (scenario 4). The application of extra external insulation and insulation of the slab-on-ground floor (scenario 5) is in this case the least cost-effective renovation measure.

6.6 Renovation scenario - Norway

6.6.1 Single-family house -1945 and single-family house 1970´s

Scenarios

The Norwegian Building Research Institute has defined three different scenarios (low, medium and high) for adding thermal insulation, better windows and reducing the lighting gains in existing buildings [34]. Besides this, also a scenario considering the application of a heat pump (COP = 3) and a ventilation system with heat recovery (both according to the minimum requirements and better) has been set up. This information has been used in this report for the definition of the different renovation scenarios for a Norwegian single-family house built before 1945 and a single-family house from the 1970’s. Both typical houses have been identified previously as typical Norwegian houses with the highest energy savings potential. For the investigation, the same renovation measures have been applied on both typical houses. However, since they differ in construction principle and age, different results for the input will be obtained, an overview is given in Table 35. Comparison with the building stock analysis and two packages of energy saving measures in chapter 3.3.3 shows that these “moderate” and “ambitious” packages are quiet similar to scenario 2 and 4, respectively, although the scenarios investigated below assume higher U-values for windows.

Table 35. Renovation measures applied for the different scenarios

Scenario	**1**	**2**	**3**	**4**	**5**
Building envelope (-1945)					
U-value walls	0.55	0.25	do	do	0.2
U-value roof	0.38	0.2	do	do	0.15
U-value floor	0.53	0.2	do	do	do
Total UA-value	**141**	**65**	**do**	**do**	**54**
U-value window	2.2	1.6	do	do	1
Building envelope (1970)					
U-value walls	0.38	0.22	do	do	0.18
U-value roof	0.2	0.15	do	do	do
U-value floor	0.36	0.2	do	do	do
Total UA-value	**121**	**75**	**do**	**do**	**71**
U-value glazing	2.2	1.6	do	do	1
Ventilation system	Natural	do	do	VHR 70/85%	do
Heat supply	Electric heaters	do	Heat pump, COP 3	do	do

Energy performance

As for the typical house in Sweden, also the calculations for both typical houses in Norway have been performed using different weather data. Both weather data for Bergen and Oslo has been used in the calculations. All other assumptions are the same as assumed for the Danish houses, except that the ventilation rate is set to 0.6/0.5h^{-1} according to the scenarios defined by the Norwegian Building Institute when mechanical ventilation is used. More details can be found in Appendix 4.

Results for single-family house built before 1945 and the house from the 1970's located in Bergen and Oslo respectively are shown in Table 36 and Table 37. Since there is no consensus in Norway regarding the use of primary energy factors [35], a primary energy factor of 2.5 has been used to take into account the use of electricity in the calculations of the primary energy use.

Table 36. Energy performance of the different renovation scenarios (kWh/m^2 per year) for the single-family house built before 1945.

Oslo, Scenario	**1**	**2**	**3**	**4a**	**4b**	**5**
Energy need for space heating	**142**	**84**	**84**	**47**	**42**	**32**
Length heating season	287	252	252	226	219	208
Hours of overheating (>26°C)	422	591	591	655	654	550
Hot water use	13	13	13	13	13	13
Non-utilized heat losses	4	4	4	5	5	4
Contribution solar heating	-	-	-	-	-	-
Energy need for heating	**159**	**102**	**102**	**65**	**59**	**50**
Efficiency of heat supply system (-)	1	1	3	3	3	3
Energy use for heating	**159**	**102**	**34**	**22**	**20**	**17**
Electric. use for heating and ventilation	0	0	0	3	3	3
Primary energy use	**398**	**254**	**85**	**61**	**56**	**48**
Bergen, Scenario	**1**	**2**	**3**	**4a**	**4b**	**5**
Energy need for space heating	**138**	**80**	**80**	**43**	**38**	**30**
Length heating season	365	302	302	248	241	231
Hours of overheating (>26°C)	192	253	253	269	269	238
Hot water use	13	13	13	13	13	13
Non-utilized heat losses	3	4	4	4	4	4
Contribution solar heating	-	-	-	-	-	-
Energy need for heating	**154**	**97**	**97**	**60**	**55**	**47**
Efficiency of heat supply system (-)	**1**	**1**	**3**	**3**	**3**	**3**
Energy use for heating	**154**	**97**	**32**	**20**	**18**	**16**
Electric. use for heating and ventilation	**0**	**0**	**0**	**3**	**3**	**3**
Primary energy use	**385**	**242**	**81**	**57**	**52**	**45**

Table 36 shows that the energy need for space heating can be reduced to a very low level in both locations, although not to passive house level in any of the cases. The reduction in energy need for space heating corresponds to 41% (Oslo) – 42% (Bergen) of the original energy need for space heating when adding insulation to the building envelope components in scenario 2.

Using the primary energy factor of 2,5 for electricity, the installation of a heat pump (scenario 3) prior to the installation of a VHR system (scenario 4) reduces the primary energy use by about 79% in Oslo and Bergen, resulting in a primary energy use lower than the recommendations by the Low Energy Working Group (Lavenergiutvalget), appointed by the Norwegian Government (Appendix 1).

The installation of a VHR system with an efficiency of 70% and 85%, scenario 4a and 4b, reduces the primary energy use with respectively 85% and 86% in both locations. As for the standard detached house in Sweden, the difference in reduction of primary energy use between the use of a the two VHR systems is rather small because of the installation of the heat pump prior to the installation of the VHR system.

Applying extra external insulation to the walls and better performing windows (Scenario 5) reduces the primary energy use with 88%.

Table 37. Energy performance of the different renovation scenarios (kWh/m^2 per year) for the single-family house from the 1970's.

Oslo, Scenario	**1**	**2**	**3a**	**3b**	**4**	**5**
Energy need for space heating	**105**	**76**	**76**	**40**	**36**	**31**
Length heating season	272	255	255	232	227	217
Hours of overheating (>26°C)	389	340	340	387	386	349
Hot water use	13	13	13	13	13	13
Non-utilized heat losses	6	6	6	6	6	6
Contribution solar heating	-	-	-	-	-	-
Energy need for heating	**125**	**95**	**95**	**59**	**55**	**50**
Efficiency of heat supply system (-)	1	1	3	3	3	3
Energy use for heating	**125**	**95**	**32**	**20**	**18**	**17**
Electric. use for heating and ventilation	0	0	0	3	3	3
Primary energy use	**312**	**238**	**79**	**56**	**53**	**48**
Bergen, Scenario	**1**	**2**	**3**	**4a**	**4b**	**5**
Energy need for space heating	**100**	**71**	**71**	**35**	**33**	**27**
Length heating season	365	322	322	255	248	238
Hours of overheating (>26°C)	182	169	169	183	183	174
Hot water use	13	13	13	13	13	13
Non-utilized heat losses	7	7	7	6	6	6
Contribution solar heating	-	-	-	-	-	-
Energy need for heating	**120**	**91**	**91**	**54**	**52**	**46**
Efficiency of heat supply system (-)	1	1	3	3	3	3
Energy use for heating	**120**	**91**	**30**	**18**	**17**	**15**
Electric. use for heating and ventilation	0.0	0.0	0.0	2.6	2.6	2.6
Primary energy use	**299**	**227**	**76**	**52**	**50**	**45**

As for the single-family houses built before 1945, the energy need for space heating in Norwegian single-family houses from the 1970´s can be reduced to a very low level. The reduction in the energy need for space heating, both in Oslo and Bergen, corresponds to 28% of the original energy need for space heating when adding insulation to the building envelope components in scenario 2. This reduction is smaller than the reduction of the energy need for space heating in the previous described typical single-family houses built before 1945 since the houses from the 1970´s had a better insulation level.

Using the primary energy factor of 2,5 for electricity, the installation of a heat pump (scenario 3) prior to the installation of a VHR system (scenario 4) reduces the primary energy use by about 75% (Oslo and Bergen), resulting in a primary energy use lower than the recommendations by the Low Energy Working Group (Lavenergiutvalget), appointed by the Norwegian Government. (Appendix 1).

The installation of a VHR system with an efficiency of 70% and 85%, scenario 4a and 4b, reduces the primary energy use with respectively 81% and 82% in both locations. Again, the difference in reduction of primary energy use between the use of a the two VHR systems is rather small because of the installation of the heat pump prior to the installation of the VHR system.

Applying extra external insulation to the walls and better performing windows (Scenario 5) reduces the primary energy use with 85%.

Thermal indoor environment

Table 38. Energy performance of the different renovation scenarios (kWh/m^2 per year) for the single-family house built before 1945.

Scenario		1	2	3	4a	4b	5
Oslo	Energy need for space heating (kWh/m^2)	142	84	84	47	42	32
	Hours of overheating (>26ºC)	422	591	591	655	654	550
Bergen	Energy need for space heating (kWh/m^2)	138	80	80	43	38	30
	Hours of overheating (>26ºC)	192	253	253	269	269	238

As can be seen in Table 36 and Table 37, there could be a lot of problems with overheating in the typical Norwegian houses, especially in the single-family houses built before 1945. In Table 38, a comparison between the energy need for space heating and hours of overheating has been made for the single-family house built before 1945, located in Oslo and in Bergen. Table 38 shows that overheating is less of an issue for these single-family houses located in Bergen than in Oslo although the energy need for space heating is also less for the houses located in Bergen. This is due to the specific climate conditions in Bergen. The smaller amount of hours with overheating is due to less solar radiation, whereas the smaller energy need for space heating is due to slightly higher temperatures in Bergen than in Oslo.

In order to reduce the number of hours with overheating in single-family houses built before 1945, again the use of a higher venting rate, good external solar shading and a combination (as previously defined for the Danish standard detached house) has been investigated. The results for the houses located in Oslo are presented in Table 39 below. The increased ventilation rate strategy is usually already now applied in older houses by opening the windows and/or doors during hottest days in summer.

Table 39. Hours of overheating (>26ºC) and space heating demand when using higher venting rate, external solar shading and a combination in single-family houses built before 1945.

Scenario		1	2	3	4a	4b	5
Reference[1]	Energy need for space heating (kWh/m^2)	142	84	84	47	42	32
	Hours of overheating (>26ºC)	422	591	591	655	654	550
Venting 3h^{-1}	Energy need for space heating (kWh/m^2)	143	86	86	49	43	34
	Hours of overheating (>26ºC)	211	243	243	249	251	204
External shading	Energy need for space heating (kWh/m^2)	158	96	96	56	40	31
	Hours of overheating (>26ºC)	92	111	111	121	120	81
Venting and shading	Energy need for space heating (kWh/m^2)	158	96	96	56	50	40
	Hours of overheating (>26ºC)	42	40	40	38	38	26

[1] Venting rate of 1.5h^{-1} and no external shading

Using a good external solar shading or the combination of a good external solar shading and a higher venting rate reduce the number of hours with overheating a lot, but at the expense of an increase in energy need for space heating. In this case, where the number of hours with overheating is very large, the effect of using a higher venting rate can also clearly be seen.

6.7 Renovation scenarios - Finland

6.7.1 Veteran house 1940-1960 and houses from the 1960´s and 1970´s

Scenarios

For the analysis of the effect of different renovation measures on the typical Finnish single-family houses with large energy saving potential, different renovation scenarios have been defined based on the requirements for the transmission losses through building envelope components in the Finnish Building Code from 2008 and the tightening of these requirements for the future. Besides this, also a scenario considering the application of a ventilation system with heat recovery (both according to the minimum requirements and better) to ensure a good indoor environment and the application of a heat pump (COP = 3) to further reduce the energy needed for heating of the typical houses, has been investigated. In contrast of applying the same measures (i.e. the same insulation thickness) on the typical single-family houses as in Norway, different measures (different insulation thicknesses) have been applied to the typical Finnish single-family houses. However, they all result in the same transmission losses through the building envelope but like the results for the Norwegian typical single-family houses, the results for the typical Finnish single-family houses will also differ, due to the difference in age, shape and surface area of the typical single-family houses.

An overview of the different requirements for the transmission heat losses for the building envelope components, the ventilation system and heating system for the different renovation scenarios, applied on each one of the typical single-family houses; Veteran house from 1940-1960 and typical single-family houses from 1960’s and 1970’s, can be seen in Table 39.

Table 39. Renovation measures applied for the different scenarios

Scenario	**1**	**2**	**3**	**4**	**5**
Building envelope (1940-1960)					
U-value walls	0.7	0.24	0.24	0.24	0.17
U-value roof	0.4	0.15	0.15	0.15	0.09
U-value floor	0.45	0.16	0.16	0.16	0.16
Total UA-value	**129**	**47**	**47**	**47**	**35**
U-value window	3.7	1.4	1.4	1.4	0.8
Building envelope (1960´s)					
U-value walls	0.45	0.25	0.25	0.25	0.17
U-value roof	0.35	0.16	0.16	0.16	0.09
U-value floor	0.4	0.2	0.2	0.2	0.16
Total UA-value	**174**	**88**	**88**	**88**	**61**
U-value window	3.14	1.4	1.4	1.4	0.8
Building envelope (1970´s)					
U-value walls	0.28	0.24	0.24	0.24	0.17
U-value roof	0.3	0.15	0.15	0.15	0.09
U-value floor	0.22	0.19	0.19	0.19	0.16
Total UA-value	**85**	**61**	**61**	**61**	**44**
U-value window	2.1	1.4	1.4	1.4	0.8
Ventilation	Natural	do	do	VHR	do
Heat supply	Electric heaters	do	Heat pump, COP 3	do	do

Energy performance

The results for the three typical single-family houses located in Helsinki, can be seen in Table 40, 41 and 42. More information about input data and results can be found in Appendix 3 and 4. All other assumptions are the same as assumed for the Swedish houses. More details can be found in Appendix 3.

Table 40. Energy performance of the different renovation scenarios (kWh/m^2 per year) for the Veteran houses from 1940-1960.

Scenario	**1**	**2**	**3**	**4a**	**4b**	**5**
Energy need for space heating	**264**	**108**	**108**	**75**	**61**	**40**
Length heating season	365[1]	285	285	256	246	229
Hours of overheating (>26°C)	125	246	246	246	248	186
Hot water use	13	13	13	13	13	13
Non-utilized heat losses	39	48	48	45	45	43
Contribution solar heating	-	-	-	-	-	-
Energy need for heating	**316**	**169**	**169**	**133**	**119**	**97**
Efficiency of heat supply system (-)	1	1	3	3	3	3
Energy use for heating	**377**	**202**	**56**	**44**	**40**	**32**
Electric. use for heating and ventilation	6	6	1	4	4	4
Primary energy use	**395**	**220**	**173**	**145**	**130**	**108**

From the calculations, it seems that Finnish Veteran houses need heating all year round. However, usually they do not need heating all year round, differences between calculated results and reality could be explained by the use of an IWEC weather data file.

Energy need for space heating in Finnish Veteran houses can be reduced with 59% through improving the building envelope with easy-to-carry-out renovation measures in Scenario 2.

Using a primary energy factor of 3 for electricity based on the comparison of CO2-emissions relative to light fuel [36], the installation of a heat pump (scenario 3) prior to the installation of a VHR system (scenario 4) reduces the primary energy use by about 56%. The installation of a VHR system with an efficiency of 60% and 85%, scenario 4a and 4b, reduces the primary energy use with respectively 63% and 67%. Adding extra insulation and better windows in scenario 5, the primary energy use has been reduced with 73%. However, taking into account a future change in the Finnish energy supply system (nuclear power replacing thermal energy, [36]), the primary energy factor for electricity is predicted to decrease to 1,7-2,1, which will further improve the primary energy efficiency of the applied renovation measures.

In Finnish energy rating system, the primary energy factor is not used. The energy rating is based on the energy need of the house, including energy need for heating, hot water and electricity. In energy rating system for small houses, the analysed scenarios 2 to 5 would lead to energy efficiency classes of C to A (Appendix 1, assuming electricity need of 50 kWh/m^2, per year).

Scenarios 2 and 3 would lead in an energy use corresponding with the Finnish energy rating class C. Class B (= the rating for new buildings built according to the current building code) could be achieved with scenario 4a. Energy rating class A could be achieved by applying scenario 4b or 5.

Table 41. Energy performance of the different renovation scenarios (kWh/m^2 per year) for the single-family house from the 1960's.

Scenario	**1**	**2**	**3**	**4a**	**4b**	**5**
Energy need for space heating	**178**	**88**	**88**	**61**	**53**	**30**
Length heating season	306	255	255	235	226	196
Hours of overheating (>26°C)	361	641	641	646	644	595
Hot water use	13	13	13	13	13	13
Non-utilized heat losses	32	34	34	32	32	31
Contribution solar heating	-	-	-	-	-	-
Energy need for heating	**224**	**134**	**134**	**107**	**98**	**74**
Efficiency of heat supply system (-)	1	1	3	3	3	3
Energy use for heating	**266**	**160**	**45**	**36**	**33**	**25**
Electric. use for heating and ventilation	3	3	1	3	3	3
Primary energy use	**275**	**169**	**136**	**116**	**108**	**84**

Energy need for space heating in Finnish houses built during the 1960´s can be reduced with 51% through improving the building envelope with easy-to-carry-out renovation measures in Scenario 2.

Using a primary energy factor of 3 for electricity, the installation of a heat pump (scenario 3) prior to the installation of a VHR system (scenario 4) reduces the primary energy use by about 50%. The installation of a VHR system with an efficiency of 60% and 85%, scenario 4a and 4b, reduces the primary energy use with respectively 58% and 61%. Adding extra insulation and better windows in scenario 5, the primary energy use has been reduced with 70%. Taking into account a future change in the Finnish energy supply system and a decrease in the primary energy factor for electricity will further improve the primary energy efficiency of the applied renovation measures.

In Finnish energy rating system, the primary energy factor is not used. The energy rating is based on the energy need of the house, including energy need for heating, hot water and electricity. In energy rating system for small houses, the analysed scenarios 2 to 5 would lead to energy efficiency classes of C to A (Appendix 1, assuming electricity need of 50 kWh/m^2, per year).

Scenarios 2 and 3 would lead in an energy use corresponding with the Finnish energy rating class C. Class B (= the rating for new buildings built according to the current building code) could be achieved with scenario 4a. Energy rating class A could be achieved by applying scenario 4b or 5.

Table 42. Energy performance of the different renovation scenarios (kWh/m^2 per year) for the single-family house from the 1970's.

Scenario	**1**	**2**	**3**	**4a**	**4b**	**5**
Energy need for space heating	**138**	**102**	**102**	**71**	**58**	**36**
Length heating season	286	265	265	242	231	208
Hours of overheating (>26°C)	397	452	452	454	460	397
Hot water use	13	13	13	13	13	13
Non-utilized heat losses	20	22	22	22	22	23
Contribution solar heating	-	-	-	-	-	-
Energy need for heating	**171**	**138**	**138**	**106**	**93**	**71**
Efficiency of heat supply system (-)	1	1	3	3	3	3
Energy use for heating	**171**	**138**	**46**	**35**	**31**	**24**
Electric. use for heating and ventilation	4	4	1	4	4	4
Primary energy use	**526**	**426**	**140**	**117**	**104**	**82**

Energy need for space heating in Finnish houses built during the 1970's can be reduced with 26% through improving the building envelope with easy-to-carry-out renovation measures in Scenario 2. This reduction is lower than the reduction of the energy demand for space heating in the previously described Finnish typical single-family houses since the single-family houses from the 1970's are better insulated.

Using a primary energy factor of 3 for electricity, the installation of a heat pump (scenario 3) prior to the installation of a VHR system (scenario 4) reduces the primary energy use by about 73%. The installation of a VHR system with an efficiency of 60% and 85%, scenario 4a and 4b, reduces the primary energy use with respectively 78% and 80%. Adding extra insulation and better windows in scenario 5, the primary energy use has been reduced with 84%.Taking into account a future change in the Finnish energy supply system and a decrease in the primary energy factor for electricity, will even further improve the primary energy efficiency of the applied renovation measures.

The results concerning the energy rating in this case are similar to the cases presented above for houses from 1940's and 1960's. Scenarios 2 and 3 would lead in an energy use corresponding with the Finnish energy rating class C. Class B (= the rating for new buildings built according to the current building code) could be achieved with scenario 4a. Energy rating class A could be achieved by applying scenario 4b or 5.

It is worth to notice that the energy renovation measures applied to this house will not result in better energy rating class than for the houses from 1940's or 1960's, where the starting point was class F. In 1970's house the starting point is class D. This is due to the fact that the Finnish energy rating system does not currently take into account the energy production side.

Thermal indoor environment

As can be seen from previous tables, there are also a lot of problems with overheating in the typical Finnish houses, especially in the single-family houses built during the 1960´s. In order to reduce the number of hours with overheating in these houses, again the use of a higher venting rate, a good external solar shading and a combination has been investigated. Only the results for the single-family house built during the 1960´s are presented in Table 43 below.

Table 43. Hours of overheating (>26ºC) and space heating demand when using higher venting rate, external solar shading and a combination in single-family houses built during the 1960´s.

Scenario		1	2	3	4a	4b	5
Reference[1]	Energy need for space heating (kWh/m^2)	178	88	88	61	53	30
	Hours of overheating (>26ºC)	361	641	641	646	644	595
Venting 3h^{-1}	Energy need for space heating (kWh/m^2)	181	92	92	64	56	34
	Hours of overheating (>26ºC)	209	295	295	295	300	234
External shading	Energy need for space heating (kWh/m^2)	200	102	102	72	62	38
	Hours of overheating (>26ºC)	80	145	145	147	147	130
Venting and shading	Energy need for space heating (kWh/m^2)	200	103	103	72	62	38
	Hours of overheating (>26ºC)	57	77	77	78	77	63

[1] Venting rate of 1.5h^{-1} and no external shading

Again, using a good external solar shading or the combination of a good external solar shading and a higher venting rate reduce the number of hours with overheating a lot. In this case, where the number of hours with overheating is very large, the effect of using a higher venting rate can also clearly be seen. However, in order to fulfil the requirements as stated in EN15251, only solar shading or a combination of a good external solar shading and a higher venting rate can be used. But as can be seen from Table 42, this results in a higher space heating demand.

6.8 Conclusions on analysis of renovation scenarios

Different technical renovation scenarios have been tested for the typical single-family houses with large energy saving potential in each of the participating countries. Since the typical single-family houses differ from each other regarding type and age, the renovation measures in the renovation scenarios also differ from each other. For example, in some houses, post-insulation of cavity walls can be used whereas in other houses extra external insulation is applied to the walls. According to the different renovation measures and differences between the typical single-family houses, also the results regarding energy performance and indoor environment will differ.

Some general conclusions can, however, be made. Considering the different renovation scenarios, it can be seen from the investigations that with the application of easy-to-carry-out renovation measures, the installation of a state-of-the-art energy efficient mechanical ventilation system with heat recovery (VHR) with low electricity use and good air tightness of the house and a more efficient heating system, the energy use for heating in the typical Danish detached houses can be reduced by more than 50%. However, VHR can be expensive to install and the primary energy savings depends on the air tightness of the house, electricity used to operate the system and the energy supply system. Hence, for the typical houses not connected to any gas or district heating network (use of electric heaters and oil boilers), the installation of a heat pump prior to a VHR system has been investigated for Finnish, Swedish and Norwegian houses. In these cases, the primary energy use is reduced with 50-80%. Installation of a VHR system after installation of a heat pump reduces the primary energy use even further but not as much as if the heating came from electric heaters. Hence, the cost-effectiveness of the installation of a VHR system is reduced but it is of course still wise to combine the installation of a heat pump with VHR and air tightness measures due to the many non-energy benefits of VHR.

Considering the differences between the ages of the different typical single-family houses, the investigations show as expected that the older the houses are, the more primary energy can be saved by applying the different renovation scenarios. However, with the assumed measures the primary energy use after renovation will usually still be higher than for new low energy houses but better than standard new houses. The same conclusion can also be drawn for the typical houses located in different climate zones. The more severe the climate, the more energy can be saved but again the resulting total energy use in these buildings will be higher than for the same buildings located in a less severe climate zone.

As the investigations have shown, applying easy-to-carry-out renovation measures together with the use of a heat pump in typical Swedish, Norwegian and Finnish buildings, even in severe climate zones, can result in significant reduction in primary energy use. In Denmark, the requirements for new buildings are stricter than in the other Nordic countries. However, the calculations show that typical Danish single-family houses can be renovated to the a level of energy performance below the requirement for new houses today. Reaching Passive house level will be very demanding in renovation. With the investigated scenarios the Passive house level could not be reached in any of the cases.

Also regarding the thermal indoor environment some general conclusions can be drawn. The excessive solar radiation in summer is likely to result in overheating, especially when applying extensive energy renovation measures that reduce heat losses. Most problems with overheating occur for houses built during the 1960´s. In order to reduce the problems with overheating, external solar shading - whether or not combined with a higher venting rate by use of automatically controlled windows - is the most efficient. The external shading should optimally be moveable but it is usually costly to install and may increase the space heating demand by blocking solar heat gain when there is energy need for room heating.

7 ANALYSIS OF FULL-SERVICE RENOVATION CONCEPTS

The one most promising existing full-service renovation concepts for each of the Nordic countries (described in D1.1) will be evaluated according to the general method or ”ideal” process for sustainable renovation concepts (chapter 4).

7.1 Denmark – Clean Tech

The CleanTech concept developed by Dong Energy is offering heat pump solutions, insulation, windows, solar heating and building thermography.

The target group for heat pumps is homeowners with old oil-fired burners and the many for whom change to district heating or natural gas is no option. There is a well-defined target group of 100,000 to 200,000 homes. The target group for insulation and windows is around 1 million owner of single-family houses build before 1973.

The package offered includes full service in cooperation with partners. Dong Energy themselves takes care of advice, sale and coordination, e.g. handles the necessary paperwork and possible application for a national renovation subsidy and offers a financing solution (bank loan, up to DKK 250,000). Hence this makes life easier for the client. Advice is offered by phone, and through their homepage the homeowner can use a calculator to get an indication of relevant solutions and potential for energy savings.

Many of the older, especially pre-war houses have a facade worth to preserve and that is presumably why external and internal insulation solutions are not included in the package. Cavity wall insulation is offered but results in limited energy savings since only a limited amount of insulation and rather ineffective insulation can be added (thermal bridges are not eliminated).

With its concept, Dong Energy relies on easy-to-carry out measures and investments with a short payback time. The company thus focuses on delivering solutions to save energy right away and does not include plans for renovation. On the other hand, the company also has a commitment to document a certain amount of energy savings to the Danish Energy Agency.

The concept could focus more on user needs, e.g. that the targeted houses do generally not have a very good indoor environment. Hence, internal or external insulation of exterior walls and installation of ventilation with heat recovery could be included in the package to save energy and improve the indoor environment. However, both internal/external insulation and adding a ventilation system is problematic in the many old pre-war master builder houses with e.g. a facade worth to preserve but may be useable in houses from the 1960/70’s.

The package includes no impartial quality assurance and continuous commissioning.

7.2 Sweden - Sustainable renovation of heating systems

This concept, limited to renovation of heating systems, was developed by Jämkraft and is based on a package offer including fixed price for the removal of existing resistance heaters and the installation of water-based heat distribution system and heat exchanger and the connection to a biomass-based district heating network.

By the end of 2006, a market campaign by Jämtkraft convinced 78 % of the 456 homeowners in Östersund of all age and income group to sign contracts to connect to its biomass-based district heating network. The concept was successful because of its package offer and information provision, which addressed factors that were important in homeowners' choice of heating system. A survey prior to the campaign showed that homeowners gave priority to economic aspects and functional reliability, and preferred to collect information from installers and interpersonal sources.

Primary energy use can be reduced significantly, indoor environment will be improved, and energy costs can be lowered. The reduction in final energy use is, however, quite limited and the concept could be more sustainable.

It is obvious to have a more integrated approach, offering also solutions to reduce the heating and energy demand before introducing measures to ensure energy efficient energy supply.

7.3 Norway - JADARHUS Rehab

The Jadarhus Rehab group sees a lot of energy saving potential in retrofitting of the existing building stock and decided in 2007 to found a separate company to develop this market in order to help buyers of old houses with the renovation.

They provide information and tailor-made energy efficient solutions, both easy-to-carry out solutions and advanced solutions, in order to reduce the energy use but also to improve the indoor environment. Besides this, they want to offer the most economical and environmental friendly solutions to their customers and put a strong focus on the market value, architectural quality and comfort of the building after renovation.

They takes care of the whole process. A more ideal process may include tools for the pre-project phase to demonstrate the customers how the house will be like after the renovation, a ventilation system as an integrated part of insulation and air tightness measures, financing package and monitoring system.

7.4 Finland - ENRA

The ENRA concept/program for energy efficient renovation and living started in 2009 with a pilot in the Pakila area in Helsinki, an area with typical single-family houses from 1940-50's (mainly so called "Veteran houses") and houses from 1960-70's.

It is a well designed concept, developed by a renovation company in cooperation with the most relevant suppliers, aimed at helping homeowners to reduce the energy use but also to improve thermal comfort and air quality.

One innovative element of the concept is the handling of potential clients who are invited to participate in a homeowners' evening. This is a good way of introducing homeowners to the challenges and opportunities of sustainable renovation and to get to know other people with plans for renovation and to exchange ideas and experiences.

Another positive element is the systematic way of finding out the individual renovation needs of the family in question and the drawing up of a scheduled renovation plan where the needs are mapped and their priority order is noted. This is relevant as many people want to do renovation step-wise, e.g. because they want to do some of the renovation work by themselves or the optimal total low energy renovation may be out of reach from an economical point of view.

A wish for some “do-it-your-self” participation should be handled by the ENRA concept, just the same as the ENRA expert will look for other suppliers if the homeowner wants something that is not covered by the ENRA-group.

8 CONCLUSIONS

Detached single-family houses account for large share of the total number of dwellings in the Nordic countries. Final energy use for space heating and hot water is in the range of 135 to 200 kWh/m^2. Existing single-family houses need to be significantly upgraded to comply with the minimum energy requirements for new houses and they can contribute in big savings in energy consumption. Electric heating (and oil heating) of single-family houses is very common in the Nordic countries, except for Denmark where oil/gas boiler and district heating is mostly used. Natural ventilation is widespread in Denmark while mechanical ventilation is more often applied in Norway, Sweden and Finland, although also there the older houses use natural ventilation. Houses in Norway, Sweden and Finland are typically built with wood as a main construction material, but the insulation and/or finishing materials differ. In Denmark bricks are used as a dominant construction material for cavity walls.

The typical single-family houses identified to have large primary energy saving potential (both due to big volume and big energy use) almost descend from the same time period in each Nordic country. The first segment is houses built in large numbers in the 1960 and 1970 before tightening of the insulation standards in the building codes in the late 1970’s due to the oil crisis. The second segment is houses built before 1940 pre-war (except for Finland) where a large part of them has been renovated, but energy renovation of those houses today would still account for a large energy saving. The third segment is houses from the post-war period in Finland, houses that are all individual but built in the same way, using the same materials.

A general working method (ideal process) for proposals on sustainable renovation concepts for single-family houses is described. The method consists of four steps, going from investigation of the house to planning and commissioning after renovation: Step 1: Initial house condition and energy evaluation, Step 2: Pre-project – proposal for sustainable renovation, Step 3: Detailed planning and contract work, Step 4: Quality assurance and continuous commissioning.

The one most promising existing full-service renovation concept in each of the Nordic countries were analysed towards the ideal process (step 1-4). These pilot full-service concepts have just recently entered the market and are not well established and their success is yet to be evaluated. It can be concluded that the success of the concepts is strongly influenced by the current renovation market that is dominated by a craftsman based approach with individual solutions, traditional warehouses ”do-it-yourself-shops” and some actors marketing single products. There is a need for a more integrated approach and application of the full range of technical solutions to ensure the homeowner a sustainable renovation to a reasonable price.

Energy efficiency calculations for individual measures for each of the typical single-family houses in the Nordic countries have been made, and also some examples of cost analysis based on the criterion of cost of conserved energy (CCE). The CCE method takes into account the investment and running cost and savings during a defined relevant reference period. Another method that could be used to illustrate the economic implications is “annual economic balance”, i.e. savings minus repayments on a mortgage credit loan, which may be relevant for homeowners who want to utilize cheap long-term financing based on equity.

Energy efficiency measures in connection with renovation of single-family houses have the potential for very large energy savings and reduction of energy use to the level of a new house or better. The potential is particularly high for houses with electric heating where installation of a heat pump and water-based heat supply system will reduce primary energy use and heating cost with about 70%. When an efficient heat supply system is in place, then mechanical ventilation with heat recovery (VHR) will result in less energy saving compared to heat supply with e.g. electric heaters but still the quality of indoor environment is likely to improve, especially due to better indoor air quality. The primary energy efficiency effectiveness of VHR depends very much on energy supply system, the air tightness of the building envelope and the electricity use to run the system.

Energy efficiency measures have mostly a positive impact on the indoor environment. Thermal comfort will be improved by insulation and air-tightness measures that will increase surface temperatures and reduce draught from e.g. badly insulated windows. A ventilation system with heat recovery will also contribute to a good thermal comfort by draught-free supply of fresh air and make sure of an excellent air quality. A side effect of insulation measures may be some overheating, which can effectively be avoided by external movable solar shadings and/or to some extent by higher venting rate by use of e.g. automatically controlled windows.

This report provides the background for deliverable D1.3: Proposals on sustainable renovation concepts suitable for different categories of single-family houses with regard to type and age.

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10 APPENDICES

Appendix 1: Building regulations

Appendix 2: Calculation tools

Appendix 3: Applied energy renovation scenarios

Appendix 4: Energy use

APPENDIX 1: BUILDING REGULATIONS

Passive House standard

The Passive House standard is a consequent further development of the low energy house and requires, compared to a conventional building, 80-90% less heat energy. This is mainly achieved by "passive" energy utilization: within a Passive House the heat from occupants or the sun is almost sufficient enough, to keep the building warm. Fresh air is supplied by a ventilation system with high efficiency heat recovery, which at the same time, if needed, covers the residual heat energy needs.

A Passive House is characterized by exceptionally high comfort and very low energy use. This is mainly achieved by "passive" components such as: insulating windows, insulation and ventilation with heat recovery. The house will heat and cool itself, "passive".

The criteria for the Passive House standard for dwellings are [36]:

- Annual energy need for space heating of max. 15 kWh/m^2/year or specific heat load for the heating source at design temperature to be less than 10 W/m².

The 10 W/m^2 is the maximum heat load that can be supplied without the supply air being uncomfortably warm and the indoor climate too dry.

- Annual total primary energy use for space heating, hot water, ventilation and household electricity of max. 120 kWh/m^2/year

The primary energy factor for electricity is 2.7.

- The building envelope must not leak more air than 0.6 times the house volume per hour at 50 Pa as tested by a blower door.

This requirement is to ensure that the heat losses by air exchange can be kept as low as possible.

These are the main three criteria that should be met for a house to be called a Passive House. The documentation is carried out using the Passive House Planning Package (PHPP) [36]. Specific calculation assumptions are used, e.g. internal heat gain of 2.1 W/m^2 and an air change rate of 0.3 h^{-1}. A building can be certified by the Passive House Institute in Darmstadt, Germany, but also other organizations in a few other countries have been selected to certify passive houses.

Denmark

As the Danish Building Code states: "Buildings must be constructed so as to avoid unnecessary energy use for heating, hot water, cooling, ventilation and lighting while at the same time achieving healthy conditions".

New buildings

Requirements to reduce this energy use in new buildings have been implemented in the Danish Building Regulations BR 2008 [27] (based on the EU EPB directive) by the introduction of a called "energy frame" and the definition of two low energy classes (class 1 and 2). According to a planned tightening of the code, primary energy use for heating, ventilation, cooling and hot water in new dwellings will have to comply with low energy class 2 (= 25% less energy use than in BR 2008) by 2010, and low energy class 1 (= 50% less energy use than BR 2008) by 2015. In 2020, another tightening of the "energy frame" is expected, lowering the minimum requirements of new buildings to the level of a passive house (class 0). An overview is given in Table 35.

Table 35. BR 2008 requirements for the energy use for new single-family houses in the and expected energy frames in the future (kWh/m^{2}year). A is the heated gross floor area.

Building Regulations	Low energy class def. in BR2008	Energy frame
BR 2008 (kWh/m²year)	-	70+2200/A
BR 2010 (kWh/m²year)	2	50+1600/A
BR 2015 (kWh/m²year)	1	35+1100/A
BR 2020 (kWh/m²year)	(0)	(17.5+550/A)

In the course of the project and writing of the report the BR2010 [37] was published. In here the energy frames are as shown in Table 36. There are requirements for maximum energy use in new dwellings (≈ low energy class 2 in BR 2008) and a definition of a low-energy building class 2015 (≈ low energy class 1 in BR 2008).

Table 36. BR 2010 requirements for energy use and air tightness in new single-family houses and expected energy frames in the future (kWh/m^{2}year).

Building Regulations	Low energy class def. in BR2010	Energy frame	Maximum air change through leakages at 50 Pa (l/s/m²)
BR 2010 (kWh/m²year)	-	52.5+1650/A	1.5
BR 2015 (kWh/m²year)	2015	30+1000/A	1.0
BR 2020 (kWh/m²year)	2020	Expected spring of 2011	Expected spring of 2011

Existing buildings

BR 2010 includes energy requirements for building envelope, boilers, pumps and ventilation systems. There are two types of component requirements. The first type includes requirements for the energy efficiency of components such as windows, boilers, heat pumps etc. The second type includes requirements for additional insulation as the private economic viability is dependent on the amount of insulation already in the building and each building's design. BR 2010 provides guidance and examples of how the requirement can be complied with.

In connection with renovations of single-family houses, building components that are renovated should be updated to new building standards (see Table 37). Insulation measures are only to be carried out if it is economically profitable to do so. The criterion is that the payback time should be within 75% of the expected life time of the renovation measure.

Table 37. BR 2010 requirements for renovation of building envelope components and introduction of ventilation with heat recovery in single-family houses.

Requirements for single measures in connection with renovation	
U-values (W/m^2 K)	
External walls and basement walls in contact with the soil	0.20
Partition walls adjoining rooms that are unheated or heated to a temperature more than 8 K lower than the temperature in the room concerned.	0.40
Ground slabs, basement floors in contact with the soil and suspended upper floors above open air or a ventilated crawl space.	0.12
Ceiling and roof constructions, including jamb walls, flat roofs and sloping walls directly adjoining the roof.	0.15
External doors, roof lights (horizontal), removable windows, hatches to the outside	1.65
Energy gain (kWh/m^2/year) – solar gains minus heat loss	
New façade windows	> -33
New roof lights (sloping roof)	> -10
Linear heat losses (W/m K)	
Foundations around spaces that are heated to a minimum of 5°C.	0.12
Joint between external wall and windows or external doors and hatches.	0.03
Joint between roof construction and windows in the roof or roof lights.	0.10
Ventilation with heat recovery	
Minimum temperature efficiency (%)	70
Maximum Specific Fan Power (SFP) (kJ/m^3)	1.0

Sweden

In course of time, the requirements in the Swedish Building Code have undergone significant change concerning the formulation of energy requirements. While the 2002 requirements targeted thermal insulation and heat losses, the 2007 requirements set a maximum limit for the total annual energy use for space heating, cooling and hot water in all types of new buildings, and renovated buildings with a floor area greater than 1000 m^2 (Table 16). For residential buildings without electric heating the maximum limit is 110 kWh/m^2A_{temp}/year and 150 kWh/m^2A_{temp}/year in respectively the southern (climate zone III) and northern (climate zone I) part of the country.

Table 38. Energy performance requirement of newly-built Swedish residential buildings and renovated buildings with a floor area greater than 1000 m^2 (Boverket, 2009a) [1]

Specific energy use (kWh/m^2A_{temp}/year)	**Climate zone**		
	I	**II**	**III**
Non-electrically heated buildings	150	130	110
Electrically heated buildings	95	75	55

A_{temp} is the sum of floor areas heated to more than 10°C

Instead of the requirements as specified in Table 39, buildings can have alternative requirements in form of maximum allowed U-values for building envelope components, see Table 39, if the sum of their heated floor areas A_{temp} is up to 100 m^2, their window and door area are up to 20% of the total heated floor area A_{temp} and if they have no cooling demand.

Table 39. U-values of building envelope components of buildings with A_{temp} up to 100 m^2 (Boverket, 2009a)[1]

U-value (W/ m^2K)	**Non-electrically heated buildings**	**Electrically heated buildings** [1)]
Walls	0.18	0.10
Floors	0.15	0.10
Roof	0.13	0.08
Windows	1.3	1.1

1) Buildings with electicity heating and A_{temp} up to 50 m^2 are treated as buildings without electricity heating.

Norway

The Norwegian Building Code from 2007 dictates maximum U-values and air-tightness that cannot be exceeded, see Table 40. The focus of this building code is, however, mainly on new buildings. The current building regulations for retrofitting are very limited and only state that for major changes of the house, in respect to enlargement, demolition and/or major changes in the facades and technical installations and a change of use of the building (example: from office to dwelling) an application for approval is needed. Minor changes in facades or retrofitting where the facades are brought back to the original look, however, do not require any application.

[1] Full reference Boverket 2009a here

Table 40. Requirements in the Norwegian Building Code from 2007

Requirements Norwegian Building Code 2007	
U-values (W/m^2 K)	
Externall walls	0.18
Roof	0.13
Floor on ground or towards outdoor air	0.15
Windows and doors	1.2
Thermal bridges (W/m^2 K)	0.03
Air change through leakages at 50 Pa (l/s/m^2)	2.5
Annual average efficiency of heat exchanger in ventilation systems (%)	70
Specific fan power (SFP) for ventilation fans (kJ/m^3)	2.5

Source: IEA SHC Task 37 Subtask A: Energy Analysis of the Norwegian Dwelling Stock, Internal working document

Future development

Besides the requirements in the Norwegian Building Code, a Low Energy Working Group (Lavenergiutvalget), appointed by the Norwegian Government, presented recommendations for strategies to further reduce energy use in the building stock and to enforce the building codes by adding a maximum limit for the energy use both in new and existing buildings, see Table 41.

Table 41. Proposal for overall performance value for buildings in Norway

Overall performance value (kWh/m^2/year)	**New buildings**		**Retrofitting**	
	Dwellings	**Commercial**	**Dwellings**	**Commercial**
TEK 2007	130	155	160	170
TEK 2012	100	110	125	130
TEK 2017	65	70	85	90
TEK 2022	30	40	50	55
TEK 2027	0	0	30	40

Source: Lavenergiutvalget Juni 2009, http://www.sintef.no/upload/OED_Energieffektivisering.pdf

Finland

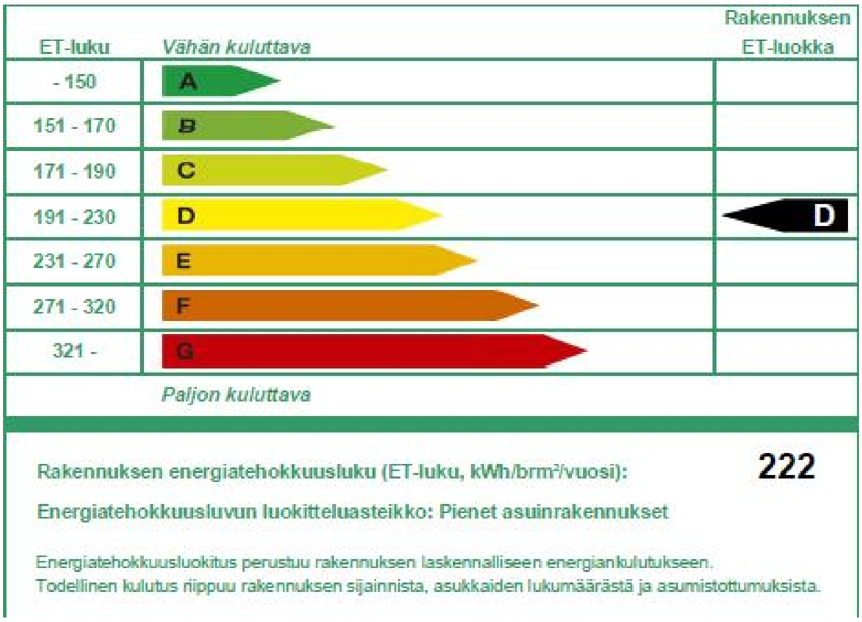
Finland has set minimum requirements in the National Building Code for thermal insulation and ventilation of new buildings since 1976. In Table 42, the current and future tightened energy regulations for 2010 as well as the Finnish passive house level for different building components is shown. However, these requirements are for new buildings and they are not obligatory for renovation of existing buildings.

Table 42. Maximum allowed U-values (W/m^{2}K) for different building components in Finland.

Building component	2008	2010	Passive house
Outer wall	0.24	0.17	0.1-0.15
Base floor	0.19	0.16	0.09-0.15
Roof	0.15	0.09	0.08-0.15
Windows	1.4	1.0	< 0.8-1.0
Outer doors	1.4	1.0	< 0.4-0.8

Source: Pekka Tuomaala, Ilpo Kouhia and Jyri Nieminen, VTT

Besides the requirements in the Building Code, Finland also has introduced the energy rating of buildings. The energy rating of new buildings and small houses is based on the calculated energy need for heating, hot water and electricity. Existing big buildings are rated according to their actual energy use. The energy rating (see Figure 22) classifies the buildings on an efficiency scale ranging from A (high energy efficiency) to G (poor efficiency). This energy rating of building fits in the future plans to reduce the energy use in Finnish buildings. The Finnish Ministry of Housing has namely announced that in 2012 Finland will introduce a regulation based on overall energy use, where the energy source will be taken into account (primary resource factor).



Rakennuksen energiatehokkuusluku (ET-luku, kWh/brm²/vuosi): 222

Energiatehokkuusluvun luokitteluasteikko: Pienet asuinrakennukset

Energiatehokkuusluokitus perustuu rakennuksen laskennalliseen energiankulutukseen. Todellinen kulutus riippuu rakennuksen sijainnista, asukkaiden lukumäärästä ja asumistottumuksista.

Figure 22. The energy ratings in Finland. Source: Ministry of Environment. 2009.

APPENDIX 2: CALCULATION TOOLS

WinDesign (Denmark)

WinDesign is a program developed at Technical University of Denmark, Department of Civil Engineering (DTU Byg) and has been created in Microsoft Office Excel 2007 using built-in and user defined functions programmed in Visual Basic for Applications (VBA).

The program has originally been created to help architects and engineers optimize the selection of windows in buildings, both during the early design phase of new buildings or for the renovation of existing ones, and is based on the requirements in the ISO-standard 13790. Now the program has been extended also to include the optimization of other building components such as exterior walls, roof, set points for heating and cooling systems etc. Optimization can both be carried out using the energy performance and thermal comfort (indoor temperature).

WinDesign consists of four steps. In each step, calculations are performed on a different level. In Step 1, the net energy gain for individual windows is calculated. In Step 2, the seasonal energy performance of windows in a dwelling are calculated for different scenarios and in Step 3 energy performance and thermal comfort are calculated on hourly basis according to the “simple hourly method” described ISO-standard 13790 on room level. Furthermore, for the calculations in Step 3, the electricity needed for lighting has been taken into account and an intelligent control for the building systems has been set up in order to maintain a comfortable indoor environment using no or very little energy.

Step 4 consists of an economic evaluation based on the calculation of the cost of conserved energy for each of the scenarios defined in Step 2.

Making use of a method to calculate the solar radiation on windows with arbitrary orientation and slope, weather data, an estimation of the energy use for electrical lighting and an intelligent control of the building systems for the calculations, WinDesign is still a very user-friendly program with a fast calculation time that can be used early in the design process. This is in contrast with more advanced programs that are often not used until much later in the design process.

The latest version of the program, WinDesign 2.0, is accessible at DTU Byg’s Internet portal: http://www.vinduesvidensystem.dk/. (In Danish)

BE06 (Denmark)

Energy regulations in the Danish Buildings Code in force became much stricter from 1 January 2006. The Be06 calculation program has been developed by SBi (the Danish Building Research Institute) for the calculation of the energy balance in buildings and can be used to document that buildings comply with the new energy requirements in the Building Regulations. The program has later on been updated to the version BE10 in connection with the new Building Regulations of 2010. The program is to be used by consulting engineers, architects in the design stage and other energy consultants to issue energy labels, etc. and requires that users have thorough knowledge of the requirements in the building code and how to calculate heat loss from buildings.

Five different levels of calculation can be performed in Be06: calculation of the building with its current condition, calculation of a reference according to the requirements in the Building Code, calculation of the energy balance of the existing building for labelling and saving suggestions and other calculations according to the users´ wishes.

The latest version of the program is available on the official site of SBi: http://www.sbi.dk/miljo-og-energi/energiberegning/anvisning-213-bygningers-energibehov/ (In Danish)

EnergiKoncept (Denmark)

Energikoncept.dk is a digital tool that is designed to give a rough calculation of energy use and advice on energy optimal renovation of multi-storey buildings (but it could also be used for small houses). The tool is developed as a free utility to be used by building owners, engineering consultants and executive craftsmen who want to get a quick introductory overview of possible energy saving measures and is not a true design tool but a tool, where the few entries can get estimates and calculations of energy savings and advice on eco-renovation of a building. The estimates of energy savings calculated with the tools may thus differ from more detailed calculations in BE06 according to the Danish energy requirements.

The tool consists of three modules, namely concept, configuration and results, of which only the first module is available today. In the concept part, a basic 3D model of the existing building is generated based on user input data. Based on this basic model for the existing building, the tool offers tips of how the building could be improved to reduce the energy use.

If users want to modify the existing building to reduce the energy use, they can do this in the configuration part of the tool where they can choose between a number of generic (unspecified) structural components and energy-saving actions. Version 2 of the tool, expected January 2010, will include a catalogue of possible energy saving measures and examples of concrete energy renovation projects.

The implication of energy saving actions on the building´s energy use and energy class before and after the modification of the building can be consulted in the third module. This module which contains the results also presents economic consequences, expected architectural and indoor air quality and operational consequences of the changes made. A report of the energy saving measures imposed on the existing building can also be printed out in this module.

The present version of the program is available on www.energikoncept.dk. (In Danish)

Enorm (Sweden)

Enorm is a calculation tool designed to quickly determine the energy use of a building with reasonable request for input and can be used by building consultants, architects, energy consultants, contractors and even building owners. Since the calculations are based on the Building Regulations, the tool gives the possibility to easily verify if the regulation requirements regarding energy use are met. The tool can also be used for energy calculations of existing buildings and the results can then be used as basis for the choice between different energy saving measures in order to reduce the energy use.

The program contains four modules: a module for data input, a module that calculates the energy use of the building and compares it to the requirements in the Building Regulations, a module to calculate U-values and transmission heat loss coefficients and a module that analyses the economy of the building by taking into account energy savings and total lifecycle costs during the in-use phase of the building. The calculated energy use of the building is subdivided into specific parts: energy needed for heating, electricity needed to operate the fans and pumps, the driving energy for heat pumps and heat exchangers and electricity needed for household and appliances. If detailed calculations of the thermal indoor environment are required, especially in buildings with a risk of overheating, it is advisable to use the IDA Climate and Energy calculation program.

VIP+ (Sweden and Norway)

The VIP+ program is the Nordic version of the VIP-Energy program and is similar to the Bsim simulation tool used in Denmark. VIP+ is used to calculate the energy balance in buildings according to known and measurable energy flows so there is no need to estimate any part of the energy balance. VIP+ contains two primary calculation models. One model for heat accumulation and one model for calculation of air flow trough ventilation and infiltration. A dynamic calculation model gives the result hourly trough a year.

The program also includes a building part catalogue where the composition of different building components can be defined and which is coupled to a data catalogue including different materials and possible operating scenarios for the building. Furthermore, a function to calculate 2D and 3D heat flows is integrated in the program.

When calculating the energy balance of the building, the program makes three calculations that can be compared to each other. In the first calculation, the building and its operation are exactly calculated according to the user input. The result of this calculation should thus be comparable to the situation in reality. For the second calculation, only the composition of the building is calculated according to the user input. The operation of the building is calculated according to the Swedish building code BBR2002. The result of this second calculation should then be compared with the result from the third calculation where both the building and its operation are calculated according to the requirements in the Swedish Building Code.

WinEtana (Finland)

The WinEtana program has been developed together with the Helsinki Energy, the Public Works of the City of Helsinki and VTT Building Technology and is used for support for energy audits, building design (preliminary design of new buildings and energy analysis for renovation projects), energy advisory services and training of energy advisors and consultants.

WinEtana is an easy to use calculation tool for energy balance calculations. The calculation method is based on the simple single-zone steady-state thermal analysis and the calculations are based on the Finish building regulation D5 and the European standard proposal pr EN 832 1994 and are performed in three steps.

The program makes intelligent assumptions for the building during the first calculation. Most of the input data needed for normal energy analyses is located in a knowledge data base, from which the program collects appropriate information according to user input about building type, location, construction year and geometrical information (volume, shape of the building, number of floors, floor height). On the basis of these the program selects U-values, window types, hot water use, ventilation system, electricity use and internal gains from the data base and calculate necessary estimates of envelope areas. All generated input values can be changed after the first calculation if more reliable estimates are needed and if more information is known. A weakness of the program is, however, that the knowledge database is fixed for Finish buildings only and that the results for energy balance calculated with the steady-state method have been investigated only to be reliable when the heating demand compared to heat gains is over 30% as it is in Northern Europe.

RIUSKA (Finland and Norway)

RIUSKA is a tool developed by the company Granlund Oy to be used by engineers for the dynamic simulation of comfort and energy balance in building services design and facilities management in everyday design processes. The tool covers the thermal simulation needs of the whole building life cycle from the preliminary design to renovations and is useful at all stages of design. It calculates inside temperatures and the heating and cooling demands of individual spaces, and can be used to compare and dimension HVAC systems as well as for calculating the energy balance of whole buildings. RIUSKA also has a module to calculate the heat loss of a building in steady-state conditions.

The main components of the simulation tool are a simulation database, user interfaces, a result module, a building geometry modeller and a calculation engine. The building geometry modeller generates a 3-D surface model of the building. The building geometry modelling for use in RIUSKA can be performed by SMOG, an object-oriented 3D space modelling software program also developed by Granlund. However, it is also possible to directly transfer and reuse digital building geometry data from IFC-compliant architect software, such as AutoCad and ArchiCAD. The user can then add building envelope materials, internal loads and HVAC-system into the created 3D-model of the building, or can choose from predefined library values, in order to perform the calculations. As a calculation engine RIUSKA is presently using DOE-2.1E. DOE was chosen because it is widely known among Building Services designers around the world, and it is well optimised for building services engineering purposes in terms of calculation accuracy and calculation time.

Hourly or yearly output values for cooling and heating energy uses, temperatures and cooling loads can be viewed in the result module of the tool or with a stand-alone result viewing application, which allows designers and engineers to compare different simulations with a light and easy-to-use program.

Simien (Norway)

Simien is a dynamic building simulation program for calculating the annual energy, power demand and indoor climate in buildings. The results from the calculations for the annual net energy (calculated with the Oslo climate data) are divided into several energy budgets for heating, cooling, lighting, ventilation and equipment and are evaluated according to the revised Norwegian Standard NS3031: 2007 and the Norwegian technical requirements TEK07. Also input values for U-values, heat losses, infiltration, fan power, efficiencies,...are compared to the requirements in the Norwegian Building Code.

APPENDIX 3: RENOVATION SCENARIOS

Denmark

Master builder house (-1930)

Scenario	**1**	**2**	**3**	**4**	**5**
General					
Heated surface area (m²)	161	do	do	do	do
Heat capacity	Heavy	Heavy	Heavy	Medium heavy	Heavy
Internal gains (W/m²)	5	do	do	do	do
Building envelope					
U-value walls	1.26	0.6	do	0.29	0.22
U-value roof	0.61	0.19	do	do	do
U-value floor	1.12	1.12	do	0.4	do
Total UA-value	317.5	197.8	do	86.5	79.4
U-value window	3.27	1.60	do	0.8	do
Ventilation					
Ventilation system	Natural	do	Mechanical with heat recovery	do	do
Ventilation rate (1/h)	0.5	do	do	do	do
Infiltration rate (1/h)	Incl.	Incl.	0,18/0.13	do	do
Efficiency of heat recovery (%)	-	-	80/85	-	-
SFP (kJ/m³)	-	-	1.0/0.6	do	do
Heating					
Heat supply	Old oil-fired boiler	do	New condensing boiler	do	do
Power circulation pump	60W	do	25W	do	do
Hot water tank	200l, 30mm insulation	do	do	do	do
Domestic Hot Water use (l/m²/year)	250	do	do	do	do

Standard detached house (1961-1978)

Scenario	**1**	**2**	**3**	**4**	**5**
General					
Heated surface area (m²)	154.5	do	do	do	do
Heat capacity	Heavy	do	do	do	do
Internal gains (W/m²)	5	do	do	do	do
Building envelope					
U-value walls	0.53	0.19	do	do	0.13
U-value roof	0.27	0.10	do	do	do
U-value floor	0.36	0.36	do	do	0.15
Total UA-value	180.67	106.30	do	do	70.4
U-value window	2.8	1.34	do	do	0.8
Ventilation					
Ventilation system	Natural	do	Mechanical with heat recovery	do	do
Ventilation rate (1/h)	0.5	0.5	0.5	do	do
Infiltration rate (1/h)	-	-	0,18/0.13	do	do
Efficiency of heat recovery (%)	-	-	80/85	do	do
SFP (kJ/m³)	-	-	1.0/0.6	do	do
Heating					
Heat supply	gas boiler	do	New condensing gas boiler	do	do
Solar heating	-	-	-	solar heating	do
Power circulation pump	60W	do	25W	do	do
Power pump solar heating	-	-	-	40W	do
Hot water tank	90l, 30mm insulation	do	do	200 l, 40mm insulation	do
Domestic Hot Water use (l/m²/year)	250	do	do	do	do

Sweden

Standard detached house (1961-1976)

Scenario	**1**	**2**	**3**	**4**	**5**
General					
Heated surface area (m²)	236	do	do	do	do
Heat capacity (eenheid)	Medium heavy	do	do	do	do
Internal gains (W/m²)	5	do	do	do	do
Building envelope					
U-value walls	0.40	0.32	0.32	0.32	0.18
U-value roof	0.25	0.11	0.11	0.11	0.11
U-value floor	0.45	0.27	0.27	0.27	0.15
Total UA-value	165.32	112.72	112.72	112.72	71.04
U-value window	2.70	1.20	do	do	0.8
Ventilation					
Ventilation system	Natural	do	Mechanical with heat recovery	do	do
Ventilation rate (1/h)	0.5	do	0.5	do	do
Infiltration rate (1/h)	0.1	do	0.1	do	do
Efficiency of heat recovery (%)	-	-	70/85	do	do
SFP (kJ/m³)	-	-	1	do	do
Heating					
Heat supply	Electric resistance heaters	do	do	Heat pump, COP 3.1	do
Hot water tank	200l, 30mm insulation	do	do	do	do
Domestic Hot Water use (l/m²/year)	250	do	do	do	do

Norway

Scenario	**1**	**2**	**3**	**4**	**5**
Building envelope (-1945)					
U-value walls	0.55	0.25	0.25	0.25	0.2
U-value roof	0.38	0.2	0.2	0.2	0.15
U-value floor	0.53	0.2	0.2	0.2	0.2
Total UA-value	140.76	64.75	64.75	64.75	54.25
U-value window	2.24	1.6	1.6	1.2	1
Building envelope (1970)					
U-value walls	0.38	0.22	0.22	0.22	0.18
U-value roof	0.2	0.15	0.15	0.15	0.15
U-value floor	0.36	0.2	0.2	0.2	0.2
Total UA-value	120.75	75.11	75.11	75.11	71.45
U-value window	2.24	1.6	1.6	1.2	1
Ventilation					
Ventilation system	Natural	do	Mechanical with heat recovery	do	do
Ventilation rate (1/h)	0.6/0.5	do	0.6/0.5	do	do
Infiltration rate (1/h)	0.1	do	0.1	do	do
Efficiency of heat recovery (%)	-	-	70/85	do	do
SFP (kJ/m³)	-	-	1	do	do
Heating					
Heat supply	Electric resistance heaters	do	do	Heat pump, COP 3	do
Hot water tank	90l, 30mm insulation	do	do	do	do
Domestic Hot Water use (l/m²/year)	250	do	do	do	do

Finland

Scenario	**1**	**2**	**3**	**4**	**5**
Building envelope (-1945)					
U-value walls	0.7	0.24	0.24	0.24	0.17
U-value roof	0.4	0.15	0.15	0.15	0.09
U-value floor	0.45	0.16	0.16	0.16	0.16
Total UA-value	129.33	46.62	46.62	46.62	35.49
U-value window	3.7	1.4	1.4	1.4	0.8
Building envelope (1960)					
U-value walls	0.45	0.25	0.25	0.25	0.17
U-value roof	0.35	0.16	0.16	0.16	0.09
U-value floor	0.4	0.2	0.2	0.2	0.16
Total UA-value	173.54	88.38	88.38	88.38	61.02
U-value window	3.14	1.4	1.4	1.4	0.8
Building envelope (1970)					
U-value walls	0.28	0.24	0.24	0.24	0.17
U-value roof	0.3	0.15	0.15	0.15	0.09
U-value floor	0.22	0.19	0.19	0.19	0.16
Total UA-value	84.5	61.13	61.13	61.13	44.49
U-value window	2.1	1.4	1.4	1.4	0.8
Ventilation					
Ventilation system	Natural	do	Mechanical with heat recovery	do	do
Ventilation rate (1/h)	0.5	do	0.5	do	do
Infiltration rate (1/h)	0.1	do	0.1	do	do
Efficiency of heat recovery (%)	-	-	60/85	do	do
SFP (kJ/m³)	-	-	1	do	do
Heating					
Heat supply	Oil-fired boiler/ resistance heaters	do	do	Heat pump, COP 3	do
Power circulation pump	60W	do	25W	do	do
Hot water tank	70l/90l, 30mm insulation	do	do	do	do
Domestic Hot Water use (l/m²/year)	250	do	do	do	do

APPENDIX 4: CALCULATION RESULTS FOR ENERGY USE

Denmark

Masterbuilder house (built in 1927) 161 m2

	Scenario 1	Scenario 2	Scenario 3a	Scenario 3b	Scenario 3c	Scenario 4	Scenario 5
Results winDesign							
Space heating demand (kWh/m2)	209.4	130.4	110.4	103.6	103.6	37.1	33.1
Space cooling demand (kWh/m2)	-	-	-	-	-	-	-
Length heating season	365	365	328	318	318	256	240
Length cooling season	0	0	0	0	0	66	47
Hours of overheating > 26ºC	0	0	0	0	0	24	6
Electrical light demand (kWh/m2)	36	36.7	36.7	36.7	36.7	36.7	37.8
Energy need for space heating (kWh/m2)	**209.4**	**130.4**	**110.4**	**103.6**	**103.6**	**37.1**	**33.1**
Hot water consumption (kWh/m2)	13.08	13.08	13.08	13.08	13.08	13.08	13.08
Heat loss coefficient pipes	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Lenght pipes	109	109	109	109	109	109	109
Utilization factor heating season	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Utilization factor cooling season	0	0	0	0	0	0	0
Non-utilized heat losses from pipes heating season (kWh/m2)	20.83	20.83	18.65	18.15	18.15	14.61	13.70
Non-utilized heat losses from pipes cooling season (kWh/m2)	0.00	0.00	0.00	0.00	0.00	7.53	5.37
Heat loss coefficient hot water tank	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Utilization factor heating season	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Utilization factor cooling season	0	0	0	0	0	0	0
Non-utilized heat losses from hot water tank heating season (kWh/m2)	2.48	2.48	2.22	2.16	2.16	1.74	1.63
Non-utilized heat losses from hot water tank cooling season (kWh/m2)	0.00	0.00	0.00	0.00	0.00	0.90	0.64
Non-utilized heat losses from pipes (kWh/m2)	20.83	20.83	18.65	18.15	18.15	22.15	19.06
Non-utilized heat losses from hot water tank (kWh/m2)	2.48	2.48	2.22	2.16	2.16	2.63	2.27
Contribution solar heating (kWh/m2)	-	-	-	-	-	-	
Energy need for heating (kWh/m2)	**245.79**	**166.79**	**144.36**	**136.99**	**136.99**	**74.96**	**67.51**
Yearly efficiency of heat supply system	0.65	0.65	1	1	3.6	1	1
Energy use for heating (kWh/m2)	**378.14**	**256.61**	**144.36**	**136.99**	**38.05**	**74.96**	**67.51**
Electricity use for circulation pump (kWh/m2)	2.61	2.61	0.54	0.54	0.54	0.54	0.54
Electricity use for pump solar heating (kWh/m2)	-	-	-	-	-	-	-
Electricity use for ventilation (kWh/m2)	-	-	3.15	1.58	1.58	1.58	1.58
Electricity use for heating and ventilation (kWh/m2)	**2.61**	**2.61**	**3.70**	**2.12**	**2.12**	**2.12**	**2.12**
Primary energy use (excl. household appliances) (kWh/m2)	**384.67**	**263.13**	**153.61**	**142.29**	**100.44**	**80.26**	**72.82**

Standard detached house (built in 1972)

154.5 m2

	Scenario 1	Scenario 2	Scenario 3a	Scenario 3b	Scenario 4	Scenario 5
Results winDesign						
Space heating demand (kWh/m2)	159.6	81.1	61.2	54.6	54.6	35
Space cooling demand (kWh/m2)	-	-	-	-	-	-
Length heating season	287	241	225	219	219	201
Length cooling season	103	142	134	134	134	135
Hours of overheating > 26ºC	217	397	346	363	363	270
Electrical light demand (kWh/m2)	36	37.8	37.8	37.8	37.8	37.8
Energy need for space heating (kWh/m2)	**159.6**	**81.1**	**61.2**	**54.6**	**54.6**	**35**
Hot water consumption (kWh/m2)	13.08	13.08	13.08	13.08	13.08	13.08
Heat loss coefficient pipes	0.2	0.2	0.2	0.2	0.2	0.2
Lenght pipes	94	94	94	94	94	94
Utilization factor heating season	0.4	0.4	0.4	0.4	0.4	1
Utilization factor cooling season	0	0	0	0	0	0
Non-utilized heat losses from pipes heating season (kWh/m2)	17.60	14.78	13.80	13.43	13.43	0.00
Non-utilized heat losses from pipes cooling season (kWh/m2)	10.53	14.51	13.70	13.70	13.70	13.80
Heat loss coefficient hot water tank	1.6	1.6	1.6	1.6	2.3	2.3
Utilization factor heating season	0.5	0.7	0.7	0.7	0.7	1
Utilization factor cooling season	0	0	0	0	0	0
Non-utilized heat losses from hot water tank heating season (kWh/m2)	1.25	0.63	0.59	0.57	0.82	0.00
Non-utilized heat losses from hot water tank cooling season (kWh/m2)	0.90	1.24	1.17	1.17	1.68	1.69
Non-utilized heat losses from pipes (kWh/m2)	28.13	29.29	27.50	27.13	27.13	13.80
Non-utilized heat losses from hot water tank (kWh/m2)	2.14	1.86	1.75	1.74	2.50	1.69
Contribution solar heating (kWh/m2)	-	-	-	-	5.24	5.24
Energy need for heating (kWh/m2)	**202.96**	**125.34**	**103.53**	**96.55**	**92.07**	**58.33**
Yearly efficiency of heat supply system	0.85	0.85	0.98	0.98	0.98	0.98
Energy use for heating (kWh/m2)	**238.77**	**147.46**	**105.65**	**98.52**	**93.95**	**59.52**
Electricity use for circulation pump (kWh/m2)	2.72	2.72	0.57	0.57	0.57	0.57
Electricity use for pump solar heating (kWh/m2)	-	-	-	-	0.26	0.26
Electricity use for ventilation (kWh/m2)	-	-	3.15	1.58	1.58	1.58
Electricity use for heating and ventilation (kWh/m2)	**2.72**	**2.72**	**3.72**	**2.14**	**2.40**	**2.40**
Primary energy use (excl. household appliances) (kWh/m2)	**245.58**	**154.27**	**114.95**	**103.88**	**99.95**	**65.53**

Sweden

Detached house 1961-1976

236 m2

	Scenario 1			Scenario 2			Scenario 3			Scenario 4a			Scenario 4b			Scenario 5		
Results winDesign	Stockholm	Ostersund	Kiruna	Stockholm	Ostersund	Kiruna	Stockholm	Ostersund	Kiruna	Stockholm	Ostersund	Kiruna	Stockholm	Ostersund	Kiruna	Stockholm	Ostersund	Kiruna
Space heating demand (kWh/m2)	103.1	134.9	196.9	61.8	82.6	125.9	61.8	82.6	125.9	33	45.9	73.9	27.3	38.6	63.2	13.9	22.1	38.1
Space cooling demand (kWh/m2)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Length heating season	273	340	358	242	302	348	246	246	348	207	246	299	195	234	288	150	168	252
Length cooling season	107	51	7	133	77	29	77	77	29	133	77	29	133	77	29	154	110	54
Hours of overheating > 26ºC	197	108	-	169	93	-	169	93	-	169	93	-	169	94	-	207	120	-
Electrical light demand (kWh/m2)	38.025	38.61	45.63	40.82	41.47	45.63	40.82	41.47	45.63	40.82	41.47	45.63	40.82	41.47	45.63	40.82	41.47	45.63
Energy need for space heating (kWh/m2)	**103.1**	**134.9**	**196.9**	**61.8**	**82.6**	**125.9**	**61.8**	**82.6**	**125.9**	**33**	**45.9**	**73.9**	**27.3**	**38.6**	**63.2**	**13.9**	**22.1**	**38.1**
Hot water consumption (kWh/m2)	13.08	13.08	13.08	13.08	13.08	13.08	13.08	13.08	13.08	13.08	13.08	13.08	13.08	13.08	13.08	13.08	13.08	13.08
Heat loss coefficient pipes	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Lenght pipes	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Utilization factor heating season	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Utilization factor cooling season	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-utilized heat losses from pipes heating season (kWh/m2)	1.40	1.74	1.83	1.24	1.55	1.78	1.26	1.26	1.78	1.06	1.26	1.53	1.00	1.20	1.48	0.77	0.86	1.29
Non-utilized heat losses from pipes cooling season (kWh/m2)	0.91	0.44	0.06	1.14	0.66	0.25	0.66	0.66	0.25	1.14	0.66	0.25	1.14	0.66	0.25	1.32	0.94	0.46
Heat loss coefficient hot water tank	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Utilization factor heating season	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Utilization factor cooling season	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-utilized heat losses from hot water tank heating season (kWh/m2)	0.51	0.63	0.66	0.45	0.56	0.64	0.46	0.46	0.64	0.38	0.46	0.55	0.36	0.43	0.53	0.28	0.31	0.47
Non-utilized heat losses from hot water tank cooling season (kWh/m2)	0.99	0.47	0.06	1.23	0.71	0.27	0.71	0.71	0.27	1.23	0.71	0.27	1.23	0.71	0.27	1.43	1.02	0.50
Non-utilized heat losses from pipes (kWh/m2)	2.31	2.18	1.89	2.38	2.21	2.03	1.92	1.92	2.03	2.20	1.92	1.78	2.14	1.86	1.72	2.08	1.80	1.75
Non-utilized heat losses from hot water tank (kWh/m2)	1.50	1.10	0.73	1.68	1.27	0.91	1.17	1.17	0.91	1.61	1.17	0.82	1.59	1.15	0.80	1.70	1.33	0.97
Contribution solar heating (kWh/m2)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Energy need for heating (kWh/m2)	**119.99**	**151.26**	**212.61**	**78.94**	**99.16**	**141.93**	**77.97**	**98.77**	**141.93**	**49.90**	**62.07**	**89.59**	**44.11**	**54.69**	**78.81**	**30.77**	**38.31**	**53.90**
Yearly efficiency of heat supply system	0.97	0.97	0.97	0.97	0.97	0.97	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
Energy use for heating (kWh/m2)	**123.70**	**155.94**	**219.18**	**81.38**	**102.23**	**146.32**	**23.63**	**29.93**	**43.01**	**15.12**	**18.81**	**27.15**	**13.37**	**16.57**	**23.88**	**9.32**	**11.61**	**16.33**
Electricity use for circulation pump (kWh/m2)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electricity use for pump solar heating (kWh/m2)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electricity use for ventilation (kWh/m2)	-	-	-	-	-	-	-	-	-	2.63	2.63	2.63	2.63	2.63	2.63	2.63	2.63	2.63
Electricity use for heating and ventilation (kWh/m2)										**2.63**	**2.63**	**2.63**	**2.63**	**2.63**	**2.63**	**2.63**	**2.63**	**2.63**
Primary energy use (excl. household appliances) (kWh/m2)	**327.82**	**413.25**	**580.83**	**215.66**	**270.91**	**387.74**	**62.61**	**79.32**	**113.97**	**47.03**	**56.81**	**78.90**	**42.39**	**50.88**	**70.25**	**31.67**	**37.73**	**50.25**

Norway

Single-family house -1945

124 m2

	Scenario 1		Scenario 2		Scenario 3		Scenario 4a		Scenario 4b		Scenario 5	
Results winDesign	Oslo	Bergen	Oslo	Bergen	Oslo	Bergen	Oslo	Bergen	Oslo	Bergen	Oslo	Bergen
Space heating demand (kWh/m2)	142.4	137.8	84.1	79.8	84.1	79.8	47.4	43.2	41.5	37.6	32.2	29.8
Space cooling demand (kWh/m2)	-	-	-	-	-	-	-	-	-	-	-	-
Length heating season	287	365	252	302	252	302	226	248	219	241	208	231
Length cooling season	121	88	141	117	141	117	148	122	148	122	143	118
Hours of overheating > 26ºC	422	192	591	253	591	253	655	269	654	269	550	238
Electrical light demand (kWh/m2)	37.12	37.38	39.98	40.82	39.98	40.82	39.98	40.82	39.98	40.82	41.28	42.19
Energy need for space heating (kWh/m2)	**142.4**	**137.8**	**84.1**	**79.8**	**84.1**	**79.8**	**47.4**	**43.2**	**41.5**	**37.6**	**32.2**	**29.8**
Hot water consumption (kWh/m2)	13.08	13.08	13.08	13.08	13.08	13.08	13.08	13.08	13.08	13.08	13.08	13.08
Heat loss coefficient pipes	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Lenght pipes	12	12	12	12	12	12	12	12	12	12	12	12
Utilization factor heating season	1	1	1	1	1	1	1	1	1	1	1	1
Utilization factor cooling season	0	0	0	0	0	0	0	0	0	0	0	0
Non-utilized heat losses from pipes heating season (kWh/m2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-utilized heat losses from pipes cooling season (kWh/m2)	1.97	1.43	2.29	1.90	2.29	1.90	2.41	1.98	2.41	1.98	2.32	1.92
Heat loss coefficient hot water tank	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Utilization factor heating season	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Utilization factor cooling season	0	0	0	0	0	0	0	0	0	0	0	0
Non-utilized heat losses from hot water tank heating season (kWh/m2	0.62	0.79	0.55	0.65	0.55	0.65	0.49	0.54	0.49	0.54	0.45	0.50
Non-utilized heat losses from hot water tank cooling season (kWh/m2	1.31	0.95	1.53	1.27	1.53	1.27	1.60	1.32	1.60	1.32	1.55	1.28
Non-utilized heat losses from pipes (kWh/m2)	1.97	1.43	2.29	1.90	2.29	1.90	2.41	1.98	2.41	1.98	2.32	1.92
Non-utilized heat losses from hot water tank (kWh/m2)	1.93	1.75	2.07	1.92	2.07	1.92	2.09	1.86	2.09	1.86	2.00	1.78
Contribution solar heating (kWh/m2)	-	-	-	-	-	-	-	-	-	-	-	-
Energy need for heating (kWh/m2)	**159.39**	**154.06**	**101.55**	**96.71**	**101.55**	**96.71**	**64.98**	**60.13**	**59.08**	**54.53**	**49.61**	**46.58**
Yearly efficiency of heat supply system	1	1	1	1	3	3	3	3	3	3	3	3
Energy use for heating (kWh/m2)	**159.39**	**154.06**	**101.55**	**96.71**	**33.85**	**32.24**	**21.66**	**20.04**	**19.69**	**18.18**	**16.54**	**15.53**
Electricity use for circulation pump (kWh/m2)	-	-	-	-	-	-	-	-	-	-	-	-
Electricity use for pump solar heating (kWh/m2)	-	-	-	-	-	-	-	-	-	-	-	-
Electricity use for ventilation (kWh/m2)	-	-	-	-	-	-	2.63	2.63	2.63	2.63	2.63	2.63
Electricity use for heating and ventilation (kWh/m2)							**2.63**	**2.63**	**2.63**	**2.63**	**2.63**	**2.63**
Primary energy use (excl. household appliances) (kWh/m2)	**398.46**	**385.15**	**253.88**	**241.77**	**84.63**	**80.59**	**60.72**	**56.68**	**55.81**	**52.01**	**47.91**	**45.39**

Single-family house 1971-1980

137 m2

	Scenario 1		Scenario 2		Scenario 3		Scenario 4a		Scenario 4b		Scenario 5	
Results winDesign	Oslo	Bergen	Oslo	Bergen	Oslo	Bergen	Oslo	Bergen	Oslo	Bergen	Oslo	Bergen
Space heating demand (kWh/m2)	105.3	99.6	75.9	71.3	75.9	71.3	44.3	39.8	39.5	35.2	30.8	27
Space cooling demand (kWh/m2)	-	-	-	-	-	-	-	-	-	-	-	-
Length heating season	272	365	255	322	255	322	232	255	227	248	217	238
Length cooling season	127	101	132	106	132	106	138	113	138	113	141	116
Hours of overheating > 26ºC	389	182	340	169	340	169	387	183	386	183	349	174
Electrical light demand (kWh/m2)	37.12	37.38	39.98	40.82	39.98	40.82	39.98	40.82	39.98	40.82	41.28	42.19
Energy need for space heating (kWh/m2)	**105.3**	**99.6**	**75.9**	**71.3**	**75.9**	**71.3**	**44.3**	**39.8**	**39.5**	**35.2**	**30.8**	**27**
Hot water consumption (kWh/m2)	13.08	13.08	13.08	13.08	13.08	13.08	13.08	13.08	13.08	13.08	13.08	13.08
Heat loss coefficient pipes	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Lenght pipes	12	12	12	12	12	12	12	12	12	12	12	12
Utilization factor heating season	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Utilization factor cooling season	0	0	0	0	0	0	0	0	0	0	0	0
Non-utilized heat losses from pipes heating season (kWh/m2)	2.00	2.69	1.88	2.37	1.88	2.37	1.71	1.88	1.67	1.82	1.60	1.75
Non-utilized heat losses from pipes cooling season (kWh/m2)	1.87	1.49	1.94	1.56	1.94	1.56	2.03	1.66	2.03	1.66	2.07	1.71
Heat loss coefficient hot water tank	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Utilization factor heating season	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Utilization factor cooling season	0	0	0	0	0	0	0	0	0	0	0	0
Non-utilized heat losses from hot water tank heating season (kWh/m2	1.33	1.79	1.25	1.58	1.25	1.58	1.14	1.25	1.11	1.22	1.06	1.17
Non-utilized heat losses from hot water tank cooling season (kWh/m2	1.25	0.99	1.29	1.04	1.29	1.04	1.35	1.11	1.35	1.11	1.38	1.14
Non-utilized heat losses from pipes (kWh/m2)	3.87	4.17	3.82	3.93	3.82	3.93	3.74	3.54	3.70	3.49	3.67	3.46
Non-utilized heat losses from hot water tank (kWh/m2)	2.58	2.78	2.55	2.62	2.55	2.62	2.49	2.36	2.47	2.33	2.45	2.31
Contribution solar heating (kWh/m2)	-	-	-	-	-	-	-	-	-	-	-	-
Energy need for heating (kWh/m2)	**124.83**	**119.64**	**95.35**	**90.93**	**95.35**	**90.93**	**63.61**	**58.78**	**58.75**	**54.10**	**50.00**	**45.85**
Yearly efficiency of heat supply system	1	1	1	1	3	3	3	3	3	3	3	3
Energy use for heating (kWh/m2)	**124.83**	**119.64**	**95.35**	**90.93**	31.78	30.31	**21.20**	**19.59**	**19.58**	**18.03**	16.67	15.28
Electricity use for circulation pump (kWh/m2)	-	-	-	-	-	-	-	-	-	-	-	-
Electricity use for pump solar heating (kWh/m2)	-	-	-	-	-	-	-	-	-	-	-	-
Electricity use for ventilation (kWh/m2)	-	-	-	-	-	-	2.63	2.63	2.63	2.63	2.63	2.63
Electricity use for heating and ventilation (kWh/m2)							**2.63**	**2.63**	**2.63**	**2.63**	**2.63**	**2.63**
Primary energy use (excl. household appliances) (kWh/m2)	**312.09**	**299.09**	**238.37**	**227.33**	**79.46**	**75.78**	**59.58**	**55.56**	**55.53**	**51.65**	**48.24**	**44.78**

Finland

Veteran house -1945

70 m2

	Scenario 1	Scenario 2	Scenario 3	Scenario 4a	Scenario 4b	Scenario 5
Results winDesign						
Space heating demand (kWh/m2)	264.1	108	108	74.5	61	40.4
Space cooling demand (kWh/m2)	-	-	-	-		-
Length heating season	365	285	285	256	246	229
Length cooling season	20	117	117	117	117	119
Hours of overheating > 26ºC	125	246	246	246	248	240
Electrical light demand (kWh/m2)	36.73	39.65	39.65	39.65	39.65	40.95
Energy need for space heating (kWh/m2)	**264.1**	**108**	**108**	**74.5**	**61**	**40.4**
Hot water consumption (kWh/m2)	13.08	13.08	13.08	13.08	13.08	13.08
Heat loss coefficient pipes	0.2	0.2	0.2	0.2	0.2	0.2
Lenght pipes	66	66	66	66	66	66
Utilization factor heating season	0.4	0.4	0.4	0.4	0.4	0.4
Utilization factor cooling season	0	0	0	0	0	0
Non-utilized heat losses from pipes heating season (kWh/m2)	34.69	27.09	27.09	24.33	23.38	21.76
Non-utilized heat losses from pipes cooling season (kWh/m2)	3.17	18.53	18.53	18.53	18.53	18.85
Heat loss coefficient hot water tank	1.3	1.3	1.3	1.3	1.3	1.3
Utilization factor heating season	0.8	0.8	0.8	0.8	0.8	0.8
Utilization factor cooling season	0	0	0	0	0	0
Non-utilized heat losses from hot water tank heating season (kWh/m2)	1.14	0.89	0.89	0.80	0.77	0.71
Non-utilized heat losses from hot water tank cooling season (kWh/m2)	0.31	1.83	1.83	1.83	1.83	1.86
Non-utilized heat losses from pipes (kWh/m2)	37.86	45.62	45.62	42.86	41.91	40.61
Non-utilized heat losses from hot water tank (kWh/m2)	1.45	2.71	2.71	2.62	2.59	2.57
Contribution solar heating (kWh/m2)	-	-	-	-	-	-
Energy need for heating (kWh/m2)	**316.49**	**169.42**	**169.42**	**133.07**	**118.59**	**96.67**
Yearly efficiency of heat supply system	0.84	0.84	3	3	3	3
Energy use for heating (kWh/m2)	**376.78**	**201.69**	**56.47**	**44.36**	**39.53**	**32.22**
Electricity use for circulation pump (kWh/m2)	6.01	6.01	1.25	1.25	1.25	1.25
Electricity use for pump solar heating (kWh/m2)	-	-	-	-	-	-
Electricity use for ventilation (kWh/m2)	-	-		2.63	2.63	2.63
Electricity use for heating and ventilation (kWh/m2)	**6.01**	**6.01**	**1.25**	**3.88**	**3.88**	**3.88**
Primary energy use (excl. household appliances) (kWh/m2)	**394.80**	**219.71**	**173.17**	**144.71**	**130.23**	**108.31**

Single family house 1960´s	147 m2					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4a**	**Scenario 4b**	**Scenario 5**
Results winDesign						
Space heating demand (kWh/m2)	178.2	87.8	87.8	61.2	53.3	29.9
Space cooling demand (kWh/m2)	-	-	-	-	-	-
Length heating season	306	255	255	235	226	196
Length cooling season	106	146	146	146	146	159
Hours of overheating > 26ºC	361	641	641	646	644	695
Electrical light demand (kWh/m2)	36.73	39.65	39.65	39.65	39.65	40.95
Energy need for space heating (kWh/m2)	**178.2**	**87.8**	**87.8**	**61.2**	**53.3**	**29.9**
Hot water consumption (kWh/m2)	13.08	13.08	13.08	13.08	13.08	13.08
Heat loss coefficient pipes	0.2	0.2	0.2	0.2	0.2	0.2
Lenght pipes	91	91	91	91	91	91
Utilization factor heating season	0.4	0.4	0.4	0.4	0.4	0.4
Utilization factor cooling season	0	0	0	0	0	0
Non-utilized heat losses from pipes heating season (kWh/m2)	19.09	15.91	15.91	14.66	14.10	12.23
Non-utilized heat losses from pipes cooling season (kWh/m2)	11.02	15.18	15.18	15.18	15.18	16.54
Heat loss coefficient hot water tank	1.6	1.6	1.6	1.6	1.6	1.6
Utilization factor heating season	0.5	0.5	0.5	0.5	0.5	0.5
Utilization factor cooling season	0	0	0	0	0	0
Non-utilized heat losses from hot water tank heating season (kWh/m2)	1.40	1.17	1.17	1.07	1.03	0.90
Non-utilized heat losses from hot water tank cooling season (kWh/m2)	0.97	1.33	1.33	1.33	1.33	1.45
Non-utilized heat losses from pipes (kWh/m2)	30.12	31.10	31.10	29.85	29.29	28.77
Non-utilized heat losses from hot water tank (kWh/m2)	2.37	2.50	2.50	2.41	2.37	2.35
Contribution solar heating (kWh/m2)	-	-	-	-	-	-
Energy need for heating (kWh/m2)	**223.77**	**134.48**	**134.48**	**106.54**	**98.04**	**74.10**
Yearly efficiency of heat supply system	0.84	0.84	3	3	3	3
Energy use for heating (kWh/m2)	**266.39**	**160.10**	**44.83**	**35.51**	**32.68**	**24.70**
Electricity use for circulation pump (kWh/m2)	2.86	2.86	0.60	0.60	0.60	0.60
Electricity use for pump solar heating (kWh/m2)	-	-	-	-	-	-
Electricity use for ventilation (kWh/m2)	-	-		2.63	2.63	2.63
Electricity use for heating and ventilation (kWh/m2)	**2.86**	**2.86**	**0.60**	**3.22**	**3.22**	**3.22**
Primary energy use (excl. household appliances) (kWh/m2)	**274.98**	**168.68**	**136.27**	**116.21**	**107.71**	**83.77**

Single family house 1970´s	100 m2					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4a**	**Scenario 4b**	**Scenario 5**
Results winDesign						
Space heating demand (kWh/m2)	137.9	102.3	102.3	70.7	58	35.6
Space cooling demand (kWh/m2)	-	-	-	-		-
Length heating season	286	265	265	242	231	208
Length cooling season	124	139	139	139	139	142
Hours of overheating > 26ºC	397	452	452	454	460	460
Electrical light demand (kWh/m2)	36.73	39.65	39.65	39.65	39.65	40.95
Energy need for space heating (kWh/m2)	**137.9**	**102.3**	**102.3**	**70.7**	**58**	**35.6**
Hot water consumption (kWh/m2)	13.08	13.08	13.08	13.08	13.08	13.08
Heat loss coefficient pipes	0.2	0.2	0.2	0.2	0.2	0.2
Lenght pipes	85	85	85	85	85	85
Utilization factor heating season	1	1	1	1	1	1
Utilization factor cooling season	0	0	0	0	0	0
Non-utilized heat losses from pipes heating season (kWh/m2)	0.00	0.00	0.00	0.00	0.00	0.00
Non-utilized heat losses from pipes cooling season (kWh/m2)	17.71	19.85	19.85	19.85	19.85	20.28
Heat loss coefficient hot water tank	1.6	1.6	1.6	1.6	1.6	1.6
Utilization factor heating season	0.8	0.8	0.8	0.8	0.8	0.8
Utilization factor cooling season	0	0	0	0	0	0
Non-utilized heat losses from hot water tank heating season (kWh/m2)	0.77	0.71	0.71	0.65	0.62	0.56
Non-utilized heat losses from hot water tank cooling season (kWh/m2)	1.67	1.87	1.87	1.87	1.87	1.91
Non-utilized heat losses from pipes (kWh/m2)	17.71	19.85	19.85	19.85	19.85	20.28
Non-utilized heat losses from hot water tank (kWh/m2)	2.44	2.58	2.58	2.52	2.49	2.47
Contribution solar heating (kWh/m2)	-	-	-	-	-	-
Energy need for heating (kWh/m2)	**171.13**	**137.81**	**137.81**	**106.15**	**93.42**	**71.43**
Yearly efficiency of heat supply system	1	1	3	3	3	3
Energy use for heating (kWh/m2)	**171.13**	**137.81**	**45.94**	**35.38**	**31.14**	**23.81**
Electricity use for circulation pump (kWh/m2)	4.20	4.20	0.88	0.88	0.88	0.88
Electricity use for pump solar heating (kWh/m2)	-	-	-	-	-	-
Electricity use for ventilation (kWh/m2)	-	-		2.63	2.63	2.63
Electricity use for heating and ventilation (kWh/m2)	**4.20**	**4.20**	**0.88**	**3.50**	**3.50**	**3.50**
Primary energy use (excl. household appliances) (kWh/m2)	**526.00**	**426.06**	**140.44**	**116.66**	**103.93**	**81.94**