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Zero energy renovation of single family houses

Thesis for the degree of Philosophiae Doctor

Trondheim, June 2013

Norwegian University of Science and Technology
Faculty of Architecture and Fine Art
Department of Architectural Design,
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PREFACE

The Norwegian Research Council established the research centre Zero emission buildings in 2009. The main objective of the research centre is to develop competitive products and solutions for existing and new buildings that will lead to market penetration of buildings that have zero emissions of greenhouse gases. It is not only a goal to build new zero emission buildings, but also to make it possible to upgrade already existing buildings to become zero emission buildings. This PhD is a part of the research on optimal thermal performance of buildings in the research centre, and I am grateful for the financial support and for the opportunity to carry out this research.

The research had not been possible without the good guidance and constructive feedback from my three supervisors Professor Anne Grete Hestnes, Senior Researcher Berit Time and Professor Tore Kvande. I have learned a lot from our discussions.

Acknowledgement is also given to my research colleagues at SINTEF Building and Infrastructure and NTNU for offering a stimulating working environment pushing me forward. Being a PhD candidate sometimes feels lonesome, but your enthusiasm and positivity has given me inspiration.

The home manufacturer Nordbohus allowed me to work in their offices in the winter 2011. The knowledge I gained on house and home design and on home buyer preferences has influenced my research on social aspects of home renovation.

I have also had the pleasure of supervising bachelor and master students. The students have given valuable input to my research.

Finally, I wish to thank my wonderful and patient husband Eirik and my sons (and possible future engineers?) Snorre and Einar. You give meaning to life. The 3 year period of intense work would not have been possible without your support.

Trondheim, June 2013

Birgit

SUMMARY

There are 1.2 million single family houses in Norway constituting approximately 50 % of the total dwelling stock. The energy use related to Norwegian single family houses was 30 TWH in 2009. There is a potential of an annual saving of 8 TWh within 2020, if the building envelope of all single family houses built before 1990 are upgraded. When supplementing such an upgrade with installation of energy efficient ventilation and renewable energy production on site, the energy saving potential is even greater.

This research investigates if it is possible to renovate a single family house to become a zero energy building and at the same time fulfil requirements related to cost and improved home qualities. This is analysed doing a case study of houses built in the 1980s.

Two strategies for zero energy renovation of a single family house built in the 1980s are analysed. The Façade strategy includes upgrade of the thermal properties of the façade including walls, windows and doors, installation of ventilation with heat recovery and renewable energy production on site. The Ambitious strategy includes renovation of the whole building envelope to passive house performance, installation of ventilation with heat recovery and renewable energy production on site. The higher heating requirement for the Façade strategy is compensated with more renewable heat production. The more extensive Ambitious renovation results in higher lifecycle cost than the less extensive upgrade.

Norwegians spend huge sums of money on upgrading their homes. Upgrading kitchens and bathrooms are most common for single family houses built in the 1980s, and some of the houses are renovated. However, there is no correlation between the number of defects and the renovation status of the houses. Four categories of houses with common characteristics regarding technical condition and renovation status are identified:

a) The ‘as built’ houses have not been maintained, redecorated or renovated.
b) The ‘do-it-yourself’ houses have been redecorated and/or renovated by the homeowner and their social network, but may not be in a good technical condition.
c) The ‘aesthetic upgrade’ houses have been redecorated and the visual qualities are upgraded, but may not be in a good technical condition.
d) The ‘well-kept’ houses are maintained and renovated and are in a good technical condition.

For privately owned dwellings, the optimal sustainable renovation strategy can be identified using energy performance, lifecycle cost and home qualities as indicators. The optimal zero energy renovation strategy depends on the homeowner priorities for home improvement. The 'Aesthetic' innovators and the 'Well kept' homeowners are the ones likely to prefer the Ambitious strategy due to its social impacts on factors such as aesthetics and indoor comfort, while owners of 'Do it yourself' houses and the owners of 'Aesthetic' houses wanting to keep the qualities of their house, are most likely to prefer the Façade strategy. The owners of 'As built' houses do not renovate and leave a renovation backlog to future owners of the house.

Market success for zero energy renovation of dwellings depends on homeowners' priorities for improved home qualities. However, the homeowners face barriers such as lack of knowledge, lack of services and attractive products and bad advice from craftsmen when they want to carry out energy saving renovation measures. The homeowners that renovate and succeed in energy savings today are either conscious consumers or they have the required knowledge from their profession.

SAMMENDRAG

Det er 1,2 millioner eneboliger i Norge, og eneboligene utgjør ca 50% av den totale boligmassen. I 2009 var energibruken knyttet til norske eneboliger 30 TWh. Dersom bygningskroppen til alle eneboliger bygget før 1990 blir oppgradert til dagens energistandard, kan dette resultere i årlig energisparing på 8 TWh. Denne energisparingen kan realiseres innen 2020. Installerer man i tillegg energieffektiv ventilasjon og utstyr for fornybar energiproduksjon, blir det årlige potensialet for energisparing betydelig større.

Tema for denne PhD avhandlingen er å undersøke om det er mulig å rehabilitere en eksisterende enebolig til å bli et nullenergi bygg, og samtidig oppfylle behov knyttet til kostnader og oppgraderte bolig kvaliteter. Dette er analysert ved hjelp av et case studie av eneboliger bygget på 1980-tallet.

To strategier for nullenergi rehabilitering av en enebolig bygget på 1980-taller er evaluert. Strategien "Facade" omfatter oppgradering av de termiske egenskapene til fasaden inklusive vegger, vinduer og dører, samt installasjon av ventilasjon med varmegjenvinning og utstyr for lokal fornybar energiproduksjon. Strategien "Ambitious" inkluderer rehabilitering av hele bygningskroppen til passivhusnivå, installasjon av ventilasjon med varmegjenvinning og utstyr for lokal fornybar energiproduksjon. For "Facade" strategien er det høyere varmetapet kompensert med mer fornybar varmeproduksjon på stedet. Den mer omfattende "Ambitious" oppgraderingen resulterer i høyere livsløpskostnader enn den mindre omfattende oppgraderingen, "Facade".

Nordmenn bruker enorme summer på å pusse opp og rehabilitere sine hjem. Rehabilitering av kjøkken og bad er mest vanlig for hus bygget på 1980-tallet, og mange av husene som ble bygd i denne perioden er også rehabilitert i større eller mindre grad. Det er imidlertid ingen sammenheng mellom antall tekniske feil og i hvor stor grad husene er rehabilitert og pusset opp. Fire kategorier av eneboliger er identifisert med felles kjennetegn hva angår teknisk tilstand og rehabiliterings status:

a) "As built" hus ikke har blitt vedlikeholdt, pusset opp eller rehabilitert
b) "Do it yourself" hus har blitt pusset opp og / eller rehabilitert av huseierne og deres sosiale nettverk, men husene trenger ikke å være i god teknisk stand.
c) "Aesthetic upgraded" hus har blitt pusset opp og de visuelle kvalitetene er oppgradert, men husene trenger ikke å være i god teknisk stand.
d) "Well kept" hus vedlikeholdes og rehabiliteres og er i god teknisk stand.

For privateide boliger, kan den optimale bærekraftige rehabiliterings strategien identifiseres ved hjelp indikatorer som omfatter energibehov, livsløpskostnader og bolig kvaliteter. Den optimale rehabiliterings strategien avhenger av huseierens prioriteringer

når det gjelder hvilke boligkvaliteter som verdsettes. Estetiske innovatører og eiere av "well kept" eneboliger foretrekker sannsynligvis Ambitious strategien på grunn av de resulterende sosiale gevinstene slik som fornyede arkitektoniske kvaliteter og bedre komfort, mens eierne av "Do it yourself" hus og eierne av "Aesthetic upgraded" hus som ønsker å beholde de husets kvaliteter, vil mest sannsynlig å foretrekke "Facade" strategien.

Markedssuksess for nullenergi rehabilitering av eneboliger avhenger av huseierne sine prioriteringer når det gjelder forbedring av boligkvaliteter. Men huseiere møter barrierer som mangel på kunnskap, mangel på tjenester og attraktive produkter og mangelfull rådgivning fra håndverkere når de ønsker å gjennomføre energisparetiltak ved rehabilitering. Huseierne som lykkes med energisparetiltak i dag, er enten bevisste forbrukere, eller de har den nødvendige kunnskapen fra sitt yrke.

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1 INTRODUCTION

1.1 THE FIELD OF RESEARCH

This PhD deals with the energy use in buildings. More specificcally the PhD investigates the possibilities for saving energy through energy efficient renovation of detached residential buildings in Norway. The detached single family houses are the preferred homes for Norwegian families (Støa, 1996). The total population of 1.2 million detached single family houses in Norway represent approximately 50 % of the total number of dwellings (Statistisk sentralbyrå, 2010).

Roughly 60 % of the single family houses were built in the period 1960 – 1990 and are from 20 – 50 years old (Statistisk sentralbyrå, 2010). This population of detached houses have fairly uniform constructional features (SINTEF Building and Infrastructure, 2010) and are in need of minor or major renovation (Thyholt et al., 2009, Myhre, 1995). These houses are wood frame houses in 1 – 2.5 floors and with a concrete or masonry basement construction. The exterior walls are insulated with mineral wool and have a wooden exterior cladding. The houses represent a potential for energy saving renovation because the building envelope and technical systems are less energy efficient than the houses being built today. One example of this is the insulation requirements of exterior walls presented in table 1.1. In the period 1960 – 1980 the requirement was equivalent to using 100 mm of mineral wool in the exterior walls, while the current requirement is equivalent to using 250 mm (National Office of Building Technology and Administration, 2010b).

Table 1.1 U-value requirements and equivalent insulation thicknesses for wood frame walls built in the period 1945 – 2010 (SINTEF Building and Infrastructure, 2010)

Building period	1945-1960	1960-1980	1980-1997	1997-2007	2007-
Insulation material	Air	Mineral wool	Mineral wool	Mineral wool	Mineral wool
Insulation thickness [mm]		100	150	200	250
U-value [W/m^{2}K]	1.5	0.5	0.29	0.22	0.18

The annual Norwegian energy use related to dwellings was 46 TWh in 2009 whereof 30 TWh was linked to the 1.2 million single family houses (Statistisk sentralbyrå, 2010). The annual energy use in dwellings built before 1990 was approximately 27 TWh (Dokka et al., 2009). This report states that

> *"If all residential buildings built before 1990 were upgraded with 10 cm additional insulation in the walls, floors and ceilings, new windows with an average U-value of 1.2 W/m^{2}K, and an improved air-tightness value (n_{50}) to*

> *between 2.5 and 3 h^{-1} (at 50 Pa), the reduction in energy use would be approximately 12 TWh/year, or 25 %. The single family house segment accounts for the largest reduction potential about 70 % of the total potential in the dwelling stock."*

The quotation illustrates the potential for realizing large energy savings if renovation of single family houses is done on a massive scale. More than 8 TWh can be saved annually only through traditional energy efficiency of the building envelope of single family houses. The number does not include installation of balanced ventilation with heat recovery or renewable energy production on site. This research investigates the possibilities and the alternatives for net and nearly zero energy renovation of single family houses. This means that the energy performance will be further improved giving only a small or no need for delivered energy from the grid. Thereby the annual energy saving potential will be even greater than 8 TWh, if the upgrades are done in a massive scale.

Dealing with energy efficiency and renovation of Norwegian single family houses, one important aspect is that almost 8 of 10 Norwegians own their own home (Statistisk sentralbyrå, 2010). This means that most of the single family houses are owned by private non-professional owners. These owners evaluate the technical condition of their dwelling and assess the need for energy efficiency, general upgrades, repairs and renovation. The homeowner perspective is little dealt with in previous studies. In this research the objective is to gain new knowledge on renovation solutions that result in energy efficiency and that also consider the preferences, needs and wishes of the homeowner and other residents.

1.2 DEFINITIONS

Several of the concepts related to energy use in buildings and renovation has been given different meanings in previous studies. I therefore find it necessary to clarify the definitions of the concepts used in this research.

<u>Zero energy building</u> describes a building that produces an amount of renewable energy annually that cover the energy required for operation of the building. The concept can be rewritten as "Zero energy in operation building". This means that the energy budget excludes embodied energy from production of materials and components as well as the required energy for construction and demolition of the building. The annual zero energy demand includes energy for space heating, cooling, ventilation, domestic hot water, lighting and electrical appliances. Cooling is not allowed in the design of single family houses in Norway (National Office of Building Technology and Administration, 2010b)

and is not included in this research. The concept zero energy building can be used for both 'Net zero energy buildings' and 'Nearly zero energy buildings' as described below.

Net zero energy building is used for a building where the annual renewable energy production on site equals the annual energy demand. The on site renewable energy production shall cover both the need for heat and electricity.

Nearly zero energy building means a building that requires delivery of a very low amount of energy. The energy demand is covered to a very significant extent by energy from renewable sources produced on-site. This is in accordance with the definition of nearly zero energy buildings in the European Union Directive 2010/31 (European Parliament and The Council, 2010).

Renovation deals with improvement of the technical condition of the house, its elements and its technical systems. Refurbishment is another concept used for upgrading the technical standard of a component or a building (Anink et al., 1996, International Energy Agency, 2010). When it comes to energy efficiency of buildings, the concepts renovation and refurbishment are both used in literature. In this work it is chosen to use the concept renovation to cover both the alternative of bringing a component to its original state and to upgrade the technical performance of a component or a building. This definition is in accordance with definitions in the previous studies (Botta, 2005, Thyholt et al., 2009, Tommerup et al., 2010, Juan et al., 2010, Martinaitis et al., 2007, Strongman, 2008).

Zero energy renovation means renovation of an existing building resulting in a zero energy building, both including an annual net zero and nearly zero energy status.

Redecoration results in an visual and aesthetical upgrade of the home. New floor coverings and wall surfaces, painting and installation of new fixtures in the kitchen or the bathroom are redecoration actions.

Home upgrade is used as a definition covering both redecoration and renovation. Home upgrades can be merely aesthetical or technical, or the home upgrades can include both aesthetical and technical improvements. The concept is introduced in Paper 4, see section 6.3.

Home qualities are the appreciated qualities of living in a house seen from the perspective of the residents, their neighbourhood and society. The home quality concept includes the physical structure of the home and its functionality. The physical characteristics can be summarized as the house qualities (Guttu, 2003). However, a house is also a home and the concept home also include the people living in the house (Clapham, 2005). The home quality definition is not limited to physical qualities but also encompasses the non-physical and functional characteristics that are valued such as a home being cosy, comfortable and secure (Aune, 1998). Throughout this thesis, home qualities are used as a concept including both the physical and non-physical characteristics of the house as a home.

Sustainable renovation includes the renovation and home improvement measures that result in a building that are better suited to meet current and future needs of the society. The sustainable renovation definition is further elaborated in section 3.1 and in paper 6.

Renovation strategy includes all the renovation measures, the renovation planning, the design and the construction work required to implement the renovation.

1.3 OUTLINE OF THE THESIS

The thesis is built up in four parts. The first part of the thesis describes *what* is done with an introduction to the field of research as well as definitions of the objectives of the research. The objectives are presented as a number of research questions in Chapter 2.

Chapter 3 is the second part of the thesis and deals with *why* the research is performed. Theory in the field of energy use in buildings and dwelling renovation are presented and discussed to identify the knowledge gaps to be explored in the research. The current Norwegian legislation and financial incentives for energy efficiency and renovation are also summarized.

Part three, Chapters 4 and 5, describes *how* the research is carried out, meaning a presentation of the case study and the selection of research methods to explore the case and the research question. Chapters 4 and 5 also include the background for the selection of research methods based on case study and research methodology.

The fourth and final part of the thesis presented in chapters 6, 7 and 8 presents *the results and the knowledge gained* from the research. The main findings of the research are presented in six scientific papers. These papers are included as sections in chapter 6. The main findings and conclusions from the research are listed and discussed to answer the research questions and to show implication for known theory in Chapter 7. Recommendations for further work are summarized in Chapter 8.

Three of the six papers in Chapter 6 were presented at scientific conferences in 2011 and 2012, and three papers are articles that are and will be published in scientific journals in 2013. Two of the articles are accepted for publishing, and one is awaiting review comments. Table 1.2 presents the six papers including information related to the publication details and the role of the co-authors.

Table 1.2 Overview of published papers

Paper no	1	Title	Strategies for renovation of single family dwellings from the 1980s towards zero energy levels	
Authors	Birgit Risholt, Professor Tore Kvande (NTNU), Research manager Berit Time (SINTEF) and Professor Anne Grete Hestnes (NTNU)			
Publication channel	11th World Sustainable Building Conference in Helsinki	Published	18.10.2011	
Role of co-authors	The co-authors provided ideas to the paper on establishing the influence of the different parameters on the energy demanded for operation of the house. They also contributed to quality assurance and proof reading of the text.			

Paper no	2	Title	Fenestration solutions for zero emission renovation of dwellings	
Authors	Birgit Risholt			
Publication channel	4th Nordic Passive house Conference in Helsinki	Published	18.10.2011	
Role of co-authors	None			

Paper no	3	Title	Life Cycle Cost Perspectives on Zero Energy Renovation of a Single Family House	
Authors	Birgit Risholt and Research manager Berit Time (SINTEF)			
Publication channel	Technoport Renewable Energy Research Conference in Trondheim	Published	17.04.2012	
Role of co-authors	The co-author provided input to the outline of the paper. She also assisted in quality assurance and proof reading of the text			

Paper no	4	Title	Technical condition and renovation status of Norwegian dwellings	
Authors	Birgit Risholt, Researcher Elisabeth Wærness (SINTEF), Senior Researcher Berit Time (SINTEF) and Professor Anne Grete Hestnes (NTNU)			
Publication channel	Structural Survey	Published	Accepted for publishing	
Role of co-authors	Elisabeth Wærness assisted in searching for the condition reports, in collecting data from the condition reports and in discussion of the house typologies. Berit Time and Anne Grete Hestnes contributed in discussions on house typologies and provided input to the outline of the paper and to quality assurance of text			

Paper no	5	Title	Success for energy efficient renovation of dwellings. -Learning from private homeowners	
Authors	Birgit Risholt and Associate professor Thomas Berker (NTNU)			
Publication channel	Energy Policy		Published	Under review
Role of co-authors	Thomas Berker gave input to interview guide. He wrote paragraphs on homeowner and energy use theory. He also contributed in quality assurance of the paper as well as in proof reading of the text.			

Paper no	6	Title	Sustainability assessment of zero energy renovation of dwellings. Based on energy, economy and home quality indicators	
Authors	Birgit Risholt, senior researcher Berit Time (SINTEF) and professor Anne Grete Hestnes (NTNU)			
Publication channel	Energy and Buildings		Published	Volume 60 (2013) pages 217-224
Role of co-authors	The co-authors provided input to the outline of the paper and quality assurance of text.			

2 RESEARCH QUESTIONS

The objective of this research is to investigate and explore the possibilities for renovating and upgrading Norwegian single family houses to zero energy buildings. In a technical context this means that after the renovation, the annual renewable energy production equals the energy required to live in the house. The thermal properties of the building envelope shall be improved to reduce the heat loss in the cold season. Technologies for renewable energy capture, storage and distribution shall be evaluated and be included in the recommendations for renovation. The recommendations shall also include actions such as installation of a ventilation system to achieve a good indoor climate after renovation. All renovation measures shall be in accordance with the Norwegian building regulations (Ministry of the Environment, 2008, National Office of Building Technology and Administration, 2010b).

A house is not only a climate shelter. It is also someone's home. In this context, the energy performance is not the only criterion to be considered when renovating a house. When evaluating if it is possible to achieve a zero energy building after renovation, it is necessary to have a holistic approach looking at more relevant aspects for renovation of the single family house and for the people living in the house. In this research, the three factors energy performance after renovation, lifecycle cost and home qualities are chosen as evaluation factors. The motives for this choice are elaborated in Chapter 3 and in paper 6. This approach is one approach to assess the sustainability of building renovation. The evaluated factors are not a complete list of factors for analysis of sustainability of the renovation measures (World Commission on et al., 1987, Standard Norge, 2010a). All environmental properties are not included. Regarding economy, only the situation related to the homeowner is analysed, and the economic considerations for society are not dealt with. Sustainable development is closely linked to a time factor and future needs. The evaluations in this work focus on current residents. Still, it was decided to draw parallels to sustainability assessment in this research as the chosen parameters energy performance, lifecycle cost and home qualities are indicators of the environmental, economical and social aspects of sustainability (Institute for Sustainability, 2012, Standard Norge, 2010a).

The main research question of this research is *if it is possible to renovate a single family house to become a zero energy building and at the same time fulfil requirements related to cost and improved home qualities*. The zero energy renovation can result in a net or a nearly zero energy balance. The home qualities, see the definition in section 1.2, includes the indoor environment and comfort, aesthetics, room plans, usability, functionalities and the use patterns for the house including both the indoor and the outdoor spaces. The cost aspect includes both investment costs for the renovation and operational cost for living in the house such as energy costs for space heating, lighting, ventilation, domestic hot water and electrical appliances.

The research question implies that strategies for zero energy renovation that are better for the homeowner and their household economy do exist. It is thus a search among the possible zero energy renovation strategies to find the optimal choice for the homeowner. The main research question encompasses three factors; energy use, economy and home qualities. In a sustainable renovation context illustrated in figure 2.1 the zero energy balance represents the environmental factor, the lifecycle cost denotes the economy, and home qualities represent the social factors. The research question is thus exploring the possibility of sustainable renovation where the energy saving-, lifecycle cost -, and home quality optimal solutions overlap, as illustrated by the green triangle in figure 1.

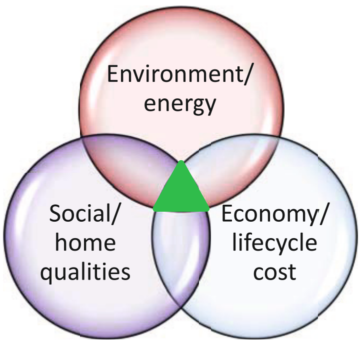


Figure 2.1 The green triangle shows how sustainable renovation measures aiming towards zero energy levels should fulfil requirements related to energy and environmental aspects, as well as social and economical aspects.

More sub-questions must be answered to gain the required knowledge to answer the main research question. First, the main research question is based on the hypothesis that it is possible to renovate a single family house to become a zero energy building. There are no Norwegian examples of such renovation being carried out or even proved theoretically. The first sub-question of this research is therefore whether it is technically possible to transform an existing single family house to become a zero energy building after renovation. The answer to this sub-question on energy optimal solutions can be seen as the total content of the red circle in Figure 2.1.

If the renovation is proved to be possible, the second sub-question is to identify the cost optimal strategies for zero energy renovation. This question is based on a hypothesis that there is more than one possible solution of combined renovation measures that will result in a zero energy building after renovation. It is also assumed that the different strategies have different cost performances over the building's lifetime and that the costs for renovation and operational costs after renovation are known or can be predicted. The question does not address the entire blue Economy circle in Figure 1. This blue circle should include all cost optimal strategies for renovation, not only the ones resulting in a zero energy requirement. But the second sub-question is an exploration to find the zero energy renovation strategies that are found in the red Energy circle segment enclosed also by the blue Economy circle.

The third and final sub-question to answer is what strategies for renovation are better for the homeowner, the other residents and the appreciated home qualities. A full social aspect assessment ought to consider current and futures users to include the time and developmental issue of sustainability. But due to the resource limitations of this research, it was decided to focus on current users. And as for the cost evaluations, the sub-question on home qualities is not related to all possible renovation strategies, but trying to find the zero energy renovation strategies that are better regarding improved home qualities.

When the three sub-questions are answered it is possible to analyse and discuss the findings to gain the necessary knowledge to answer the main research question on the more sustainable renovation strategies. The research is thus a puzzle of three parts trying to find the overlapping triangle as illustrated in figure 2.1. Summarized the research questions are as follows;

Is it possible to renovate a Norwegian single family house to become a zero energy building and at the same time fulfil requirements related to cost and improved home qualities?

With the following sub research questions:

1. ***Is it technically possible to upgrade an existing single family house to become a zero energy building after renovation?***
2. ***Are there cost optimal strategies for zero energy renovation?***
3. ***How do the homeowner's priorities regarding improved home qualities influence the design of an attractive zero energy renovation strategy?***

3 BACKGROUND

3.1 BUILDINGS AND SUSTAINABILITY

Before describing the more detailed background on energy efficiency and renovation of single family houses, there is a need to broaden up the perspective. Reduction of the energy use related to buildings is highly relevant in both a national and global sustainable development context.

Buildings account for 10 % of the global CO_2 emissions, and when including emissions from electricity use for operation of the buildings the number increases to 30 % (International Energy Agency, 2010). This means that approximately one third of the global CO_2 emissions are related to buildings and operation of buildings. Therefore, actions to reduce the greenhouse gas emissions from buildings and from operation of buildings are important to mitigate the green house effect.

It is possible to construct buildings that do not result in any greenhouse gas emissions. These buildings are referred to as zero emission buildings. The zero emission status is made possible by installations on site, producing renewable energy that compensate for emissions from the production of building materials, the construction process and the operation of the building. There are no common international definitions of the concept 'zero emission buildings' and how it should be proved that a building actually is a zero emission building. The definition, calculation tools and methods differ between countries. There is on-going work within the International Energy Agency to develop common definitions, standards and methods in the IEA Energy Conservation in Buildings and Community Systems projects Annex 52 and Annex 56 (International Energy Agency, 2011).

Global greenhouse gas emissions are closely linked to energy use. The International Energy Agency states that 84 % of the global CO_2 emissions are related to energy (International Energy Agency, 2010). As described above emissions are also linked to buildings and it has been proven that energy efficiency of buildings is a cost effective measure for reducing greenhouse gas emissions (McKinsey & Company, 2009). The European Union has a stated goal that all new building shall be nearly zero energy building from 2020. A definition of nearly zero energy buildings in the European Union are given in Directive 2010/31(European Parliament and The Council, 2010).

> *"Nearly zero-energy building means a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby."*

This definition includes two requirements to be fulfilled. First, the building must have a high energy performance and second, the energy demand to operate the building shall to a large extent be covered by renewable energy production. It is not quantified exactly how good the energy performance should be or how the energy performance should be documented. This is seen as a task for national legislation.

The European Council's strategy Energy 2020 (European Council, 2010) states that the EU energy consumption shall be reduced by 20 % by 2020. Energy efficiency of the existing building stock is one tool to be used by the member states to reach this target. Requirements regarding major renovation and construction products and elements to be used for retrofit are described in (European Parliament and The Council, 2010). The European decision does not set the specific requirements for retrofit rates and energy performance as this is a task for the national authorities.

In Norway requirements for energy performance of buildings are included in the Planning and Building Act (Ministry of the Environment, 2008) and Technical regulations (National Office of Building Technology and Administration, 2010b) and will be described in section 3.2. The national legislation is adapted to national and regional climatic conditions as well as being based on analyses of the actual energy use related to buildings. Substantial energy savings are needed to mitigate the greenhouse effect, and policy strategies such as financial incentives, laws and regulations should be tailored to the specific context of each country to reach national and international targets.

In Norway, the national electricity production is dominated by hydropower. Norway is connected to the European grid, and therefore the Norwegian electricity is not 100 % renewable. Energy savings are stated to be necessary both to reduce greenhouse gas emissions, and to secure the national supply of electricity, as it is a limited resource (Dokka et al., 2009, Kommunal- og regionaldepartementet, 2012). 22 % of the total energy use in Norway is related to dwellings and 18 % is connected to professional buildings, giving a total of 40 % of the national energy use being related to the building sector (Sartori, 2008). New buildings are often more energy efficient than already existing buildings. The building rates are low and 80 % of the buildings existing today will still be in use in 2050 (Kommunal- og regionaldepartementet, 2009). To achieve a sustainable building stock that meets the needs of this and future generations, it is necessary to reduce the energy spending related to both new and existing buildings.

The technical potential of energy saving resulting from renovation of existing buildings has been documented in several Norwegian studies (Enova, 2012, Dokka et al., 2009, Thyholt et al., 2009, Kommunal- og Regional departementets arbeidsgruppe for energieffektivisering av bygg, 2010, Lavenergiutvalget, 2009). The studies agree on an annual technical energy saving potential of 10 TWh within 2020. However, there are economic and practical factors limiting the potential. When considering limitations such as renovation rates, availability of craftsmen and economic barriers, a realistic potential is to reduce the energy requirement for operation of buildings by 3-8 TWh within 2020 (Enova, 2012).

Greenhouse gas emissions and energy use related to buildings is one part of the background for this research. But energy is only one of the research parameters of this study. Zero energy renovation of dwellings is to be investigated in a holistic context where the three factors energy use, lifecycle cost and home qualities are evaluated as indicators of sustainability.

The World Commission, also known as the Brundtland commission, defined sustainable development as (World Commission on et al., 1987):

> *"it meets the need of the present without comprising the ability of future generations to meet their own needs"*

The definition links the environment to human actions and emphasizes that human actions of today influence the possibilities for future generations. Sustainable development is economic growth that does not harm our planet and does nott negatively affect the future. The report also speaks about buildings and sustainability, defining energy efficiency of the existing buildings as more important in the industrial world than in the developing countries, because more of the future building stock is already built in the industrialized countries (International Energy Agency, 2010, World Commission on et al., 1987).

A framework for sustainability assessment of construction work is described in 'NS-EN 15643-1 Sustainability of construction works. Sustainability assessment of buildings. Part 1: General framework' (Standard Norge, 2010a). The norm states that the social, economic and environmental performance shall be evaluated over the lifetime of the building. The sustainability assessment shall include criteria on building functionality and technical characteristics. The norm defines a framework for the overall approach together with possible indicators to assess sustainability. But it does not give a method for how to actually perform the assessment and how to analyse possible conflicting performance criteria such as increased insulation levels and higher investment cost.

In the Definitions, section 1.2, sustainable renovation is defined as renovation and home improvement measures that result in a building that are better suited to meet current and future needs of the society. This is a definition very close to the definition of sustainable development in the Brundtland Commission report (World Commission on et al., 1987). The sustainable renovation definition encompasses environmental, economic and social aspects as well as the development factor.

Considering sustainable renovation of buildings, the literature gives different definitions. The Nordic research project 'SuccessFamilies' focuses on renovation of single family houses (Tommerup et al., 2010) and the projects definition of sustainable renovation was

> *"A concept that results in cost-effective renovation of a house with substantially better energy performance, coupled to a mainly renewable energy supply system, and improved indoor environment. The level of total primary energy use should be preferably equal to a new house built according to standard building code requirements or better"*

The definition of 'SuccessFamilies' uses indoor environment as the indicator of the social aspects of sustainability. In a wider definition of sustainable renovation, as used in this research, the social aspects should also include other factors such as functionality, flexibility and aesthetics. The cost definition of SuccessFamilies is linked to cost effectiveness for the homeowner. But a sustainable renovation might not be cost effective without including the gains for society or the non-energy benefits for the homeowner and residents (Mills and Rosenfeld, 1996). The non-energy benefits include factors such as indoor comfort, aesthetics and functionality. A homeowner might want to invest in the non-energy benefits even though the renovation is not cost effective. The sustainability assessment should therefore also include renovation strategies that are not cost effective with short payback times since the benefits from the renovation is more than a reduced energy bill.

The multidisciplinary aspects of sustainable renovation with multiple targets such as repair, functional and technic improvements as well as non-energy benefits such as aesthetic improvements give the need for a special focus on the decision makers, the decision process leading to renovation and the tools for assisting in decision making. The decision maker in the context of privately owned dwellings is usually an unskilled owner. The homeowners need knowledge and guidance to make the more sustainable choices. These topics are dealt with in paper 5 and 6, see section 6.3 and 6.4.

3.2 Norwegian building regulations and incentives

The Norwegian government utilizes several policy instruments targeted to reduce the energy demand for operation of the building stock. The energy requirements for new buildings are stated in The Planning and Building Act (Ministry of the Environment, 2008) and Technical regulation under the Planning and Building Act (National Office of Building Technology and Administration, 2010b). The energy performance requirements are continuously being made stricter, as illustrated in Figure 3.1. The current requirement for a 160 m^2 dwelling is that it should use less than 130 kWh/m^2 annually including space heating, ventilation, electrical appliances, lighting, and domestic hot water production. By 2015 the requirement for buildings will be to reach passive house performance (Standard Norge, 2010b) and by 2020 zero energy performance (Kommunal- og regionaldepartementet, 2012). The current legislation also requires that minimum 40 % of the net energy demand shall be covered of renewable energy sources.

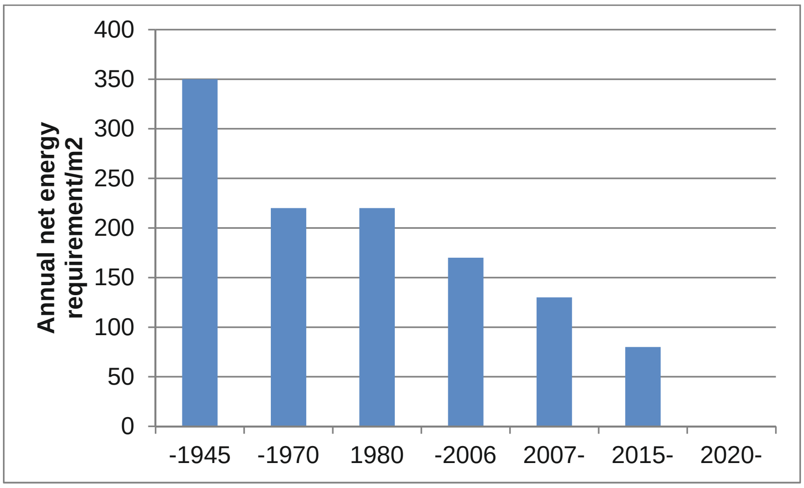


Figure 3.1 Net energy requirements for a 160 m² dwelling according to Norwegian laws and regulations (National Office of Building Technology and Administration, 2010b, Thyholt et al., 2009, Kommunal- og regionaldepartementet, 2012)

The required energy performance presented in Figure 3.1 is valid for new buildings. There is no corresponding mandatory requirement for renovation of existing buildings. The Technical Regulation states that buildings that undergo major renovation should fulfil the same requirements as new buildings (National Office of Building Technology and Administration, 2010b). It is not declared what is to be considered a major renovation, but the EPBD 2010/31 stated that if the renovation deals with more than 25 % of the building or imply costs above 25 % of the buildings financial value, it is to be considered a major renovation (European Parliament and The Council, 2010). However, the Norwegian authorities has given signals that new regulations including stepwise renovation and components will be issued. These will be mandatory from 2015 (Kommunal- og regionaldepartementet, 2012).

Minor changes to an existing building, such as replacing windows and adding on 5 cm of thermal insulation do not require a building permit. However, when considering zero energy renovation more substantial façade changes may be necessary. This can be changes as altering position of windows, increasing the roof ridge height and removing balconies. Such changes require a building permit. Building permits are granted by the planning administration in the municipalities according to the national building regulations (Ministry of the Environment, 2008, National Office of Building Technology and Administration, 2010a). The local planning administration is also responsible for issuing and managing Zoning plans with specific requirements on the design and use of land areas including the buildings in the area (Ministry of the Environment, 2008). The national legislation on minimum distances between houses, maximum roof ridge heights as well as the Zoning plan restrictions on areas and buildings may limit the possibilities for zero energy renovation of dwellings.

The technical and administrative regulations on planning and building are administered by the National Office of Building Technology and Administration. The public enterprise Enova and the Norwegian State Housing Bank are responsible for effectuating financial policy instrument targeting buildings and energy use. Enova gives financial support for investing in renewable heat production using solar collectors or air to water heat pumps. It is also possible to get support from Enova for renovating a building to low energy or passive house performance (Enova SF, 2011). The Norwegian State Housing Bank grants loan to building of passive houses and also supports projects aiming for sustainability in the planning and design phase (Norwegian State Housing Bank, 2012).

3.3 Barriers to sustainable renovation

This PhD research started out analyzing the energy performance of single family houses before and after renovation. It was soon clear that it was technically possible, using existing technology, to realize substantial energy savings after renovation. However, there seemed to be limitations of economical, legal, cultural and social character preventing market success for renovation with ambitious energy saving targets. This is in accordance with findings in Norwegian and international studies of barriers to energy efficiency (Enova, 2012, BarEnergy, 2011, International Energy Agency, 2010, Nair et al., 2010) It was therefore chosen to look at the single family house in a holistic manner as a home and financial object to find the appropriate renovation strategies to overcome some of the barriers to energy efficiency.

One way to consider a house in a holistic manner is to consider its physical characteristics. The famous Swiss architect LeCorbusier stated that "A house is a machine for living in". This can be understood as the house should simply be a shelter that gives us the needed comfort and functionality. The building envelope is the climate shelter and the technical systems help provide the appropriate indoor comfort through heating and ventilation. Other technical systems establish functionality such as lighting and domestic hot and cold water.

But a house is far more than just a climate shelter. It is also someone's home. Clapham (Clapham, 2005) summarizes that a home is the house, the residents and the use of the house. He concludes that the concept "home" is closely related to family and lifestyle, and can be seen as a place for privacy, security and relaxation. The home is also a symbol of the personality and the life story of the residents. The house as a home represents other aspects to be considered during renovation than simply a strict focus on technology.

For Norwegians, the single family house is the ideal of a family home (Støa, 1996). The 1980s houses to be studied in this research were frequently built in suburban locations. The exterior of the houses signalizes conformity with society and the neighborhood (Støa, 1996). Traditional wood frame single family houses were popular in the 1980s and are still popular house models for the home buyers of today. The traditional architectural exterior features signal conformity and traditional Norwegian values and the interiors are used to signal individuality. As described in section 3.2, the local municipalities also have strict regulations on constructional and architectural features of houses described in the local Zoning plan also contributing to neighborhoods with uniform houses. The requirements in the Zoning Plan might be a barrier to zero energy renovation. Lack of coordination of governmental policy instruments is also reported to be a barrier (BarEnergy, 2011). The Norwegian situation with three institutions; the National Office of Building Technology and Administration, Enova and the Norwegian State Housing Bank all administering policy instruments targeting buildings and energy use is thus one example of this.

Investment cost and cost effectiveness are also identified to be barriers to energy efficiency (Enova, 2012, BarEnergy, 2011, International Energy Agency, 2010, Nair et al., 2010). Almost 8 of 10 Norwegians own their own dwelling (Statistisk sentralbyrå, 2010). The purchase of a dwelling is a major investment for the household economy. The dwelling as a financial object is thus an important parameter to evaluate also for renovation.

Lack of knowledge, lack of skilled craftsmen and high transitional costs are other identified barriers to energy efficiency (Enova, 2012, BarEnergy, 2011, International Energy Agency, 2010, Nair et al., 2010). Knowledge is related to homeowners as they are unaware of the possibilities and benefits of energy efficiency (Nair et al., 2010). The barrier on skilled craftsmen is a finding related to the apparent lack of actors in the market offering energy efficiency services to households. Transitional cost is used as a concept describing the effort and troubles experienced by the homeowner in planning and effectuating renovation. All these factors are highly relevant for this study because there are no previous studies on how these barriers affect the renovation status of Norwegian single family houses.

As summarized above, numerous barriers to energy efficiency and sustainable renovation do exist. In this research, the focus is not on the barriers, but rather on finding renovation strategies that overcome some of the barriers and on identifying drivers that can make homeowners want to invest in energy efficiency. A special attention is therefore given to the role of the homeowner, identifying solutions that are optimal for saving energy and reducing cost. The ambition is also to provide knowledge on the home quality benefits following from zero energy renovation that are attractive from a homeowner's perspective.

3.4 RENOVATION AND HOME IMPROVEMENTS

Every year when new statistics are published, Norwegian newspapers celebrate Norwegians as the world champions of home improvement. A steady influx of revenue based on oil and gas exports combined with an active welfare state and low unemployment rates has made the average Norwegian a wealthy home owner. A significant part of this wealth, more than €6.2 billion in 2011, is spent on upgrading the 2.3 million Norwegian dwellings (Statistisk sentralbyrå, 2010).

These upgrades are not primarily motivated by energy or climate related concerns. They include redecoration such as new floors/wall coverings and bathroom fixtures, but also renovation including repairs and replacement of components and improvement of the qualities of the dwelling. Whereas the redecoration measures result in an aesthetical upgrade of the home and do not have a direct energy saving potential, renovation deals with the technical condition of the dwelling and are directly relevant. In fact, a recent report concluded that incremental renovation and especially improvements of the building envelope, can explain 37% of the stabilization of Norwegian household energy use since the 1990s (Hille et al., 2011).

It is necessary to look at the cultural and social meaning of the homes of Norwegians to understand the energy behavior. The Scandinavian and particularly the Norwegian home has an important cultural and social function (Aune, 1998). The home is a place for family life and entertaining guests (Garvey, 2005, Garvey, 2003). The interior is a symbol of uniqueness and the exterior is a symbol of uniformity with society (Støa, 1996, Gullestad, 1989). Norwegians use energy to have a comfortable indoor temperature, good air quality, an abundance of light in the dark seasons as well as to have the electrical appliances that are deemed necessary for their standard of living.

The Norwegian tradition for energy saving measures in single family houses is to replace windows and add on thermal insulation on the outside of the exterior wood frame wall. Adding 5 cm of mineral wool and mounting a new wind barrier are common measures when the wood panelling needs to be replaced. It is also common to add insulation on the inside of the roof. However, these actions, when not done correctly, have also resulted in damages due to condensation of moisture on cold surfaces (Geving, 2011). The book “Etterisolering” (Bøhlerengen et al., 2009) shows recommended solutions for the traditional energy efficiency measures for wood frame houses.

Renovation of single family houses is usually done by the homeowner, by the homeowner and his network or by small carpenter companies. Adding on 5 cm insulation and replacing windows are considered minor façade changes, and no building permits are required (Ministry of the Environment, 2008). The market situation, with private and small company actors and the legal situation not requiring a building permit, has resulted in a lack of public available documentation and statistics on renovation status and technical condition of the privately owned single family houses. There is a need for such knowledge in order to verify the potential for energy efficiency. Knowledge about homeowner preferences regarding renovation can also be used to tailor policy tools to accelerate the energy efficiency rates.

There are Norwegian examples of renovation of apartment buildings to passive house standard. However, there are, to my knowledge, no Norwegian examples of renovation of single family houses to passive house, zero energy or zero emission levels that have been carried out. Renovating towards zero energy performance requires that the thermal properties of the building envelope are improved. The heat loss must be minimized and passive gains from solar energy need to be optimized. The energy use for ventilation, domestic hot water, lighting and electrical appliances also need to be minimized to obtain as low energy demand as possible. Renewable energy must be produced, preferably on site, to meet the energy demand for operation of the house.

4 THE CASE STUDY OF HOUSES BUILT IN THE 1980S

The research questions encompass a zero energy renovation fulfilling requirements related to cost and home qualities. The known theory in the field shows that we have knowledge regarding energy saving and possible renovation technologies. But there is a lack of knowledge in relation to considering energy efficiency in a holistic manner, looking at the entire house, the people living in the house, the house being their home, and the house being a legal entity and an economic object.

To answer the research questions stated in Chapter 2 there is a need to develop a deeper understanding of renovation of dwellings. Case studies comprise more in depth analysis of the unit than cross unit studies (Flyvbjerg, 2011). It was therefore chosen to do a case study to gain more depth knowledge on renovation of single family houses. The case study methodology also gave me as a researcher the possibility to explore the research question in an environment as close to reality as possible.

Understanding the context of the single family house is essential to be able to answer the research questions. Case studies focus on context and relation to the environment and can therefore be a valid approach for the research (Flyvbjerg, 2011, Stake, 2006, Yin, 2003). There are many possibilities for exploring a case study, there are more sources of information and there are many variables inside the unit of analysis (Yin, 2003). The context of a single family house is not limited to energy use, home qualities and economic and legal aspects. A single family house can also be analysed in its local, national or international context. The local context is the house as home and as part of a neighbourhood. The national context includes the total number of houses and the international context focuses on single family houses in a European or worldwide perspective. In this research it is the local context of the single family house that is explored.

In addition to obtain in depth knowledge by exploring the case in its context, a case study also makes it possible to gain knowledge about processes and development over time (Stake, 2006, Yin, 2003, Flyvbjerg, 2011). This research deals with dwelling renovation with ambitious energy saving targets. It is necessary to study the renovation history of the dwellings as well as future needs and desires related to home qualities to assess the sustainability of renovation solutions and strategies. The investigation of houses in their environment and the development over time is needed for this research. This also favours a case study.

There are several possible ways to design a case study. The choice of what case to study, the units for analyses and the research methods need to reflect the research questions and must give the necessary data to analyse the problem that is addressed. The decision about what case to study can be done by random selection, by information oriented selection, by critical case selection or by paradigmatic selection (Kvale and

Brinkmann, 2009, Yin, 2003). A random selection of house type might not give information on renovation actions that can be generalized to be valid for other houses. It was therefore decided not to use a random selection of a single family house for the research. If it is possible to come up with an answer for a critical case, one has knowledge such as “if this is (not) valid for this case, it is valid for (no) all cases”. The research question deals with zero energy renovation. A house model representing the worst case scenario for achieving a zero energy house after renovation was therefore chosen as the case to study. The assumption is that if it is possible to renovate a worst case house to become a zero energy house, it should be possible for most Norwegian single family houses. By also choosing a house with the typical characteristics of a wood frame house, some or more of the findings could be relevant for other house types with similar features. It was decided to study a house with a wood frame construction, as this is the typical way to construct a single family house in Norway. Thus the house model to be analysed should be a critical case, but not a deviant and "non-typical" case.

Windows and roofing underlays have an expected lifetime of 20 – 40 years (SINTEF Building and Infrastructure, 2010). Houses built in the 1980s are therefore at a stage in their lifetime where renovation actions are needed within the next 10 years. Dwellings from the 1980s also have the highest energy use compared to dwellings from other construction periods (Bøeng, 2005). It was therefore decided to use the single family houses built in the 1980s as the case to study as these represent a worst case for energy use, as the houses are typically built as wood frame houses and as they need renovation within few years.

The single family houses that were marketed and sold through catalogues, dominated the Norwegian market in the period 1960 – 1990. The book “Klar-ferdig-hus!”(Sørby, 1992) gives an overview of the history of catalogue houses and shows the development in architecture and people’s preferences when investing in a new home. House models called "Tyroler houses" became very popular in the 1980s. These houses were characterized by a dominating gable wall with two balconies. The houses were marketed with windows with mullions, two sashes and small glass panes divided by glazing bars. However, the real life situation as shown in figure 4.1, is that they just as well were built with windows with one sash.

The highest selling house model of the 1980s was the Block 99, designed, manufactured and marketed by the company Block Watne AS. The Block 99 was a "Tyroler house" especially designed to meet the financing rules of the Norwegian State Housing Bank, only allowing a limited floor area. The Block 180 was a larger version of the house model Block 99. The Block 180 was also a popular house model in the 1980s even if it required financing from private institutions or banks.

Figure 4.1 Photos of "Tyroler houses" from the 1980s. The house in the right bottom corner is one example of the house model 'Block 180'

As a case study for zero energy renovation, Block 180 represents a worse case than the high seller Block 99 due to the larger size. A larger size means higher energy demand for heating, lighting and electrical appliances than for a smaller house. The Block 180 was therefore chosen as a case for the PhD study. The construction methods are typical for Norwegian wood frame houses making it possible to use some or more of the results from the research for more of the Norwegian single family houses.

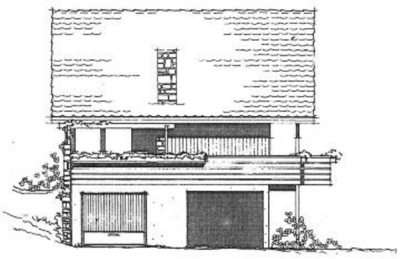
A case study can include research both on the micro and macro level (Ringdal, 2007, Yin, 2003). The house model Block 180 represents the micro level of the case study. The 207 000 single family houses built in the period 1981-1990 (Statistisk sentralbyrå, 2010) represent the macro level. This case study uses micro level analysis for energy and lifecycle cost, while the research on social aspects comprises both micro and macro level studies. See table 5.1 for an overview of the research methods.

Some basic data for Block 180 is given in table 4.1. The energy calculations were done for a Block 180 house localized in Oslo. The Oslo climate is a representative climate for a large part of the Norwegian building stock, and it is the mandatory climate to use for documentation of energy needs according to The Norwegian Building Code (National Office of Building Technology and Administration, 2010b, Standard Norge, 2007d). It was decided to orient the main gable façade 30^{o} to the southwest to have non-optimal solar energy harvesting conditions. Façade drawings of Block 180 and floor plans are shown in figures 4.2 and 4.3.

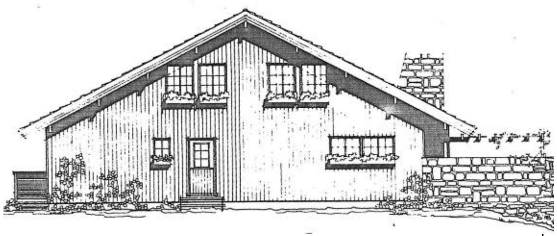
Table 4.1 Basic data for the house model 'Block 180'

No. of floors	2.5	Floor area	276 m^2
Heated volume	565 m^3	Window area	45 m^2
Thermal properties of building envelope			
Floor	Exterior wall	Roof	Windows
0.37 W/m^2K	0.47 W/m^2K	0.21 W/m^2K	1.75 W/m^2K
Energy requirement as built calculated according to NS 3031 (Standard Norge, 2007d)			
Annual net energy	215 kWh/m2	Annual space heating	145 kWh/m2

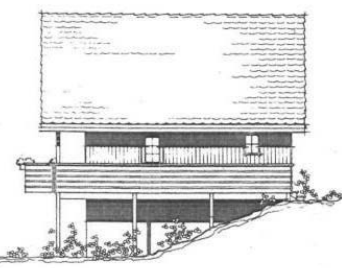
South west façade



South east façade



North east façade



North west façade

Figure 4.2 Façade drawings of Block 180

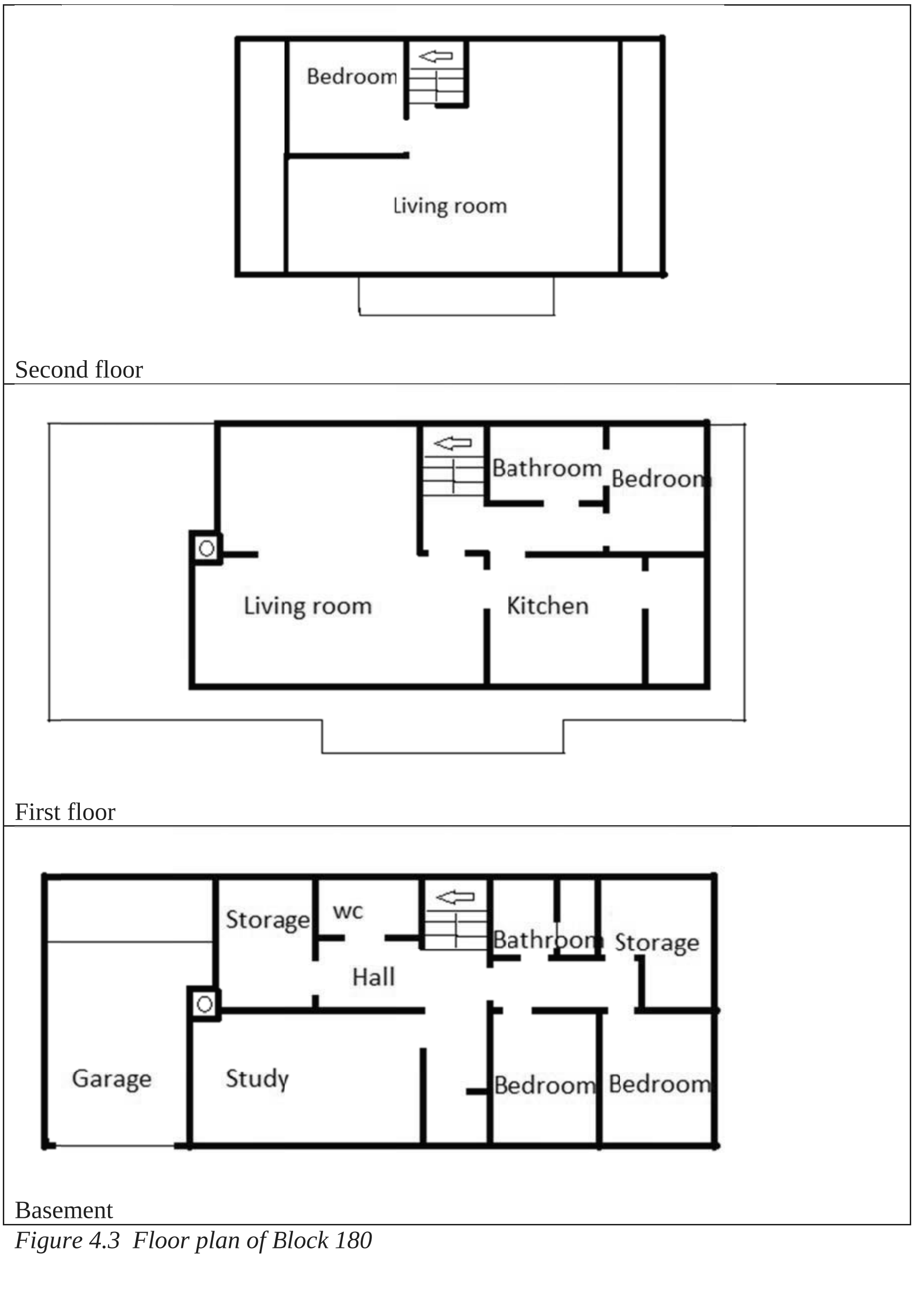


Figure 4.3 Floor plan of Block 180

5 RESEARCH METHODS

A case study can be performed using both quantitative and qualitative methods (Yin, 2003, Flyvbjerg, 2011, Stake, 2006, Stake, 1995). The case study needs to be designed to represent the complexity of the case and the research question. A case represent numerous features in itself and in its context, but only a limited selection of features can be a part of a study (Stake, 2006).

The research questions were used to design this case study of Norwegian single family houses built in the 1980s. The research questions are related to a house, its energy performance, the cost for renovation and the home qualities before and after renovation. Quantitative and qualitative methods are more or less relevant for the different aspects. Both qualitative and quantitative methods were selected in this study to obtain empirical data and to gain the knowledge required to answer the research questions.

Table 5.1 presents the outline of the case study, the research tasks, the research methods and the deliverables to give an overview of the work. The research was initiated by energy performance evaluation of renovation measures for the house model Block 180. This work is documented in the papers 1, 2 and 3. Life cycle cost analysis of net zero energy and nearly zero energy renovation is documented in paper 3. The papers 1, 2 and 3 focus on renovation of Block 180.

A qualitative interview survey and a quantitative survey on the renovation preferences of homeowners are the basis for the social aspect research and are documented in paper 4 and 5. The social aspect research targeted homeowners of large single family houses built in the 1980s in general, and not only owners of Block 180. There are no archives on where the Block 180 houses were built. It was therefore not possible to find enough informants if the interview study should include only Block 180 owners and residents. It was therefore chosen to do interviews of owners and residents of houses built in the 1980s with a floor area over 150 m^2.

Paper 6 analyses the sustainability of zero energy renovation and uses renovation of Block 180 as a case for the assessment. The results from papers 1, 2, 3, 4 and 5 are used in the sustainability assessment.

Table 5.1 Overview of the 1980s single family house study, research topics, - tasks and - methods and deliverables.

The case study of houses built in the 1980s		
Topic	Research task and - method	Deliverables
Energy	Zero energy renovation strategies for Block 180 - Energy calculations for 'Block 180' on parameters influencing the energy demand and on renovation solutions and strategies including strongly reduced energy demand as well as local renewable energy production	Paper 1, 2 and 3
Economy	Cost optimal strategies for zero energy renovation of 'Block 180' -Life cycle cost calculations including investment costs, operational cost and payback times	Paper 3
Home qualities	The influence of improved home qualities on zero energy renovation strategies -In depth interviews of homeowners on energy use, renovation experiences and home qualities - Survey on the renovation status and technical conditions of 91 Norwegian houses built in the 1980s	Paper 4 and 5
Sustainability	Sustainability analysis of zero energy renovation strategies -literature review on methods for sustainability assessment -sustainability analysis of two zero energy renovation strategies	Paper 6

As stated in the beginning of this section and illustrated in table 5.1, both qualitative and quantitative methods are used to explore the case study. Using more methods can give challenges in how to deal with recording, processing and analyzing data. The use of more research methods in one study is in literature described as mixed method research (Brannen, 1995, Bryman, 1995, Brewer and Hunter, 2006).

This research deals with exploring the complexity and the possibilities for renovation of single family houses. Several methods, including both quantitative and qualitative methods, are used to get a deeper understanding of energy use and renovation of Norwegian single family houses. The methods and the resulting data are not combined, but are used separately to gain knowledge on different aspects regarding the single family houses, the energy use, the cost and the home qualities. The data is analyzed, and the results are reported in separate deliverables. Finally, the results from the different research tasks are used for a sustainability assessment of zero energy renovation strategies. The rest of this chapter gives a more detailed description of the methods used to explore the four topics presented in table 5.1.

5.1 ENERGY EFFICIENCY

Energy performance of a house is typically evaluated by numbers. The numbers can come from calculations, from laboratory measurements, from measurements in a house, from surveys or even from interviews with homeowners. The quantitative energy performance stated in kWh gives knowledge on how much energy is used and possible also for what purpose the energy is used, being space heating, lighting, electrical appliances or domestic hot water. The numbers do not give any explanation as to why the energy is used. Qualitative research in combination with quantitative research can give us an understanding of why the different numbers of energy use occur. One example to show the relevance of combining research methods is that calculation of a nominal energy use in a house might not be relevant for the real life experienced energy use. In standardized calculations one uses fixed values for both the indoor temperatures and the domestic hot water use (Standard Norge, 2007d, Standard Norge, 2010b). In real life the residents' use pattern strongly influences the indoor temperature levels, the domestic hot water use and the resulting measured values for energy use. By learning from residents through qualitative research, one gets a deeper understanding on why the measured energy values differ from the nominal calculated values.

Calculations of the energy use in a house are a way of representing reality (Ringdal, 2007, Yin, 2003). The surroundings and context are considered to be normative, not considering individual user preferences. It is like a laboratory experiment trying to create a controlled environment to measure the effect of the variables to be investigated. When trying to evaluate the energy saving effect of different renovation measures, normative calculations give the possibility to only change one parameter at the time and thus isolating the resulting effect of the change. In the context of this research, this means that by looking at renovation measures separately in calculations, it is possible to identify the impact of each renovation measure on the energy need of the house model Block 180. Such calculations and results are shown in paper 1. The renovation measures with high impact can then be evaluated further to assess functionality, cost, legal aspects as well as the influence on home qualities as presented in papers 2, 3 and 6.

Energy performance calculations of renovation measures for the house model Block 180 are done according to national and international norms as documented in paper 1, 2 and 3. Data on energy use are also obtained from homeowner interviews. These numbers are real life energy use numbers for ten different houses built in the period 1986 – 1990 and are included in paper 5.

5.2 LIFECYCLE COSTS

Costs for renovation are calculated by numbers and the cost optimization analysis is done as a quantitative work. Investment costs are important for the homeowner that is going to pay for the renovation from his household budget. The investment cost can be used to assess the return of the investment and if investments in energy efficiency are cost effective. In this PhD research, the cost calculations are not limited to only the investment cost, as it was chosen to base cost evaluations on all costs occurring over a lifecycle, including operational costs as well as costs for maintenance and replacement. Investments on a nearly zero renovation will probably be higher than investments on a less ambitious energy upgrade, but the reduced operational energy costs could make the more extensive renovation profitable.

The term life cycle costs includes investment costs, annual costs including costs for operation, maintenance costs and costs for repair and replacement (Standard Norge, 2007a). The cost for operation includes the operational energy costs. The calculation standard 'EN 15459:2007 Energy performance of buildings; Economic evaluation procedure for energy systems in buildings' gives two alternatives for presenting the life cycle costs, as an annualized cost or as a global cost. Annuity calculations show the life cycle cost as an average annualized cost over the payback period for the renovation. Annuity cost calculations are therefore especially relevant for renovations being paid for by a mortgage since it states the annual costs for payment. The other option in EN 15459:2007 is to calculate the global cost, summarizing the total costs throughout a calculation period. A homeowner investing in renovation most probably has a likely timespan for his ownership. Global cost is linked to the calculation period and will give the homeowner knowledge on all costs that will occur during his expected ownership period. It is not linked to financing and payback-times. When evaluating different renovation measures the global costs can be used to compare different strategies as to say which give the overall lowest cost. In this work, it was chosen to calculate the global cost since the aim is to evaluate the life cycle costs for different renovation strategies in order to identify which are the better ones. It was decided to calculate the global cost over a time period of 30 years. 30 years is an estimate of a period that a homeowner is likely to own a house, representing the time where the children live in the house with their parents. The global cost calculations make it possible for the homeowner to choose a cost optimal renovation strategy for his ownership period. The cost calculation also includes the final value of the building and technical systems at the end of the calculation period as these represent values that need to be subtracted from the costs. Life cycle costs for zero energy renovation are shown in paper 3 and 6.

This work does not focus on profitability and cost effectiveness of zero energy renovation. The goal as stated above is rather to analyse what are the better zero energy renovation strategies when the goal is to get as low cost as possible. Cost numbers are not fixed numbers and will vary from region to region and from one point in time to another. The governmental incentives can change throughout an ownership period as may mortgage interest rates and energy prices. This means that a strategy that is cost optimal at one point in time may not be the cost optimal strategy a few years later. The life cycle cost analysis in papers 3 and 6 is based on obtained Norwegian renovation costs in 2011 with a specific scenario for energy prices, inflation and interest rates.

When calculating costs for an energy efficient upgrade of a house, it is necessary to separate the costs for general renovation of the house and the costs for the energy efficiency renovation actions(Martinaitis et al., 2007, Jakob, 2006). This is based on the prerequisite that renovation and energy efficiency actions are done at the end of the lifetime of a component or building element. Costs for general renovation to its original standard are not a part of the energy efficiency upgrade. Therefore, only additional costs during renovation for energy efficiency measures are considered when evaluating cost optimal zero energy renovation strategies.

5.3 HOME QUALITIES

It is necessary to have knowledge of the technical condition of the house and of the residents' needs and wishes for indoor comfort, functionality and other home qualities in order to design effective and successful renovation strategies. It is also shown that the economic way is to carry out the energy efficiency measures when other renovation actions are preformed (Martinaitis et al., 2007). The idea in the research design was therefore to gain knowledge of renovation status, experiences from renovation projects and wishes for home quality improvements in order to see how energy efficiency can be included when other renovation measures are done.

The research on home qualities and renovation preferences started out with a survey of the technical condition and the renovation status for single family houses built in the 1980s. This work was done as a quantitative survey of 91 houses built in the period 1980-1989 and is documented in paper 4. The quantitative survey gave knowledge on frequencies of different renovation measures and quantification of technical defects and the following renovation backlog. The study gives no information on why the numbers occur, and a qualitative study was needed to get an understanding of the findings.

The appreciated home qualities of a single family house described by peoples' needs, values, experiences, plans and wishes, can best be investigated through qualitative research. Interviews can both give information on the context, the past experiences, the current situation, the future plans and the user patterns. The goal is to understand how home quality factors, such as experienced indoor comfort, aesthetics and functionality, will influence the choice of zero energy renovation. It was therefore decided to use interviews as a research method to answer the research sub-question on what factors are important for people living in houses from the 1980s and thereby identifying requirements, drivers and barriers for zero energy renovation.

Kvale and Brinkman (Kvale and Brinkmann, 2009) state that there is not one standardized method for doing qualitative in depth interviews. Getting information about everyday life as well as the history and future plans regarding renovations can be mapped by doing semi-structured interviews. The homeowner and the other people living in the house can through their stories give information on the topic home qualities. New knowledge can be established by understanding and interpretation of their stories.

Tjora (Tjora, 2010) describes the use of three different interview methods: focus group interview, focused interviews and in depth interviews. Focus group interviews give access to information from more informers in one interview. But, since this research deals with peoples' homes, the nature of the information sought is individual and may even be personal. It was therefore chosen not to carry out group interviews of homeowners. Focused interviews are used to explore a specific phenomena or a small theme, and may not to be suitable for investigating home qualities. It was therefore decided to perform depth interviews of homeowners to gather data.

There is no archive on where the Block 180 houses were built. Interviews were therefore done of homeowners of 1980s houses with similar features as the Block 180. Støa wrote her PhD on the 1980s houses and neighbourhoods (Støa, 1996). She based her thesis on interviews of homeowners in three neighbourhoods in Trondheim. I chose one of these areas and contacted the homeowners by placing pamphlets in the mail boxes, asking them to participate as informants in my study. Six homeowners volunteered. The rest was recruited by ringing their door bells and asking them to participate. This gave a total of eleven informants for the interview study.

The results from the interviews were analysed to establish a preliminary taxonomy related to renovation and appreciated home qualities and thereby identifying drivers and barriers for zero energy renovation as described in paper 5.

5.4 SUSTAINABILITY

To assess if the different renovation strategies for zero energy renovation also fulfil criteria other than energy performance, a multicriteria evaluation was necessary. Legal requirements and cost effectiveness were used for evaluation as well as criteria related to homeowner preferences. There are numerous multicriteria decision models for sustainability assessment. It was not the task of this PhD to develop a decision making tool for dwelling renovation. A literature study was carried out to identify the state of the art of decision support tools for sustainable building, construction, design and planning. The purpose was to see if there were one or more feasible tools that could be used in this research and that perhaps even could be adopted as assistance for homeowners planning renovation. The study is reported in paper 6.

The evaluation of existing methods for sustainability assessment concluded in revising and using a method developed by the British Institute for sustainability (Institute for Sustainability, 2012) in analyses of sustainability of renovation of Block 180. The economic, environmental, social and usability impacts of renovation are included. The analyses of the different impact factors are quantitative or qualitative depending on the factor. It thereby allows both to assess results from quantitative assessments as well as qualitative assessments of renovation solutions. The method is not used to gather data, but is used to analyse the findings from the energy, economic and home quality research presented in papers 1 – 5.

6 RESULTS

6.1 ENERGY EFFICIENCY

The first step of zero energy renovation is to reduce the energy demand for operation of the house. This is also the first step of the Kyoto pyramid used for designing low energy and passive houses (Dokka and Hermstad, 2006) shown in figure 6.1. The pyramid is based on the main ideas of first to reduce the energy demand (steps 1-3), second to make the dweller aware of the energy use (step 4) and third to install renewable energy production (step 5).

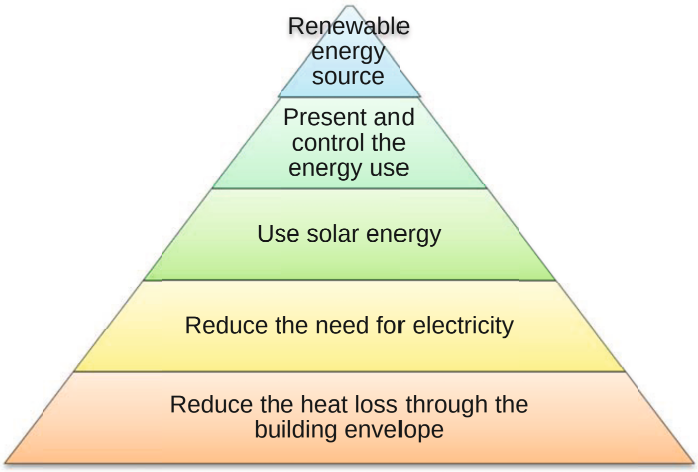


Figure 6.1 the Kyoto pyramid for planning of passive houses and low energy dwellings (Dokka and Hermstad, 2006)

Paper 1 investigates the possibilities to reduce the energy demand for operation of Block 180. Introducing renewable energy production on site to achieve a zero energy balance is discussed in section 6.2 and paper 3. User behaviour and energy use is described in paper 5.

Paper 1 is a study of what parameters affect the energy budget after renovation. The effect of each renovation measure is evaluated to identify the most critical parameters in a zero energy renovation project. The paper investigates both the effect of improving the thermal properties of the building envelope and the effect of improvements in the technical systems of the house to reduce the need for electricity, which is step 2 in the Kyoto pyramid. The glazed parts of the façade are of special importance in the energy calculations both for heat loss and solar gains, as included in step 3 of the Kyoto pyramid. Paper 1 also analyses the optimal window area for maximum solar gains and reduced heat loss, which is step 3 of the Kyoto pyramid. Solar gains through the south facing windows are optimized and the heat loss in the cold season is minimized. One approach to achieve this is to increase the glass area in the south facing facades and to minimize the glass area in the north facing facades.

However, the main function of a window is not to gain or loose heat. The main function is to let daylight enter the room and to let the residents view out. Paper 2 focuses on daylight scenarios, air tightness implications and the cost effectiveness of window and door replacements.

STRATEGIES FOR RENOVATION OF SINGLE FAMILY DWELLINGS FROM THE 1980S TOWARDS ZERO ENERGY LEVELS (PAPER 1)

presented at Sustainable Buildings 11 Conference in Helsinki, 18.10.2011

Strategies for renovation of single family dwellings from the 1980s towards zero energy levels

Birgit Risholt, Tore Kvande, Berit Time and Anne Grete Hestnes

Summary

Energy efficient renovation of existing houses is needed to meet government requirement for reduced energy consumption in the building sector. A Norwegian house from the 1980s is analyzed to identify best practice renovation actions for optimized energy performance. Energy performance simulations are performed to document possibilities when using traditional renovation actions as well as needed development for new technologies for renovation to zero energy levels. Use scenarios are applied for estimation of total energy requirements after renovation.

These analyses show that renovation using traditional technologies as improved thermal insulation, improving thermal bridges and air tightness, and installation of ventilation with heat recovery reduces the energy requirement for heating from 145 kWh/m^2 to 26 kWh/m^2. Further thermal improvement of the building envelope using innovative technologies may reduce the need for heating to 14 kWh/m^2. Combined with realistic hot tap water, lighting and electrical equipment loads, the energy consumption for use of the house can be reduced by 73 % compared to nominal values calculated for the as built case prior to installation of renewable energy production facilities.

Keywords: renovation, building, zero energy, sustainable, house, wood frame, calculation

Introduction

Energy consumption in the Norwegian building stock

40 % of energy use in Norway is related to buildings and the building sector. The residential part of the total energy use is approximately 22 % (Sartori, 2008). Energy savings in the Norwegian building sector have a potential of saving 12 TWh before 2020 (Dokka et al., 2009).

The Norwegian building stock consists of 3.8 million buildings. Of a total of 2.3 million dwellings there are 1.2 million single family detached houses. 80 % of the buildings existing today will still be in use in 2050 (Kommunal- og regionaldepartementet, 2009). Annual energy consumption in Norwegian dwellings was 46 TWh in 2009. 30 TWh was used in single family houses (Statistisk sentralbyrå, 2010). Reducing the energy requirement of these buildings is of great importance to realize the potential for energy savings in the building stock.

Norway produces electricity from hydropower and has traditionally had low prices for electricity. Electricity has therefore been widely used for heating dwellings. In 2001 69 % of Norwegian dwellings had electricity as main energy source for heating (Bøeng, 2005). Norwegian energy companies sell their electricity in a European market, leading to a substantial rise in electricity prices in Norway the last 10 years. The experienced rise in electricity prices and future scenarios of even higher electricity prices will most likely increase the demand for energy efficient renovation of single family houses. Building envelope improvement and installation of new renewable heating sources are preferred actions. Air to air heat pumps are frequently installed in existing houses and air to water heat pumps are also becoming more common.

Renovation of wood frame houses in Norway

Norwegian tradition for energy saving measures in single family houses is to replace windows and add on thermal insulation on the outside of the exterior wood frame wall. Adding 5 cm of mineral wool and mounting a new wind barrier is common measures when the wood panelling needs to be replaced. It is also common to add insulation on the inside of the roof. However, these actions, when not done correctly, have also resulted in damages due to condensation of moisture on cold surfaces. The book "Etterisolering" (Bøhlerengen et al., 2009) shows recommended solutions for the traditional energy efficient measures for traditional wood frame houses.

Renovating towards zero energy requires new technical solutions for improving the thermal properties of the building envelope. The heat loss must be minimized and gains from solar energy need to be optimized. Energy use for ventilation, hot water, lighting and electrical appliances also need to be minimized to achieve as low energy requirements as possible.

Renovation towards zero energy levels

Several new single family houses are being built according to the Norwegian passive house standard NS 3700 (Standard Norge, 2010b). However, as far as we know there are no projects in Norway that aims towards renovating houses to passive house or zero energy levels. The most energy efficient renovation cases are using passive house elements. Husarveien is an example of renovation using passive house technology (Mysen, 2008). The described renovating measures include adding on mineral wool insulation on exterior walls and roof, installing new windows, installing ventilation with efficient heat recovery and using a solar collector for heating hot tap water. The table 1 shows measured, calculated and expected energy requirement for the Husarveien house before and after renovation.

Table 1 Energy requirement for the case Husarveien before and after renovation with passive house elements (Mysen, 2008). The annual energy need include space heating, ventilation, hot tap water, lighting and electrical equipment

	Before renovation		After renovation	
	Calculated according to NS 3031 (Standard Norge, 2007d)	Measured energy consumption in 2007	Calculated according to NS 3031 (Standard Norge, 2007d)	Calculations adjusted for user behaviour
Annual energy need [kWh/m2]	243	132	123	91

The COST C23 Action entitled “Strategies for a Low Carbon Built Environment“ (COST, 2009) resulted in renovation of buildings in many countries. Cases in Belgium and Germany show energy efficient renovation of single family houses including building envelope improvement and new heating systems based on renewable energy.

Milder climates than the Norwegian give alternatives off less insulation and still achieving a net zero energy balance for operation. Palo Alto (Palo Alto Net Zero House, 2010) in California is an example of a zero energy renovation. Plastic foam insulation is used for attic and subfloor energetic improvement, cellulose heat insulation is used for walls and storm windows are installed in addition to the original windows. Electrical appliances and lighting are replaced with modern energy efficient systems. Photovoltaic produce electricity and green electricity is purchased from the grid.

This paper addresses the need to develop possible solutions for zero energy renovation of houses in cold climatic zones. Renovation should include minimizing energy requirements for heating, ventilation, lighting, hot water and domestic electrical equipment. For future design of the energy system in the renovated house, calculated energy values should separate the need for heating and need for electricity. The methods should also validate the accuracy of standardized calculations and load versus expected real energy use and real climatic conditions.

The strategies should not be limited to using traditional technologies as adding on mineral wool, but also look at potentials for developing new solutions. The analyses should include identifying actions with biggest impact on the energy requirements, identifying needed measures to achieve near zero energy in operation. The analyses should also reflect the expected energy use for future user scenarios, not only nominal values calculated according to valid norms.

The objective is to reach zero energy balance for operation of the house. Annual energy requirements for heating and electricity should be compensated with production of renewable energy on site. This research looks at all possible parameters affecting need for heating and electricity in a single family wood frame house and possibilities for energy efficiency improvements during renovation towards zero energy levels.

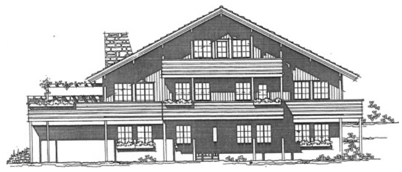
Case "Block 180"

Windows and roofing underlays have an expected lifetime of 20 – 40 years (SINTEF Building and Infrastructure, 2010). Houses built in the 1980s are at a stage in their lifetime where renovation actions are needed during the next 10 years. Dwellings from the 1980s also have the highest energy consumption compared to dwellings from other construction periods (Bøeng, 2005). Most Norwegian houses built after 1970 are named catalogue houses and are prefabricated houses bought from house manufacturing companies. Block 180 was a high selling catalogue house model in the 1980s (Sørby, 1992). By analyzing a popular house model, the results will be applicable for renovation of many houses. Block 180 was chosen as a case because the floor area is bigger than for many other popular models. A large floor area gives a larger volume to be heated as well as possible more use of electricity for lighting and equipment. A larger house will therefore be a worse case scenario when the goal is zero energy in operation. Table 2 show some basic facts for Block 180.

The floor is made of concrete casted on site. Basement walls are in light weight masonry. Exterior walls, interior walls, interior floors and roofing are wood frame constructions insulated with mineral wool. The wood frame exterior walls have wood panels as exterior cladding. Table 3 shows U-values, thermal bridge coefficient and air tightness of the house.

Table 2 Basic data for the house model "Block 180"

No. of floors	2.5
Floor area	262 m^2
Window area	45 m^2
Heated volume	565 m^3
Location	Oslo
Orientation	Main facade oriented 30^{o} to south west



Methods and tools

Energy calculations are performed according to NS 3031:2007 (Standard Norge, 2007d). Energy performance is calculated stationary giving monthly values according to NS-EN ISO 13790 (Standard Norge, 2008). Software SIMIEN 4.505 issued by Programbyggerne in 2010 is used for calculations. SIMIEN is verified for calculation according to NS 3031:2007 and Norwegian Building Code requirements.

U-values for renovation actions using traditional methods are selected from building design sheets issued by SINTEF Building and Infrastructure (SINTEF Building and Infrastructure, 2010). U-value for the original floor construction has been calculated according to NS-EN ISO 13370 (Standard Norge, 2007c). Thermal bridges of original house have been calculated according to method described in NS ISO 6946 (Standard Norge, 2007e) based on input values given in "Trehus 80" (Edvardsen et al., 1982).

Dial Europe Software © 2007 version 4.3 issued in September 2007 is used for daylight calculations.

Results and discussions

Energy performance before and after renovation

Energy performance of the original house before and after two different levels of energy efficient renovation is shown in table 3. The as built Block 180 fulfils energy label class E according to Norwegian regulations (Norges vassdrags- og energidirektorat, 2009). The first renovation case gives a net energy demand meeting the Norwegian Building Code of 2010 (National Office of Building Technology and Administration, 2010b) and is classified as an energy label C building. The second renovation case is based on state of the art renovation action using traditional technology as adding mineral wool insulation on inside and outside of exterior walls, installing super insulated windows, installing mechanical ventilation with heat recovery and adding on mineral wool insulation in floor and roof. The state of the art renovation is in accordance with energy label class B.

Calculation results are given as net energy demand including needed energy for space heating, ventilation, technical equipment, lighting and hot water. Space heating requirement includes energy need for ventilation heating, but excluding energy needs for fans, hot tap water, lighting and electrical equipment.

Table 3 Energy scenarios for Block 180 calculated according to NS 3031 (Standard Norge, 2007d). Energy label E is calculated values for the original house. Label C corresponds to net energy need fulfilling the Norwegian Building Code (National Office of Building Technology and Administration, 2010b). Energy label B is based upon renovation with traditional technologies.

Energy label	U-values [W/m²K]				Thermal bridge [W/mK]	Air tightness n50 [1/h]	Ventilation [m³/hm²]	Heat recovery efficiency	Annual net energy [kWh/m²]	Space heating [kWh/m²]
	Window	Wall	Roof	Floor						
E	1.75	0.47	0.21	0.37	0.07	3,0*	1.2	0	215	145
C	0.88	0.19	0.21	0.37	0.03	2.0	1.2	0.8	126	51
B	0.71	0.14	0.11	0.21	0.03	0.6	1.2	0.8	89	26

*) The air tightness value is a nominal value based on Thyholt et al (Thyholt et al., 2009)

Building envelope energy optimization

A parameter study of space heating requirements with further improvement of building envelope and installations are performed. Basis for the parameter study is the energy label case B in table 3. The parameter study is performed to identify factors with the biggest impact on the energy requirement and to identify criteria for wanted technological innovations for renovation. Figure 1 shows the impact on the heating when the thermal properties of building envelope components are altered. Parameters that are included are further reduction of U-values of building envelope components and the effect of further reduction of air infiltration and thermal bridges.

The diagram also shows the effect of an energy optimal window area. Some windows have been removed others have been reduced in area giving a total window area of 33 m^2. The frame/window area ratio has been reduced from 40 to 27 %. Still, the window area reduction will affect the daylight levels in bedrooms, kitchen and living rooms. Norwegian Building Code requires an average daylight factor of 2 %. Daylight calculations for the 2nd floor show that the requirement of an average daylight factor of 2 % is fulfilled if there are no interior walls. For most Block 180 houses there will be interior walls separating the 2^{nd} floor in more rooms. With interior walls, the daylight requirement is not fulfilled neither with original window area nor with reduced window area.

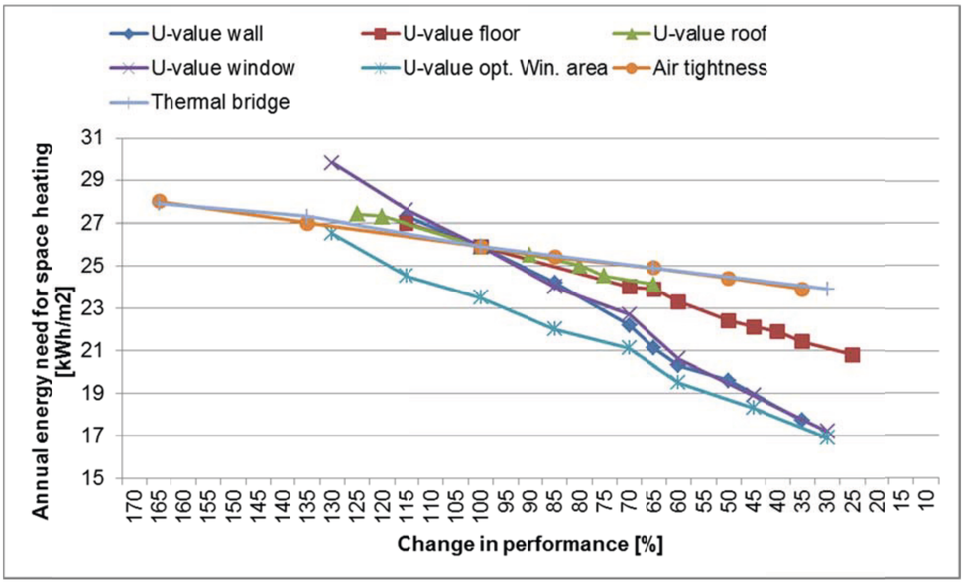


Figure 1 Annual energy need effects of further improvement of the thermal properties of the building envelope. Reference point stated as 100 % is renovation to state of the art regarding traditional renovating technologies and solutions, see energy label B status in table 3. Further improvement of thermal properties of windows and walls are of greater importance than further improvement of the other components. Lowering of the U-value of the windows from 0.71 W/m^{2}K to 0.60 W/m^{2}K (85 % in the figure) will reduce the annual heating need by 2.9 kWh/m^2. A 15 % lowering of the air infiltration by an improvement of the air tightness from 0.6 h^{-1} to 0.5 h^{-1} will give a reduction of the heating need by 0.5 kWh/m^2.

It is not possible to reach near zero heat loss without a total renovation of all building envelope components. The house is occupied by one family, and the owner should finance the renovation. In most cases wood frame houses are renovated when the building component, as window or roofing, is at the end of its lifetime. The energetic upgrade and renovation will therefore most likely occur stepwise. When conducting a stepwise upgrade some renovation actions need to be performed at the same time. Most important is to install a ventilation system when improving the air tightness. Adding on insulation and improving air tightness without installing sufficient ventilation will most likely cause moisture problems and poor indoor quality in the building due to excess internal moisture production.

Mechanical ventilation with heat recovery

The energy need is closely related to the efficiency of the heat recovery in the ventilation system. The renovation case “label B” assumes a heat recovery of 80 %. Increased efficiency to 90 % reduces the annual heating need by 2.5 kWh/m^2. Increased efficiency to 95 % reduces the annual heating need by 3.1 kWh/m^2. Energy needs for ventilation may also be reduced if the ventilation system operates with lower air exchange rates when there are no persons in the house.

Use scenarios and annual net energy requirement

NS 3031:2007 (Standard Norge, 2007d) and Norwegian Building Code (National Office of Building Technology and Administration, 2010b) defines required effect for hot tap water, lighting and electrical appliances as well as energy gains from system heat losses. NS 3700:2010 (Standard Norge, 2010b) sets lower effect requirements for lighting and equipment for passive houses. However user behaviour strongly influences on the real energy consumption for hot tap water, lighting and equipment. Figure 2 shows the effect of decrease and increase of energy requirements for hot tap water, lighting and electrical appliances for the renovated Block 180. The state of the art renovation case, energy label B in table 3, is used as the 100 % reference point with values according to NS 3700:2010 (Standard Norge, 2010b). The figure shows that hot tap water is the most important factor for reduction of the energy need. A 25 % reduction of the hot tap water consumption reduces the energy need by 4.5 kWh/m^2.

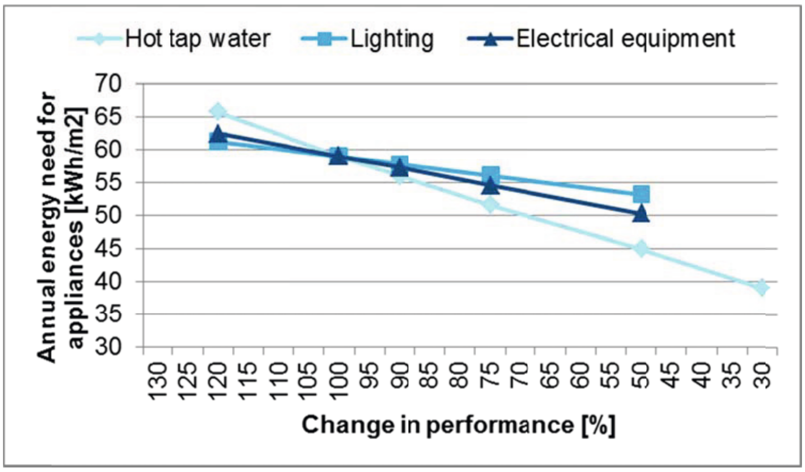


Figure 2 Annual energy need for appliances are given for hot tap water, lighting and electrical appliances. Energy label case B in table 3 is the 100 % reference point.

Figure 2 shows the great importance of having energy efficient installations and appliances. Hot water consumption dominates the energy budget of the renovation cases. Installing energy efficient hot tap water systems and monitoring hot water consumption is needed to minimize energy use in the house. In Norway there is no tradition for using heat recovery of waste water even though there are such systems for heat recovery from waste water available in the market. There is no Norwegian statistics or numbers on efficiency and heat losses related to hot tap water systems and research should be done to better understand and quantify this.

For the renovation case reaching net energy need in line with today's building code, energy label C in table 1, internal loads constitutes 55% of the calculated net energy need. The internal loads strongly depend on user behaviour. The measured internal load values for Husarveien are relevant as an example for real use and are 5000 kWh lower than the calculated annual values for Block 180. A user behaviour in accordance with the measured in Husarveien implies a difference of 26 % between nominal calculated values and real use-values.

Towards zero energy renovation

Scenario "Zero" in table 4 refers to near zero energy need according to use of new technologies. Calculations are based on results of parameter study shown in figures 1 and 2. U-values of building components have been reduced implicating use of new technologies for renovation. The suggested reduction in U-values and energy requirements are not defined stricter than it will be possible to achieve within few yeas of technological development. The air tightness of the building envelope is reduced further. Energy need for hot water, lighting and electrical appliances have been reduced by 44 %. In addition the indoor temperature has been lowered 1 ^{o}C to an average indoor temperature of 20 ^{o}C. The window area has been optimized for maximum heat gains and minimum heat loss during the cold seasons.

The standards and Building code give normalized values for indoor temperature, air exchange rates for ventilation and internal loads for hot tap water, lighting and electrical equipment. The internal loads are given as needed effect pr floor area. Block 180 as built in the 1980s has a heated floor area of 262 m^2. Regarding electrical equipment and lighting the calculation method based on effect needed pr area is relevant since all rooms need lighting and electrical equipment are installed in most rooms. For hot water needs the relevance is however less since the number of wet rooms and water consumption does not depend on the overall floor area, but more likely on the number and age of the occupants. Statistics from Norwegian dwelling energy consumption also show a close correlation between number of occupants and energy use. Dwellings with 3 occupants used approximately 2500 kWh less electricity than dwellings with 4 persons in 2001 (Bøeng, 2005). Measured energy use for hot tap water production in Husarveien is used for the case "Zero".

Table 4 Energy scenario for near zero energy renovation of Block 180 calculated according to NS 3031:2007 (Standard Norge, 2007d).

Energy scenario	U-values [W/m²K]				Thermal bridge [W/mK]	Air tightness n_{50} [1/h]	Ventilation [m³/hm²]	Heat recovery	Annual net energy requirement [kWh/m²]	Space heating requirement [kWh/m²]
	Window	Wall	Roof	Floor						
"Zero"	0.56	0.10	0.09	0.13	0.03	0.4	1.2	0.9	57,6	14

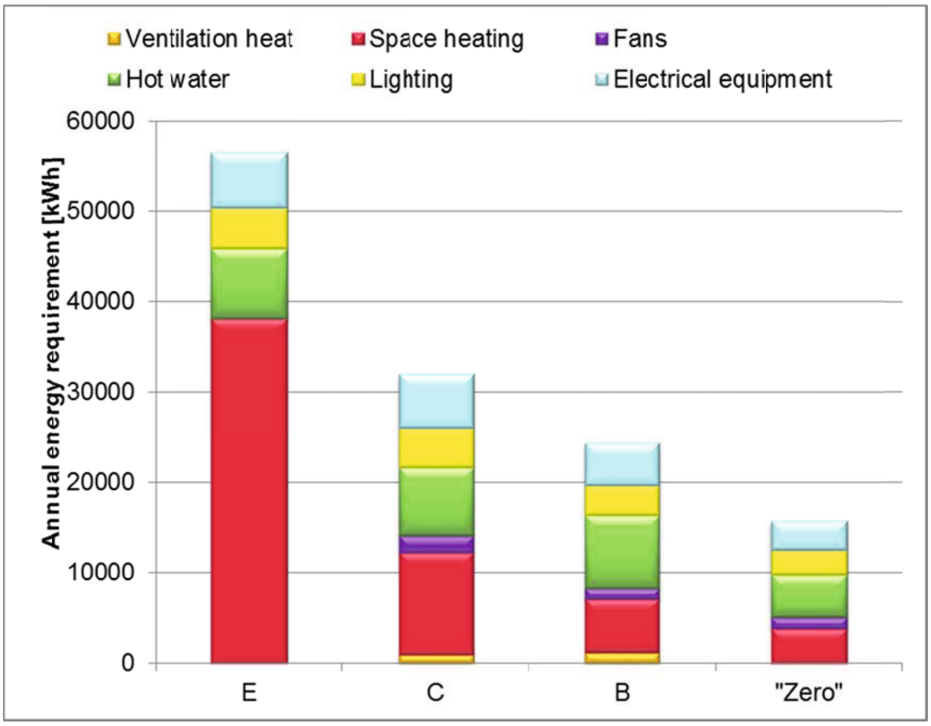


Figure 3 shows the total annual net energy need for Block 180 as built, energy label E and renovated according to today's building code, label C, renovated with state of the art technologies, label B, and renovated with even further reduction of heat loss and lower internal loads, "Zero".

Assuming 21 °C for all the heated floor area gives too high heating loads for the as built case. The heated area includes 43 m² sleeping rooms which normally are kept colder in Norway than baths, kitchen and living rooms. Natural ventilation gives the possibility of keeping different temperature zones in a building. Using lower temperature for calculations should therefore be done for estimating real energy consumption. For wood frame houses with balanced mechanical ventilation built according to the 2010 Building code (National Office of Building Technology and Administration, 2010b), calculations according to NS 3031:2007 will give a better correlation with real values for heat loss through the building envelope due to the fact that the ventilation systems give a more equal temperature in all heated rooms.

For the case Husarveien (Mysen, 2008) an average temperature of 18 ^{o}C was used for calibrating calculations estimating real energy. Husarveien has a floor area of 220 m^2. This is 50 m^2 smaller than Block 180. Block 180 may therefore have somewhat higher loads for lighting and appliances than Husarveien which are shown in table 1, but hot water use could be of equal size for the two houses. The Husarveien case also shows that lower air exchange rates for natural ventilation is possible due to infiltration and air leakages in the building envelope.

Calculations according to NS 3031:2007 and 2010 building code will most likely give an unrealistic picture of the real energy need of a wood frame house built in the 1980s. When evaluating the cost-benefit of energy efficient renovation actions it is vital to know the real energy use and energy saving effect of the chosen measure. Chosen measures should also function in future use scenarios with higher and lower energy needs than the current situation. Houses are sold and new users may have other use patterns. Using the effect requirements in the Norwegian Building Code (National Office of Building Technology and Administration, 2010b) and NS 3031:2007 (Standard Norge, 2007d) may be relevant for some occupants. The chosen energy sources and systems should however also function well with expected lower consumption as shown in Husarveien.

Calculations according to NS 3031.2007 are necessary for documentation according to the Norwegian Building Code. The calculated results in figure 1 and 2 also give a realistic view upon the effect of certain renovation measures. By evaluating the parameter study shown in the figures it is possible to identify which renovation actions that have substantial effect on the energy consumption.

When deciding upon energy sources for a renovated house, the need for heat and need for electricity should be treated separately. For the scenario “Zero” the annual energy requirements for space heating, ventilation heating and hot tap water is 8600 kWh. Annually electricity requirement for fans, electrical equipment and lighting is 7100 kWh annually.

Renewable energy sources need to be included for achieving a net zero operational energy balance. In Norwegian climatic zone sun energy may be harvested in summer, spring and autumn, but in the coldest months November- February sun availability is low. Solar collectors may supply 50 % of the annual energy need for hot tap water (Andresen, 2008). Space heating systems must include other renewable energy sources than solar energy. District heating, biopower, wind power, combined heat and power aggregates and heat pumps are potential renewable energy sources.

The need for electricity for fans, lighting and equipment may be assumed to be independent of season. Installed photovoltaic will produce electricity when sun is available. In Norway there is no system for feedback of overproduction of electricity to the grid. To reach a zero energy balance one should look for electricity production in a regional setting where more houses are connected to one energy source for instance a wind turbine or a small scale hydropower plant. If the single house should be energy neutral combined heat and power aggregates may be an option for electricity and heat production.

Conclusions

Renovation of single family houses towards zero energy levels in cold climates requires radical improvements of all building envelope components. Using traditional technologies for renovating a 1980s house annual space heating requirements may be reduced form 145 kWh/m^2 to 26 kWh/m^2. Facades including windows need special focus when developing new solutions. Further reduction of the space heating requirement to 14 kWh/m^2 can be possible.

After renovation towards zero heat loss through the building envelope, energy requirements for hot tap water, lighting and electrical equipment dominate the energy budget. Special focus during zero energy renovation should be on installations and user behaviour. Norwegian energy calculation standards and Building Code should be updated to give a better correlation with measured energy consumption in houses and to promote the use of more energy efficient installations.

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FENESTRATION SOLUTIONS FOR ZERO EMISSION RENOVATION OF DWELLINGS (PAPER 2)

presented at the Passivhus Norden Conference in Helsinki, 18.10.2011

Fenestration solutions for zero emission renovation of dwellings

Birgit Risholt

Summary

In cold climates minimizing the heat loss through windows is required when upgrading dwellings to passive houses or zero emission buildings. A study of a single family house model from the 1980s is performed for optimization of solutions for fenestration when upgrading the house to a zero emission building.

The best insulated glazings in the market have low light transmittance and the daylight level in the room is the limiting factor of how low the U-value and how small the window area can be. Renovation the house using windows with glazings with light transmittance lower than 71 % and thicker walls than 300 mm, facade changes as removing overhang over windows and increasing window size is necessary to get acceptable daylight levels.

Air tightness of the windows is an important parameter for the overall energy performance of house. The house owner buying windows for renovation should require measured air tightness values for the different window alternatives, to be able to make the best possible choice. None of the existing certification systems includes all properties that shall be documented according to the Norwegian Building Code. None of the systems give information on what windows that are the optimal choice for renovation of dwellings.

Quotes on six different window deliveries for renovating the house show that the windows with U-values of 0.8 W/m^{2}K and lower are not cost efficient over the windows lifetime with energy prices lower than 0.2 €.

Keywords: windows, energy, emissions, daylight, air tightness, costs, renovation, house

Introduction

Requirements for windows for zero emission renovation of houses

In cold climates the heat loss through the windows is often higher than the heat gains during summer. The optimal choice to save energy is to use windows with good thermal insulation and high solar gains(Urbikain and Sala, 2009). Green house gas emissions for windows are strongly related to the energy performance in the operational phase. A life cycle analysis of green house gas emissions for seven wooden windows showed that the

U-value and the heat losses through the windows during operation of the building dominated the emission calculations. The windows with the lowest U-value had the lowest emissions(Wærp and Folvik, 2009).

The primary functions of a window is to let daylight enter the room and to let us look out. The daylight requirement in the Norwegian Building Code for living rooms, kitchens, bedrooms and offices in dwellings is an average daylight factor of 2 %(National Office of Building Technology and Administration, 2010b). This paper shows how different fenestration solutions affect the daylight levels in a single family house after renovation.

The window is also a part of the building envelope and must fulfil requirements related to mechanical strength and climate resistance. The air tightness of the windows is included in the overall air tightness of the house during calculations of the nominal energy need(Standard Norge, 2007d). In Norway the building code gives minimum requirements for the air tightness of buildings and the air tightness is measured for new buildings(National Office of Building Technology and Administration, 2010b). The Norwegian passive house standard has a minimum requirement for air tightness for houses of 0.6 h^{-1} at 50 Pa pressure difference(Standard Norge, 2010b). Decreasing the air tightness to 0.4 h^{-1} for a single family house can reduce the overall annual energy need for heating by 4 %. Higher air leakages and an overall air tightness of a house of 0.8 h^{-1} result in a 4 % increase in the energy need for heating(Risholt et al., 2011). This paper analyses the windows' effect on the overall air tightness of a single family house after renovation.

Legal requirements regarding what properties that shall be documented for windows and how they shall be documented are given in the Norwegian Building Code(National Office of Building Technology and Administration, 2010b). A survey of The Building Code's requirements for documentation of properties and the different labelling possibilities for windows in Norway is given in table 1.

Table 1 The Norwegian Building Code's requirements for documentation of properties and different options for labelling of windows in Norway (Standard Norge, 2007+2010, Nordic Ecolabel, 2008, SINTEF Building and Infrastructure, 2011, Passivhaus Institut, 2011, Enova SF, 2011)

Property	Norwegian Building Code	CE-marking	SINTEF Technical Approval 1)	Nordic Eco-labelling	Passive-house certifi-cation	Enova anbefaler
U-value [W/m^{2}K]	≤1.2	X	X	≤1.0	≤0.8	≤1.0
g-value	X	X		≥0.50		
Light transmittance	X	X		≥0.63		
Air tightness	X	X	X	Class 4		
Rain tightness	X	X	X			
Resistance to wind load	X	X	X			
Load bearing capacity of safety devices		X				
Acoustic performance	X	X	X			
Dangerous substances	X	X	X	X		
Emissions to indoor air	X		X			
Hazardous waste	X		X			

X – Obligatory property that need to be documented

1) There are threshold values that need to be fulfilled for the SINTEF Technical Approval, but the guidelines are not public available.

Cost for energy efficient window renovations

Cost and expected payback time for investments on energy savings are very important parameters for the house owner that makes decision on what windows to buy for the house. Installing new and energy efficient windows might be a cost efficient solution. What windows will be the most cost optimal choice depends on the investment costs and annual costs for heating in the operational phase of the house. This paper investigates the replacement of windows that are the end of their lifetime, comparing life cycle costs for different window alternatives.

The case "Block 180"

Windows have an expected lifetime of 20 – 40 years(SINTEF Building and Infrastructure, 2010). Houses built in the 1980s are at a stage in their lifetime where renovation actions are needed during the next 10 years. Norwegian dwellings from the 1980s also have the highest energy use compared to dwellings from other construction periods(Bøeng, 2005). Block 180 was a popular house model in the 1980s(Sørby, 1992). By analyzing a popular house model, the results will be applicable for renovation of many houses. Block 180 was chosen as a case because the floor area is larger than for many other popular models. A larger house will be a worse case scenario when the goal is to achieve a zero emission building after renovation. Table 2 show some basic facts for the house Block 180.

Table 2 Basic data for the house "Block 180"

No. of floors	Floor area	Window area	Heated volume	Location
2.5	262 m^2	45 m^2	565 m^3	Oslo

Methods and tools

Daylight

Dial Europe Software © 2007 version 4.3 issued in September 2007 is used for daylight simulations. Daylight calculations are performed for three rooms of the as built and the renovated Block 180. The kitchen is chosen because the daylight level as built is low due to two balconies that are preventing daylight from entering the room, see figure 1. The office has a good daylight level as built. Daylight simulations are performed to see if it is possible to reduce the window area while keeping an acceptable daylight level. The bedroom has an acceptable daylight level as built. The room is chosen for further analysis in order to see how installing new windows with a slimmer frame construction and a larger glass area will improve the daylight conditions. Facade drawings of the Block 180 are found in figure 1 and basic data for the three rooms are given in table 3. Five different renovation scenarios are evaluated, see table 4.

Table 3 Data for three different rooms in the as built house Block 180

Room	Facade orientation	Floor area [m2]	Window area [m2]	Frame ratio [%]	Overhang		Balcony	
					Height [m]	Width [m]	Height [m]	Width [m]
Kitchen	Southwest	15.2	2.34	39	2.4	1.2	0.9	2.4
Office	Northeast	13.3	2,5	41	2.9	0.4		
Bedroom	Northeast	7.8	1.3	41	3.2	0.4		

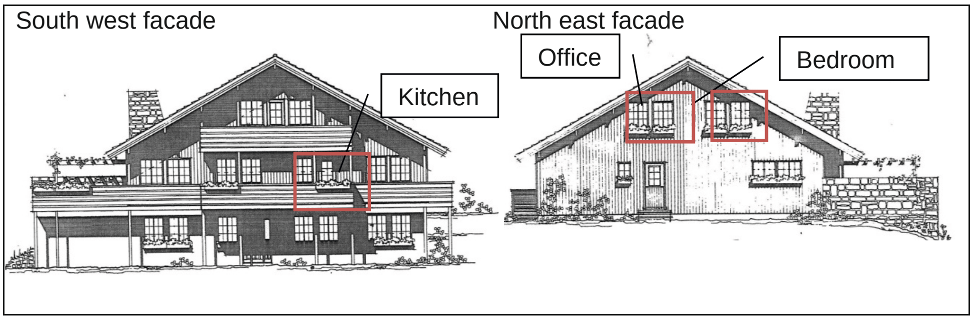

Figure 1. The southwest and northeast oriented facades of the as built Block 180

Table 4 Renovation scenarios for the Block 180 using windows with a three layered glazing

Renovation scenario	Wall thickness [m]	Average window frame ratio [%]	Thermal and radiation properties of the glazing		
			Light transmittance [%]	U-value [W/m2h]	g-value [%]
As built	150	40	70	1.7	70
Regular 150	150	30	71	0.7	56
Regular 300	300	30	71	0.7	56
Regular 400	400	30	71	0.7	56
Low	400	30	65	0.7	52
Very low	400	30	56	0.5	32

Air tightness measurement and calculation

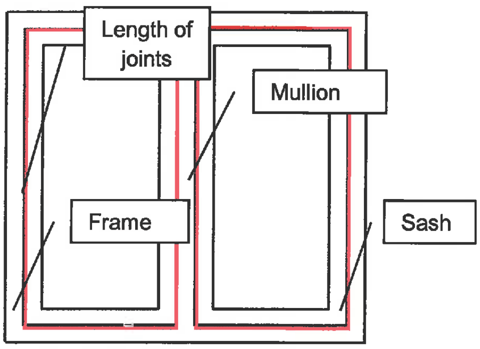

Figure 2. Length of joints for a window with a mullion and two sashes

Air tightness measurement of 30 wooden windows and window doors from Norwegian manufacturers has been performed according to NS-EN 1026 (Standard Norge, 2000a). The tests where carried out as sample testing for manufacturers in 2010. Air leakages at a pressure level of 50 Pa are recorded as leakage per length of joints between the sash and the frame, see figure 2 for definition of length of joints for a window with two sashes. The average air tightness for the 30 products at the pressure difference of 50 Pa is calculated. The average value is compared with allowed leakages for different classifications according to NS-EN 12207 (Standard Norge, 1999). The average measured air tightness value and the allowed air leakages according to NS-EN 12207 are used for calculation of the windows' effect on the overall air tightness of the renovated house Block 180.

The windows' effect on the overall air tightness of the house is calculated as:

$$air\ leakage_{house,\ windows} = (air\ leakage_{windows} * \sum length\ of\ joints)/volume_{house} \qquad (1)$$

air leakage $_{house, windows}$	$[h^{-1}]$	the resulting air leakage of the house due to window leakages
air leakage $_{windows}$	$[m^3/mh]$	is the average air leakage for the windows and window doors
∑ length of joints	[m]	the sum of the length of joints for all windows and window doors in the house
volume $_{house}$	$[m^3]$	the volume of the house, see table 2

Life cycle cost calculations

Quotes on window and window door delivery for Block 180 renovation have been collected for six alternatives, see table 5.

Table 5 Investment costs and thermal transmittance for fenestration for renovation of the Block 180.

	W1 0.8	W2 1.0	W2 1.2	W3 0.6	W3 0.7	P1 0.7
U-value $[W/m^2K]$	0.8	1.0	1.2	0.6	0.7	0.7
Material in frame and sash	Wood with insulation	Solid wood	Solid wood	Wood with insulation	Wood with insulation	Polyvinyl-chloride
Investment cost [€]	17875	16088	14479	35887	27736	20973

Life cycle costs for the different window alternatives are calculated according to NS 3454:2000(Standard Norge, 2000b) as a single measure for upgrading the house from its original state. Investment cost and annual energy costs for heat losses through the windows are included in the calculations. Costs for mounting the windows and maintenance costs are assumed to be equal for the different alternatives and are not included. According to the Norwegian Building Code an interest rate of 4 % shall be used in life cycle cost calculations(National Office of Building Technology and Administration, 2010b). Calculations are based on 30 years lifetime for the windows.

The heat loss through the windows when installed in the Block 180 is calculated using the software SIMIEN 4.505 issued by Programbyggerne in 2010. SIMIEN is verified for calculation according to NS-EN 15265(Standard Norge, 2007b), NS 3031:2007(Standard Norge, 2007d) and Norwegian Building Code requirements(National Office of Building Technology and Administration, 2010b).

Results and discussion

Results from daylight calculations

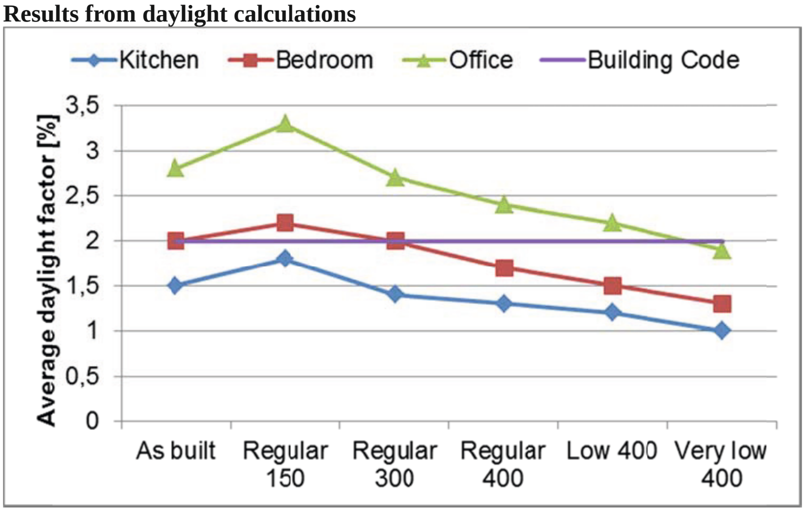

Figure 3 Calculated average daylight factors for three rooms in Block 180 for different renovation scenarios. The alternatives are according to table 4

Figure 3 shows the calculated average daylight factors for three different rooms in the Block 180 with windows with different glazings and for different wall thickness, see table 4. The figure also includes the required average daylight factor in the national building code.

The bedroom and office has sufficient daylight in the as built case. Installing windows with a light transmittance of 71 % and smaller frame area improves the daylight levels in the rooms, see Regular 150 in figure 3. Improving the U-value of the walls by adding extra insulation usually results in thicker walls. With walls thicker than 300 mm the daylight level in the bedroom will be below the requirement in the Norwegian Building Code, see Regular 400 in figure 3.

For the kitchen none of the cases give satisfying daylight levels. Changing the facade may improve the daylight levels:

- Removing the balcony over the kitchen window will increase the average daylight factor in the Regular 400 case from 1.3 % to 1.9 %.
- Increasing the window area in the kitchen from 2.3 m^2 to 3.4 m^2 can in the Regular 400 case increase the daylight factor from 1.3 % to 2.0 %.
- Increasing the window area in the kitchen from 2.3 m^2 to 4.3 m^2 can in the Very low case increase the daylight factor from 1.0 % to 2.0 %.

Discussion on the daylight requirements and the energy budget of the house

Reducing the window area is a suggested renovation action in a zero emission renovation of the Block 180(Risholt et al., 2011). Figure 4 shows that this is not possible because of the necessary daylight levels. Installing new windows with a larger glass area than the original windows and a light transmittance of 71 % give better daylight levels in the house than in the as built case, see figure 3. To achieve a zero emission house after renovation, walls need to bee thermally improved by adding extra insulation usually resulting in thicker walls. A wall thickness of 300 mm gives the same daylight levels in the room as in the as built case. Renovation solutions for wood frame walls that will give thicker walls than 300 mm will require detailed daylight simulations for most of the rooms in the house and most likely an increase of the window area or other facade changes.

To improve the daylight conditions in the kitchen one option is to reduce or remove the balcony over the window. Another alternative is to install more windows. The southwest facing facade is shown in figure 1. The facade is dominated by the two balconies and the facade already has a lot of windows. A change in the facade will have two be designed by an architect in cooperation with the owner and users of the house and the changes must be accepted by the building authorities in the municipality.

A larger window area in the south facing facade for only one room will have a minimal effect on the energy performance of the house. However more of the rooms facing the facade have insufficient daylight levels. Installing 5 more windows in the southwest facade with light transmittance 56 % and U-value 0.6 W/m^{2}K (window type Very low in table 4) increase the annual energy need of a renovated Block 180 by 3 % compared to a renovation scenario using windows with a light transmittance of 71 % and U-value 0.7 W/m^{2}K (window type Regular in table 4). A larger window area might also cause higher indoor temperatures due to solar radiation if the solar shading is not designed correctly.

There are also practical limitations preventing the necessary increase in window area for the house. In the bedroom there is no possibility for installing larger windows. Using windows in the kitchen with light transmittance of 56 % (window type Very low in table 4) resulted in an increase of window area from 2.3 m^2 to 4.3 m^2 which is equal to an increase from 15 % to 28 % of the floor area. The width of the kitchen wall is 4.1 m. By using windows with a height of 1.2 m windows will cover 3.5 m of the wall width. This means that almost the entire kitchen facade wall will have windows. This may not be a preferred solution for the house owner. A larger window area will also affect construction and investment costs for renovation.

Existing green labels and documentation systems for windows aims to help building owners to make optimal choices when buying windows. The light transmittance of the glazing is vital for deciding necessary window area. The U-value, g-value and air tightness of windows is deciding heat loss through the windows. As shown in table 1 the only labelling system including threshold values for these properties are the Nordic ecolabelling system, the Swan(Nordic Ecolabel, 2008). However, the threshold value for light transmittance of the glazing is set to 63%. Using windows with light transmittance of 63% and at the same time increasing wall thickness during renovation will reduce the daylight level in the rooms and detailed daylight calculations is necessary.

Results from air tightness measurements

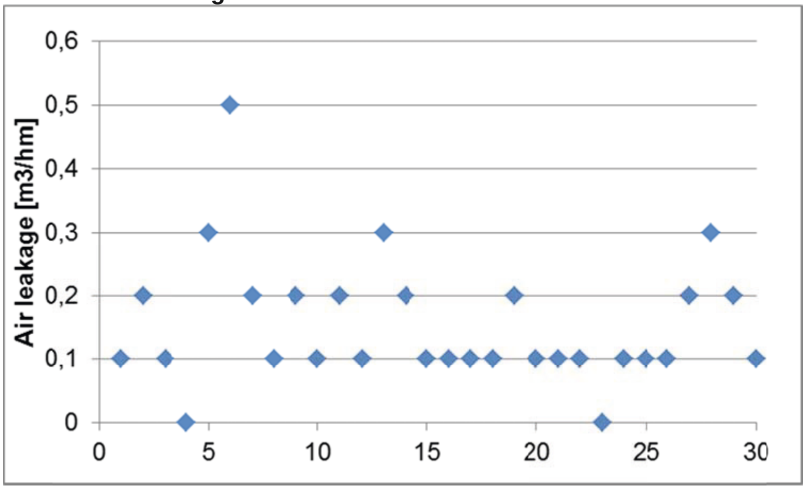

Figure 4 Air leakage for 30 windows and window doors at 50 Pa pressure difference measured according to NS-EN 1026:2000(Standard Norge, 2000a)

Figure 4 shows measured air tightness for 30 wooden windows and window doors at 50 Pa pressure. The air tightness is given as leakage per length of joint between the sash and the frame, see figure 2. The average leakage for the 30 products is 0.15 m^3/hm. The Block 180 house has a window area of 45 m^2. The total length of joints is 182 m when installing windows with two sashes. If windows with one sash are installed the joint length is 129 m.

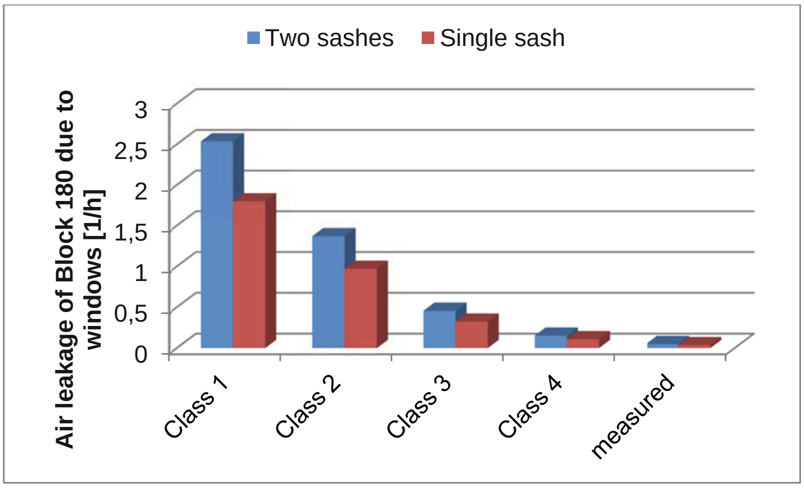

Figure 5 Air leakages at 50 Pa pressure difference for the Block 180 resulting from air leakage in the windows. Window classification is according to NS-EN 12207. Average fig. 4 values are calculated based on the average value of the measured leakages shown in figure 4.

The calculated Block 180 air leakage resulting from the windows' air leakages, calculated according to formula (1) in chapter 3.2, is shown in figure 5. The windows' air leakage is given as allowed leakage for the different classifications in NS-EN 12207 and the average measured air leakage for the 30 Norwegian wooden windows and window doors shown in figure 4. The air leakage for Block 180 is calculated for both using windows with a single sash and windows with a mullion and two sashes. The figure 5 shows that best alternative is to use the windows with one sash and an air tightness of 0.15 m^3/hm resulting in a house air leakage of 0.04 h^{-1}. Installing windows with air leakage classified in class 4 according to NS-EN 12207 with two sashes give a partial house air leakage of 0.15 h^{-1} and class 3 windows give a contribution to the house air leakage of 0.46 h^{-1}.

Discussion of the windows' air tightness and energy optimal choices

For zero emission renovations in cold climates air tightness of the building envelope is of great importance for the heating needs. Air leakages through the windows are a part of the overall house air leakage(Standard Norge, 2007d). Considering a case where the house has windows with an air leakage of 0.15 m^3/hm and a house overall air leakage of 0.6 h^{-1}. The air leakage through the windows is 0.04 h^{-1} and constitutes 7 % of the overall house air leakage. By instead installing windows with air tightness classification class 3 according to NS-EN 12207 this can result in an increase in overall air leakage of the house from 0.6 h^{-1} to 1.0 h^{-1} (the windows' air leakage increases to 0.46 h^{-1}) resulting in an increase of the energy use for space heating of 8 %.

The original house has windows with two sashes and a mullion. This paper shows that for the air tightness and the energy performance of the house, it is better to choose windows with one sash due to such windows having a shorter length of joints. For windows with very good air tightness the increase of joint length due to the second sash has less influence on the overall air tightness of the house. From an energy analysis it will still be better to choose windows with one sash. However, the window change will affect the aesthetics and the architectural expression of the building.

NS-EN 14351-1 state that window manufacturers shall declare only the classification and not the measured air tightness values(Standard Norge, 2007+2010). However, due to the shown importance of the air tightness on the energy performance of a building in cold climates, the window suppliers should state the measured air tightness values and not only the classification according to NS-EN 12207. Then it will be possible for the house owner to choose the best windows for renovation.

Life cycle costs

Table 6 shows the annual heat loss through windows and doors for the Block 180 for renovation with six window alternatives. The window alternatives are given in table 5.

Table 6 Annual heat loss through windows and doors calculated according to NS 3031(Standard Norge, 2007d)

	W1 0.8	W2 1.0	W2 1.2	W3 0.6	W3 0.7	P1 0.7
Annual heat loss through windows [kWh]	3466	4365	5250	2554	2981	2981

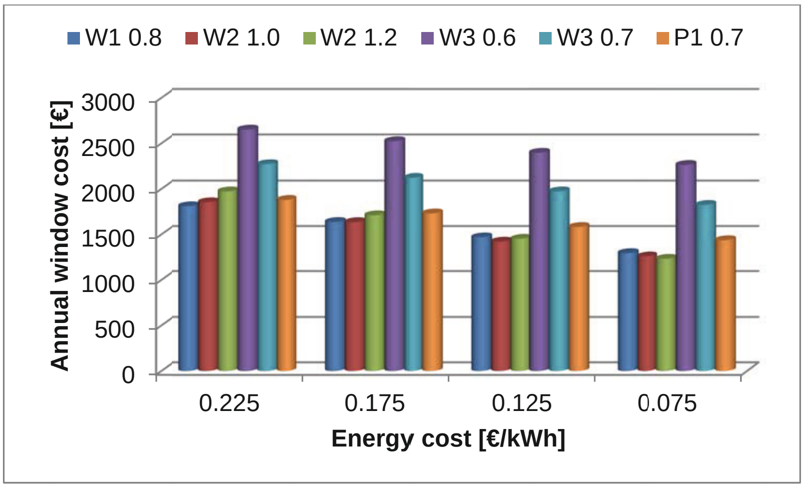

Figure 6 Annual costs for different window alternatives for the house Block 180 and different energy costs

Figure 6 shows the annual costs resulting from the investment and from the heat losses through the windows of the renovated Block 180. Five different cost levels for energy are assumed. The interest rate is 4%. The assumed lifetime is
30 years. Investment costs are from quotes from window suppliers, see table 3. In the situation with an energy cost of 0.075 € the window W2 with U-value 1.2 W/m^{2}K is the most cost efficient. With energy price 0.125 € the window W2 with U-value 1.0 W/m^{2}K is most cost efficient and in the case of energy price 0.22s € the window W1 with U-value 0.8 W/m^{2}K is most cost efficient.

Discussion of the cost optimization of the window investment
As shown in table 6 and figure 6, investment and life cycle costs are higher for the windows with the best energy performance. The renovation scenario is to upgrade the complete house to become a zero emission building. For the life cycle cost calculations, this means that no single measure can be calculated by itself. When reaching zero emission level, the need for heating is minimal. An annual energy need for heating below 15 W/m^{2}K can be possible(Risholt et al., 2011). With low heating requirements, investments in renewable energy production, heating source, -storage and -distribution system will be low. To document costs for renovation towards zero emission levels a total cost evaluation for upgrading the house and all the renovation measures is necessary. Further analyses will be done for the Block 180 house to establish optimal levels for energy need, -production, -storage and -distribution.

Conclusion

Zero emission renovation of houses in cold climates requires fenestration solutions with as low U-value and as low window area as possible to minimize heat loss during operation of the house. The best insulated glazings have low light transmittance and the daylight level in the room is the limiting factor of how low the U-value and how small the window area can be. Renovation the house Block 180 using windows with glazings with light transmittance lower than 71 % and thicker walls than 300 mm, facade changes as removing overhang over windows and increasing window size is necessary to get acceptable daylight levels.
Air tightness of the windows is an important parameter for the overall energy performance of house. The house owner buying windows for renovation should require measured air tightness values for the different window alternatives, to be able to make the best possible choice.

Existing green labels and documentation systems for windows aims to help building owners to make optimal choices when buying windows. None of the existing certification systems includes all properties that shall be documented according to the

Norwegian Building Code. None of the systems give information on what windows that are the optimal choice for renovation of dwellings.

Quotes on six different window deliveries for renovating the house Block 180 show that the windows with U-values of 0.8 W/m^2K and lower are not cost efficient over the windows lifetime with energy prices lower than 0.2 €. However, windows with low U-value may be cost efficient when looking at zero emission renovations of the entire house and possible savings from buying simpler and less costly solutions for renewable energy production, -storage and -distribution.

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6.2 Life cycle costs

Section 6.1 deals with the first three steps of the Kyoto pyramid, see figure 6.1. Step four is to present the energy use in the building to the users. Previous studies have shown an energy saving effect of 5 – 10 % from displaying the energy use to make residents aware of their energy behaviour either through detailed information on the energy bill (Wilhite and Ling, 1995) or by smart monitoring (Hargreaves et al., 2010). However, previous research has also shown limitations of the effect of displaying the energy use related to cultural barriers (Aune, 2007) and use patterns (Hargreaves et al., 2012). It was decided not to include the effect of displaying energy use in this research.

Step 5 of the Kyoto pyramid is to include renewable energy production on site to reduce the demand for delivered energy to operate the building. On site renewable energy production is also an important factor for the economic aspects of renovation.

Paper 3 deals with zero energy renovation including renewable energy production on site. Previous studies on the potential for energy saving in the Norwegian building stock state that it is possible to reach substantial energy savings using traditional technologies (Enova, 2012, Kommunal- og regionaldepartementet, 2009, Lavenergiutvalget, 2009, Dokka et al., 2009, Thyholt et al., 2009). The need for national energy savings are urgent to secure the national electricity supply (Kommunal- og regionaldepartementet, 2012), and it was therefore decided to, also in the study on renewable energy production, to investigate existing technologies and products in the Norwegian market.

Paper 3 investigates the technical possibilities for net and nearly zero energy renovation of the house 'Block 180'. The research results in paper 3 thus address the research sub-question 1, see chapter 2. The paper 3 also analyses the lifecycle cost aspects of zero energy renovation, finding results also to answer research sub-question 2.

Paper 3 presents, analyses and discusses two different strategies for renovating the building envelope and five different renewable energy production technologies. Extracts of the results in Paper 3 are also included in paper 6 on sustainability assessment of zero energy renovation, see section 6.4.

LIFE CYCLE COST PERSPECTIVES ON ZERO ENERGY RENOVATION OF A SINGLE FAMILY HOUSE (PAPER 3)

presented at the RERC Technoport 2012 conference in Trondheim, 17.04.2012

Life Cycle Cost Perspectives on Zero Energy Renovation of a Single Family House

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Abstract

This paper discusses two scenarios for energy and cost optimal renovation of a Norwegian single family house from the 1980s. The scenarios are renovation to an annual space heating need of 49 kWh/m^2 and renovating using passive house components to an annual space heating need of 24 kWh/m^2. Life cycle costs for renovating the building envelope and the life cycle costs for the required local heat production for an annual net zero and a nearly zero energy balance are analyzed. The scenario with the highest heating loads is cost optimal due to very high investment costs for the more ambitious renovation of the building envelope.

Keywords: Energy, renovation, lifecycle costs, house, dwelling

Introduction

Energy use in the Norwegian building stock

40 % of the energy use in Norway is related to buildings and the building sector. The residential part of the total energy use is approximately 22 % (Sartori, 2008). The Norwegian building sector has a potential of energy saving of 12 TWh before 2020 (Dokka et al., 2009).

The Norwegian building stock consists of 3.8 million buildings. Of a total of 2.3 million dwellings there are 1.2 million single family detached houses. 80 % of the buildings existing today will still be in use in 2050 (Kommunal- og regionaldepartementet, 2009). Annual energy consumption in Norwegian dwellings was 46 TWh in 2009. 30 TWh was used in single family houses (Statistisk sentralbyrå, 2010). Reducing the energy requirement for operation of these buildings is of great importance to realize the potential for energy savings in the building stock.

Net and nearly zero energy definitions

To achieve a zero emission building, the building needs to be constructed to minimize energy use during operation. The materials and the construction products have low greenhouse gas emissions in addition to other technical properties. Renewable energy should be used as energy source and this should balance the demand. This is valid for new buildings and for renovation measures for existing buildings. However, there are no common international definition on the term zero emission or zero energy buildings(Marzai et al., 2011). The definitions and calculation methods differ between countries. There are on-going work within the International Energy Agency to develop common definitions, standards and methods in

Annex 52 and Annex 56(International Energy Agency, 2011). Annex 56 deals with renovation of existing dwellings. The scope of the Annex 56 is to develop methods and tools for deciding upon cost optimal strategies for zero energy renovation of dwellings. This paper is a part of the Norwegian contribution to the work of the annex.

A definition of the term nearly zero energy buildings are given by the European Union in the Directive 2010/31(European Parliament and The Council, 2010):

> *"Nearly zero-energy building means a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby."*

This paper investigates the life cycle cost aspects of two renovation strategies for achieving a zero energy balance during operation of a single family house in Norway. Analyzes of embodied energy, primary energy or emissions are not included. The net zero energy ambition chosen for this study is that the onsite annual renewable energy production equals the total energy demand for operation of the house including user demands. This is according the definition in (Marzai et al., 2011) allowing on site energy generation from off-site renewables The nearly zero energy ambition is according to the definition in Directive 2010/31(European Parliament and The Council, 2010) so that the renewable energy production on site equals a significant extent of the energy need.

Renovation of single family houses towards zero energy levels

Several new single family houses claims to be built according to the Norwegian passive house standard NS 3700(Standard Norge, 2010b). The most energy efficient renovation cases are using passive house elements. Husarveien is an example of renovation using passive house technology (Mysen, 2008). The described renovating measures include adding on mineral wool insulation on exterior walls and roof, installing new windows, installing ventilation with efficient heat recovery and use of a solar collector for domestic hot water heating.

The COST C23 Action entitled "Strategies for a Low Carbon Built Environment" (COST, 2009) resulted in renovation of buildings in many countries. Cases in Belgium and Germany demonstrates energy efficient renovation of single family houses including building envelope improvement and new heating systems based on renewable energy.

The life cycle costs of renovation

The authorities aim for a drastic reduction in energy use in the building sector. This paper addresses the life cycle cost perspectives related to two strategies for zero energy renovation of a single family house in Norway. A Norwegian single family house is most likely to be owned by the persons living in the house. The life-cycle cost analysis is done from a house owner perspective.

The term life cycle costs includes investment costs, annual costs including costs for operation, maintenance costs and costs for repair and replacement (Standard Norge, 2007a). When evaluating different renovation measures the life cycle costs should be calculated over the time period the house owner will own the house, to make it possible for the house owner to choose a cost optimal renovation strategy. The cost calculation should also include the final value of the building and technical systems at the end of the calculation period as these represent values that need to be subtracted from the costs.

Annuity calculations can show the life cycle cost calculations as an average annualized cost. Another option is to calculate the global cost summarizing the total costs throughout the calculation period. A house owner investing in renovation most probably has a likely timespan for his ownership. Global cost is linked to the calculation period and will give the house owner knowledge on all costs that will occur during his expected ownership period.

The house owner should also consider the investment costs(Martinaitis et al., 2007). The renovation shall normally be covered by a family budget. It may be a better investment to buy a new energy efficient house than to do the renovation and the investment may not result in a corresponding higher market value of the house. These factors will in each case decide the upper limit for investment, the investment ceiling ($\Sigma\ I_{ETC}$). Martinaitis et al (Martinaitis et al., 2007) defines this as

$$\Sigma\ I_{ETC} \leq (P_{new} - P_{old}) \times \varphi_p \quad \text{where} \tag{1}$$

P_{old} is the market price of the building before renovation, P_{new} is the price of a newly built and energy efficient building and φ_p is a corrective factor including aesthetics, location and facilities. If the renovation results in a house that are according to a standard like a new house, the corrective factor should be 1. For most renovations this is not the situation and the factor should be less than one.

When calculating costs for an energy efficient upgrade of a house, it is necessary to separate costs for renovation of the house and the costs for the energy efficiency renovation actions(Martinaitis et al., 2007, Jakob, 2006). Renovation and energy efficiency actions are normally done at the end of the lifetime of a component or building element. Costs for renovation to its original standard are not a part of the energy efficiency upgrade. Therefore only additional costs during renovation for energy efficiency measures are considered when evaluating cost optimal zero energy renovation strategies in this paper.

Other factors than energy can be included in life cycle cost calculations. An energy efficient upgrade of a house can also have other gains for the house owner such as improved indoor comfort, less maintenance and aesthetic improvements(Verbruggen, 2008, Martinaitis et al., 2007). Multicriteria cost evaluations including such non-energy factors are not discussed in this paper.

New technologies, building concepts and processes are often expensive in the initial phase due to uncertainties in the production of new technology, the installment and the maintenance as well as lack of experience in operation (Jakob, 2006 , Martinaitis et al., 2007). Renovation towards zero energy levels represent a new way of renovation and will therefore most likely experience a decrease in cost when the market is established.

In an initial phase, favorable arrangements for financing and economic incentives are important to get house owners to do energy efficient renovations. Amstalden et al shows how Swiss policy instruments including subsidies, an income tax deduction and a carbon tax make energy efficient renovation of single family houses cost effective even at low energy prices (Amstalden et al., 2007). In Norway the public enterprise Enova offers financial support for renovation to low-energy or passive house level (Enova SF, 2011).

The cost effectiveness of renovation measures is highly dependent on the energy price (Amstalden et al., 2007, Kragh and Rose, 2011, Jakob, 2006). The Norwegian electricity price has had a higher price rise than the inflation over the last 10 years. Data from Statistics Norway show that the annual rise in electricity prices in the period 1999-2010 was 5.5 % (Statistisk Sentralbyrå, 2011b). 2010 was a very cold winter with very high electricity prices. Excluding 2010 from the calculations, gives a 4.5 % rise. An annual price rise rate of 5 % is used for the calculations in this paper.

There are no known Norwegian examples of zero energy renovation of dwellings. A renovation case of a single family house using passive house components shows that it is cost effective to install balanced ventilation with heat recovery and a solar collector for domestic hot water production (Mysen, 2008). Renovation of apartment blocks using passive house components has been shown to be cost effective over the lifetime of the renovation measures (Dokka and Klinski, 2009). However, a German study shows that costs for energy savings accounted for as euro per saved kWh is substantial higher for ambitious renovation than for renovation with lower energy saving targets (Galvin, 2010).

The case study Block 180 – a house from the 1980s

Norwegian dwellings from the 1980s also have the highest energy use compared to dwellings from other construction periods(Bøeng, 2005). Houses built in the 1980s are at a stage in their lifetime where renovation actions, such as new windows and ventilation, are needed during the next 10 years. Block 180 was a popular house model in the 1980s(Sørby, 1992). By analyzing a popular house model, the results will be applicable for renovation of many houses. Block 180 was chosen as a case because the floor area is larger than for many other popular models. A larger house is a worse case scenario when the goal is to achieve a zero energy building after renovation. Table 1 presents some basic facts for the house Block 180.

The floor is made of concrete casted on site. Basement walls are in light weight masonry. Exterior walls, interior walls, interior floors and roofing are based on wooden frame structures insulated with mineral wool. The wood frame exterior walls have wood panels as exterior cladding. Table 2 shows U-values, thermal bridge coefficient and air tightness of the house before and after renovation.

Table 1 Basic data for the house model Block 180

No. of floors	2.5	
Floor area	262 m^2	
Window area	45 m^2	
Heated volume	565 m^3	
Location	Oslo	
Orientation	Main facade oriented 30^o to south west	

Renovation scenarios for the building envelope upgrade

The energy need for different renovation scenarios for the house Block 180 are shown in Risholt (Risholt et al., 2011). Two scenarios are analyzed further in this paper, see table 2 for the thermal properties and energy requirements for heating of the house before and after renovation. Scenario Facade is renovation of the facade including new windows, adding on insulation to the walls of the house and improving the air tightness. The scenario Ambitious is a deep renovation of the whole building envelope using passive house components. Both renovation scenarios require installation of a ventilation system with heat recovery. A hydronic heating system is used for energy storage and distribution for both renovation scenarios. This paper discusses different options for the energy system design for both scenarios resulting in an annual net or nearly zero energy balance for operation of the house.

Table.2 Thermal properties and the annual heating need for Block 180 before and after renovation

Energy scenario	U-values [W/m²K]				Thermal bridge [W/mK]	Air tightness n50 [1/h]	Venti-lation [m³/hm²]	Heat recovery efficiency	Annual heating need [kWh/m2]
	Window	Wall	Roof	Floor					
As built	1.75	0.47	0.21	0.37	0.07	3.0 1)	1.2	0	145
Façade	1.0	0.21	0.21	0.37	0.03 2)	2.0 2)	1.2	0.86	49
Ambitious	0.77	0.14	0.11	0.21	0.03	0.6 2)	1.2	0.86	24

1) The air tightness value is a nominal value based on Thyholt et al(Thyholt et al., 2009)
2) These values are not documented and might be lower than what can be realized after renovation.

Methods

Energy calculations

Energy calculations to set requirements for the energy system are performed according to NS 3031:2007 (Standard Norge, 2007d). The software SIMIEN 4.505 issued by Programbyggerne in 2010 is used for calculations. SIMIEN is verified for calculation according to NS-EN 15265 (Standard Norge, 2007b), NS 3031:2007 and Norwegian Building Code requirements (National Office of Building Technology and Administration, 2010b).

Calculations on solar energy systems are performed using the software PolySun V5.6.8.14719 from Vela Solaris AG(Vega Solaris, 2011).

Life cycle cost calculations

The global costs are calculated for the two renovation scenarios with different energy systems. Global costs are calculated according to the method described in EN 15459(Standard Norge, 2007a). Global costs are calculated for a 30 year period as this is a likely period to own a house. Statistics Norway (Statistisk Sentralbyrå, 2011a)show that the inflation rate from September 2010 – September 2011 is 1.6%. An inflation rate of 2 % is used in the calculations. The real interest rate used is 4 % chosen according to life cycle cost rules in the guidelines for the Norwegian Building Code(National Office of Building Technology and Administration, 2010b). The annual rise in electricity price is assumed to be 5 %, see paragraph 1.4. Only costs related to energy efficiency are included in the global costs calculations, see paragraph 1.4.

Costs for renovation measures are obtained from offers for delivery given by Norwegian product manufacturers and suppliers.

Results

The energy system of Block 180 after renovation

Monthly values for the calculated energy use according to NS 3031(Standard Norge, 2007d) are presented in figure 1. In both renovation scenarios the domestic hot water use is based on Dokka and Klinski (Mysen, 2008) giving an annual need for 4800 kWh. This corresponds to a family of five with a daily domestic hot water use of 250 l. For the Facade renovation scenario the annual electricity need for equipment and lighting of 10500 kWh is according to NS 3031 (Standard Norge, 2007d). For the Ambitious renovation scenario the annual electricity need of 8000 kWh is according to the Norwegian passive house standard NS 3700(Standard Norge, 2010b).

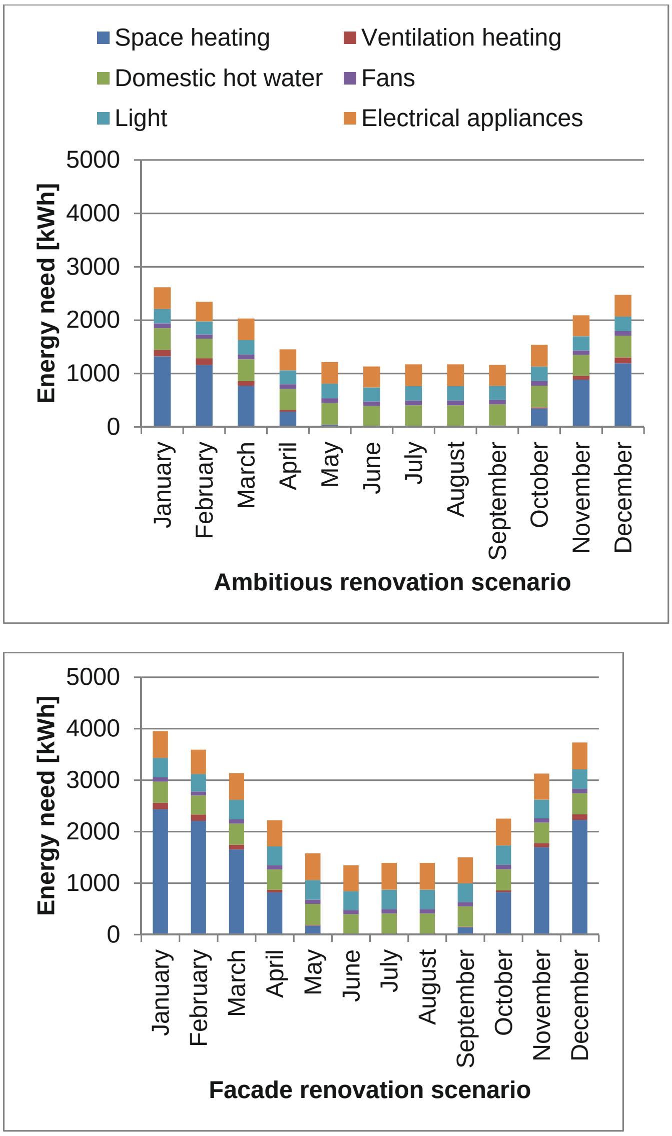

Figure 1 Monthly energy need after renovation calculated according to NS 3031(Standard Norge, 2007d)

The house Block 180 has a pitched roof. The roof facing south east has an area of 98 m^2 and is assumed to be covered with solar cells for electricity production. A total of 60 modules with dimension 0.9 x 1.65 m from the supplier REC are chosen for the renovation (Renewable Energy Corporation ASA, 2011). Figure 2 illustrates the calculated potential electricity output from the solar cell system. The found annual electricity production from the solar cells is 8600 kWh.

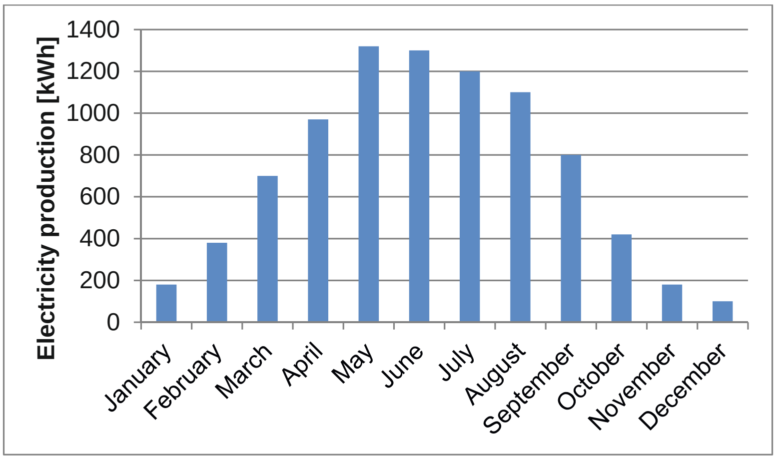

Figure 2 Monthly electricity production from solar cells on the Block 180 roof calculated by using Polysun(Vega Solaris, 2011)

The annual heat demand is 16000 kWh for the Ambitious scenario an d22000 kWh for the Facade scenario. Table 3 presents the estimated values for heat production including both space heating and domestic hot water for the different energy sources as well as required electricity for the heat production. Electricity for operation of circulation pumps are assumed to be of small scale (1%) and are not included.

The life cycle costs of renovation

Investment costs for the envelope upgrade and the energy distribution system are presented in table 4 and 5. The overall costs in table 4 include cost for general renovation, such as a new wooden cladding, and energy related costs. The energy related costs in table 4 include costs for thermal insulation and other building materials as well as labour and costs for scaffolding. The floor cost includes interior works as replacement of doors due to change of floor height. The table also includes financial support from Enova for a low energy upgrade, 75 €/m^2 (Enova SF, 2011). Table 5 shows investment costs and annual maintenance costs as well as running energy costs.

Table 3 Annual renewable heat production for space and domestic hot water heating after renovation for two renovation scenarios calculated according to NS 3031(Standard Norge, 2007d)

Heat production technology	Facade		Ambitious	
	Renewable heat production [kWh]	Electricity for heating [kWh]	Renewable heat production [kWh]	Electricity for heating[kWh]
Solar collector 1)	5800	16200	5800	10200
Biomass	22000		16000	
Solar – Biomass 1)	22000		16000	
Air-to water heat pump COP = 2.5	13200	8800	9600	6400
Brine to water heat pump COP = 3.5	15400	6600	11200	4800
Electricity		22000		16000

1) 20 m^2 flat plate solar collector. Energy output calculated in PolySun(Vega Solaris, 2011)

Table 4 Investment costs for renovation of the Block 180 building envelope including costs for installation of floor heating distribution system. The overall cost include cost for renovation and for energy efficiency measures

			Facade		Ambitious	
Element	Lifetime [years]	Area [m^2]	Overall [€]	Energy related [€]	Overall [€]	Energy related [€]
Basement walls	60	130	17900	1600	38500	15600
Wood frame walls	60	146	18000	7100	24700	14300
Windows and doors	30	45	41100	3400	47000	9300
Roof	30	180			35600	11900
Floor	60	99			20500	13900
Floor heating -hydronic - electric	 60 15	 55/95	 7100 (5800)	 7100 (5800)	 4100 (3900)	 4100 (3900)
Enova financial support		272			20400	20400
Investment cost for envelope upgrade [€]			84100	19200	150000	48700

The calculated heating power requirement for the dimensioning outdoor temperature for Oslo, which is -20 ^{o}C, is 7.3 kW for the Facade scenario and 4.3 kW for the Ambitious scenario. There are not many suppliers in the Norwegian market offering heat production technologies with a heating power as low as 4 kW. For comparing the two scenarios in this paper, the same heat production units are used. The difference is then the annual energy needed for heating. Table 5 shows the investment costs for heat production and storage as well as running energy costs. The numbers include space and domestic hot water heating. The cost numbers on investment include costs for installation. The biomass investments cost includes cost for a new steel chimney Lifetimes and maintenance levels are according to EN 15459 (Standard Norge, 2007a). An electricity price of 0.125 €/kWh is assumed as starting price. Wood and pellets are assumed to be purchased in 1 m^3 units due to low storage capacity and will give higher costs than when purchasing bulk quantities.

Table 5 Investment costs, running costs and expected lifetimes for energy production and storage

Production unit	Investment costs [€]	Enova financial support [€]	Cost for annual maintenance in % of investment	Expected lifetime in years	Energy costs [€/kWh]
Solar cells	56300	0	0.5	30	0
Ventilation with heat recovery	9400	0	2	15	0.125
Solar collector	9900	1250	2	20	0
Biomass boiler	12100	1250	2	20	0.100
Solar-biomass	18000	1250	2	20	0.100
Air to water heat pump	11700	1250	2	15	0.125
Brine to water heat pump	25000	1250	2	20	0.125

The diagram in figure 3 presents the global costs for a 30 year period for the two renovation scenarios and the different heat production technologies. Only energy related costs are included, see tables 4 and 5. Installation of solar cells for electricity production is not included. The final value of the energy upgrade of the envelope, ventilation system and energy system is subtracted from the investment costs.

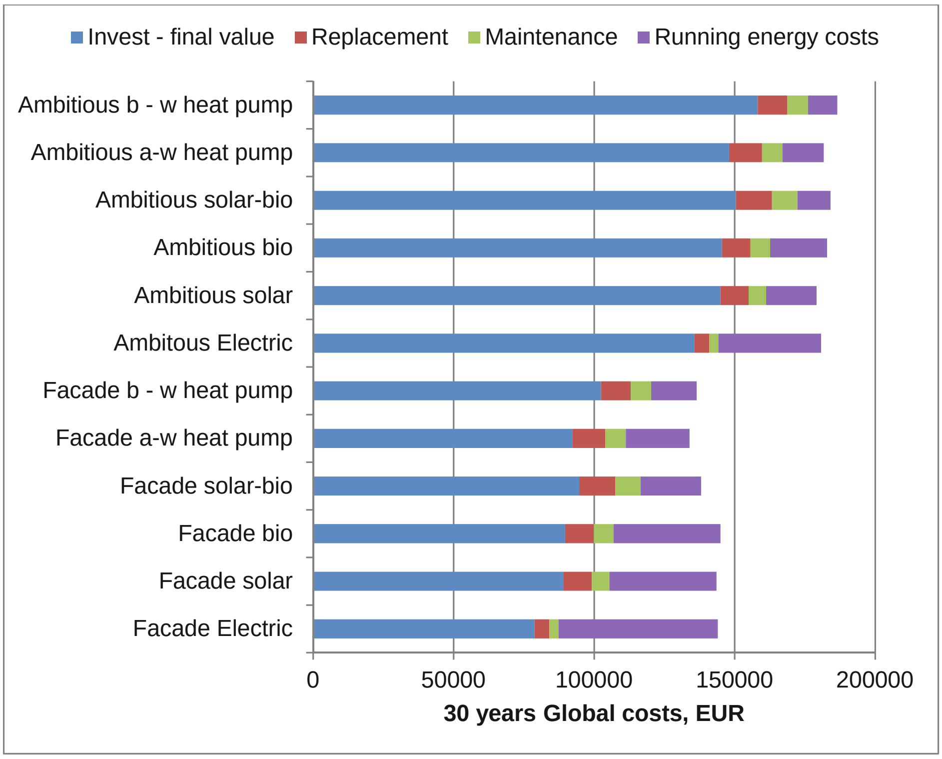

Figure 3 Global cost for two scenarios for nearly zero energy renovation of Block 180 and 6 heating alternatives. Global costs are calculated according to EN 15459(Standard Norge, 2007a) for a 30 year period.

Discussion

Net zero energy renovation and life cycle costs

According to the prevailing zero energy building definition(Marzai et al., 2011), a net zero energy renovation requires that the annual need for electricity and heat is produced on site. The house does not have a south facing roof which would be optimal for the solar cells. Still the energy calculations for the Ambitious scenario, see figure 1, and the energy production calculation for the solar cells, see figure 2, show that it is possible to produce sufficient electricity using solar cells and meet the annual requirement for operation of the house. The electricity production can cover operation of pumps, fans, lighting and electrical equipment. However, it must be noted that the internal loads are according to the Norwegian passive house standard(Standard Norge, 2010b) and lower than the nominal loads described in the Norwegian Building Code(National Office of

Building Technology and Administration, 2010b). The zero balance implies the use of energy efficient appliances and lighting.

The annual zero electricity budget requires a grid connected house where electricity is delivered in the summer months and bought back in the winter months. In Norway there are no financial incentives for a small scale on site electricity production. Assuming a 20 year lifetime for the solar cells and an annual electricity production of 8600 kWh, this give an electricity price of 0.35 €/kWh. The price being approximately three times higher than the 2011 electricity price purchased from the grid. The high investment costs for installing solar cells and lack of financial incentives make a zero energy renovation unlikely to be realized.

Since the produced electricity will be needed for electric specific uses, all heat production need to be covered without the use of electricity. The biomass alternative is then the only alternative. A combination of solar-biomass could have been an option, but the total southeast oriented roof is covered by solar cells not leaving any space for solar collectors. One possibility that is not investigated in this paper, is to mount solar collectors on the southwest facing facade.

16000 kWh is the annual heating requirement for the Ambitious scenario. To produce 16000 kWh using biomass you would need approximately 4000 kg pellets or 9 m^3 firewood. The storage capacity is demanding and the alternative is not considered realistic for urban locations. More deliveries will be required giving higher costs for the house owner than larger bulk deliveries. The higher costs for more deliveries are included in the global cost calculations. The biomass alternative also gives tasks for the house owner in maintenance and ash disposal. It may also give local pollution in the neighborhood due to the smoke.

Nearly zero heating renovation and life cycle costs

Two different renovation strategies for upgrading the thermal properties of the building envelope are analysed. For both options an annual nearly zero heating balance is achievable. Renewable energy production on site using biomass, solar energy or harvesting heat using heat pumps are alternatives see table 3.

The life cycle cost considerations shown in figure 3 give a clear difference between the two scenarios, Facade and Ambitious. The less extensive renovation of the envelope gives less life cycle cost even though the annual heat requirement is 40 % higher. The reason for this is the high investment costs for the Ambitious upgrade of the building envelope. This corresponds to Galvin (Galvin, 2010) who found that less extensive renovation gave more energy saved per euro invested than the more extensive renovation.

The Ambitious upgrade cost approximately double of the Facade alternative. Most of the costs are related to labour. To make passive house renovation attractive to the house owners, material- and labour costs need to be reduced. The calculations are sensitive to the electricity and energy prices(Amstalden et al., 2007, Kragh and Rose, 2011, Jakob, 2006). Future price changes will affect the results. Increased government financial incentives for energy efficiency would also stimulate the market for energy efficiency of houses. If a market for energy efficient renovation is established this will, over time, possibly lead to a reduction in prices that might favour ambitious renovation. It should also be noted that the cost calculations in this paper is valid for the house model Block 180 and the received offers for renovation. Other suppliers, contractors and house models might give different investment costs.

For the Ambitious renovation scenario, it is also decisive to investigate the investment ceiling, see formula (1). The total renovation of the building envelope cost 150 000 € and ventilation and heating system cost 20 000 €. If this should be a cost effective investment, the market value of a new house should be 170 000 € higher than the value of the not renovated Block 180. This is not the situation in Norway where there is not much price difference between existing and new houses. For the house owner it will be a better investment to sell the not renovated Block 180 and buy a new low-energy house. However, other aspects than cost effectiveness can be decisive for the house owner such as aesthetic and comfort improvements.

Using an air-water heat pump is the cost optimal choice for the Facade scenario. This renovation strategy requires delivery of 8800 kWh electricity for heating, see table 3. This is a 40 % reduction compared to the all electric reference case. However, the delivery represents a substantial amount of electricity. It can be discussed if this is within the definition of a nearly zero energy definition as stated in Directive 31/2010 (European Parliament and The Council, 2010). This paper does not include the alternative of a combination of a solar collector and an air-water heat pump. But this might be a more cost optimal system because this will further reduce the need for delivered electricity. The biomass-solar combination gives somewhat higher global costs, but only requires small amounts for electricity for operation of pumps.

The solar collector alternative is the cost optimal alternative for the Ambitious scenario. This alternative requires delivery of 10200 kWh only reducing the electricity need by 36 % compared to the all electric reference. The required amount of electricity is higher than for the Facade air-water heat pump alternative.

The Facade renovation scenario and air-water heat pump installation gives an energy related investment of 30900 €. The calculated energy saving compared to the as built situation is 22000 kWh. The payback period for the investment is 12 years. This means that investing in the energy upgrade can be a cost effective investment for the house owner, but the pay back time calculation should be based on the measured real energy use and other costs than energy costs should be included. The renovation also has other non-energy benefits that the house owner will gain from(Jakob, 2006 , Verbruggen, 2008) such as improved indoor comfort. The renovation will also result in an increased market value for the house.

Conclusion

It is possible to renovate the 1980s house Block 180 to become a net zero energy house with on site energy generation from off-site renewables according to a definition in (Marzai et al., 2011). This requires a grid connection, installation of solar cells for electricity production and use of biomass for heat production. However, this is not a realistic alternative for renovation because of the current high costs for solar cells.

A nearly zero energy balance according to the definition in (European Parliament and The Council, 2010) can be achieved using two strategies for renovation of the building envelope and different technologies for renewable heat production. The Ambitious strategy renovating the entire envelope using passive house components gives a 24 kWh/m^2 annual space heating need. The Facade strategy only requires renovation of outer walls and windows and results in a 49 kWh/m^2 annual space heating need. The renewable energy production on site can cover a significant amount of the heat needed for both strategies.

The Facade strategy gives lower life cycle costs for a 30 year period due to lower costs on envelope improvements. The cost optimal choice for the nearly zero energy renovation is to renovate outer walls and windows according to the Facade scenario and to install a air-water heat pump for on site heat production.

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6.3 Home qualities

The perception and priority of home qualities depend on the people living in the house. The homeowner and the other residents are individuals that represent a human random factor when it comes to energy behaviour and to renovation (Sterner, 2011). Two neighbouring houses that appear to be identical on the outside, may have different interiors (Støa, 1996) and the energy use in the houses may differ substantially (Våge et al., 2010, Wigenstad, 2007). The residents are individuals that use and keep their homes according to their needs and resources. But, to be able to develop attractive zero energy renovation strategies, it is necessary to have knowledge on how the houses are used and how the homeowners keep and improve the qualities of their home.

One important factor in renovation planning is to have knowledge on the technical condition of the building (Standard Norge, 1995). Norwegians love to redecorate their homes (Gullestad, 1989), but there are no publicly available statistics on what redecoration or renovation measures are carried out, and there is a lack of documentation on the technical condition of Norwegian houses. A British study on dwelling renovation showed that the renovation status depends on factors such as the life-phase of the residents, their knowledge of the technical condition of their house and their financial situation (Leather et al., 1998).

Paper 4 investigates the technical condition and renovation status of 92 Norwegian single family houses that were built in the 1980s. The paper also analyses the findings to see if there are homes with common characteristics regarding technical condition and renovation status.

Peoples' energy behaviour and their preferences regarding energy efficiency also need to be analysed to design optimal zero energy renovation strategies. Aune investigated the energy spending in Norwegian homes in her PhD (Aune, 1998, Aune, 2007). She identified three home categories related to energy use and renovation preferences. The first category is 'the safe haven' which is a comfortable and safe home. The residents emphasize the indoor comfort. Second, 'the home as place for activities' is a functional home where the residents do not like to carry out renovation as long as the functionality is satisfying. The third category is 'the home as a place for projects' representing the homes that are continuously upgraded and where the residents love to do home improvements. But, Aune does not investigate what redecoration or renovation measures are carried out in this category of homes.

Interviews of homeowners were performed to gain in depth knowledge on homeowner priorities regarding energy use, energy efficiency and renovation. Paper 5 presents the results from in depth interviews of eleven homeowners. The interviews were based on an interview guide including questions on renovation, home qualities and preferences, energy behaviour and energy savings.

RENOVATION STATUS AND TECHNICAL CONDITION OF NORWEGIAN DWELLINGS (PAPER 4)

Accepted for publishing in the scientific journal Structural Survey

Renovation status and technical condition of Norwegian dwellings

Birgit Risholt, Elisabeth Wærnes, Berit Time and Anne Grete Hestnes

Introduction

Energy savings in the building sector is a stated national and international goal (Kommunal- og regionaldepartementet, 2009, European Parliament and The Council, 2010, International Energy Agency, 2010). The building rates are low and energy efficiency in existing buildings is required. The domestic energy use in Norway was 46 TWH in 2009 whereof 30 TWh was related to the 1.2 million detached single family houses (Statistisk sentralbyrå, 2010). Electricity is the main energy source for these houses supplemented with use of fire wood for space heating in the cold season (Bøeng, 2005). Simulations based on knowledge about the as built energy performance and renovation estimates show that the annual energy saving potential of single family houses is from 7 – 12 TWh if the energy efficiency is done on a massive scale (Dokka et al., 2009, Thyholt et al., 2009).

There are no Norwegian public statistics or documented data on the renovation status or the current technical condition for the existing dwellings. There is a need for such knowledge in order to verify the potential for energy efficiency. Knowledge about homeowner preferences regarding renovation can also be used to tailor policy tools to accelerate the energy efficiency rates.

The single family houses are primarily owned by the occupants. Media reports that Norwegians are world champions in home upgrades, spending more than €6.2 billion every year (Dagbladet, 2010, P4, 2010). The home upgrades include redecoration such as new floors/wall coverings and bathroom fixtures, renovation such as repairs, replacement of components and energy efficiency. The redecoration measures result in an aesthetical upgrade of the home while renovation and home improvements deal with the technical condition of the home. But there is no available knowledge about whether the money Norwegians invests in home upgrades is spent for redecoration or renovation or both.

This research investigates the home upgrade status and the technical condition of the dwellings to analyse how Norwegian homeowners keep their homes and how different homeowners prioritize renovation tasks. The gained knowledge about renovation priorities is used to define categories of houses with common characteristics. The research is done as a case study of Norwegian detached single family houses built in the 1980s.

Technical condition and renovation of dwellings

The technical condition of the dwelling

Norwegian single family houses are normally constructed with a concrete or masonry basement and exterior and interior walls are timber frame structures. Wooden boards are used as exterior cladding. The expected lifetimes and the maintenance requirements for some elements and components of Norwegian timber-framed houses are presented in table 1. This article focuses on single family houses built in the 1980s. The technical condition of a dwelling after 30 years of use depends on factors such as the material and construction robustness, the climatic conditions, the maintenance and the renovation. These issues are reflected in the timespan for lifetimes stated in table 1. The lifetimes are estimated based on laboratory testing and experience from climate exposure according to guidelines in ISO 15686-9 (International Organization for Standardization, 2008). A ground consisting of gravel and rock will in most cases give a longer lifetime for the drainage than if the ground is of clay while the maintenance and climatic loads are critical for the building envelope components.

The Norwegian climate varies from a tempered climate on the south west coast to an arctic climate in the northern inlands(Lisø et al., 2007a, Lisø et al., 2007b). For timber frame houses moisture and wind are the dominant degradation factors for climate exposed building components. Western parts of Norway are exposed to high driving rain loads of more than 1000 mm/year, and combined with a temperate climate this give high risk of rot decay for wooden parts of the envelope (Lisø et al., 2007a, Lisø et al., 2006). In this tough climate, the maintenance including repainting windows and renovation such as replacement of damaged parts is important for the lifetime expectancies of the building envelope components shown in table 1.

Table 1: Expected lifetime and maintenance recommendations for wooden house elements and components. The data are from SINTEF Building Research Design Guides no. 700.320, 700.330 and 752.215 (SINTEF Building and Infrastructure, 2010)

Component/element	Expected lifetime	Maintenance recommendation
Exhaust ventilation	15	Cleaning, air volume check, fan belt check
Bathrooms	25-30	
Drainage	20-60	Flushing
Floors, concrete and wooden	40-80	Replacement of damaged parts
Masonry basement walls	20-60	Repair cracks, mortar and plaster repair, new drainage. Walls towards ground – moisture barrier and moisture measurements on the inside
Exterior timber-framed walls and cladding	40-80	Painting, replacement of damaged parts
Wooden windows and doors	20-60	Painting, cleaning, lubrication of hinges
Roofing - bitumen shingle - concrete tiles	 20-30 30-60	 Cleaning Replace damaged tiles. Re-roofing due to damaged roof underlay

Home upgrades

A house is far more than a climate shelter. The house is someone's home. The Norwegian family ideal is to live in a single family house (Støa, 1996), and a single family house is typically built for a family or a couple who plan for future family life. In a home context, more factors than the technical condition of the house influence the renovation preferences. The quality of a house can be described by its architecture, location, size, layout and material use (Narvestad, 2008). Guttu (Guttu, 2003) states that the quality of a house is the physical characteristics that represent values. The single family houses are owned by the occupants. Their views on what features and function of the house that represent values will influence renovation priorities and what factors are appreciated will vary over time due to changes in the family situation (Clapham, 2005). But it is not described in the literature how the changes in family and lifestyle influence estimation of house qualities and home upgrades.

As described in the introduction, home upgrade includes both renovation and redecoration. Gullestad (Gullestad, 1989) found that Norwegians are very interested in redecorating their homes. Redecorating was found to be in accordance with Norwegian culture and morals. It has practical aspects and falls into a cultural norm of sobriety when the work is done when it is necessary to do it. In addition to the cultural norms, the present financial situation in Norwegian households also influences the home investments. Norway has a steady influx from oil and gas export, and the unemployment rate is only 3.0%(Statistisk Sentralbyrå, 2012). The Norwegian income levels are high and this is also reflected in the high investments in home upgrades. However, since there are no statistics on what the money is spent for it is not evident that the investments results in a better technical condition of the dwellings.

Energy efficiency is a national goal and must be considered when evaluating renovation of dwellings. Aune (Aune, 1998, Aune, 2007) discusses social and cultural aspects regarding redecoration and renovation as a basis for analysing energy efficiency policies. Aune found three categories of Norwegian homes: "the home as a haven" being comfortable and safe, "the home as a project for constant improvement" and "the home as a place for activities". The two last categories of homes have dwellers with different priorities regarding home upgrades. The "home as a project" dwellers love to redecorate and/or renovate.

Aune's research verifies the findings of Gullestad (Gullestad, 1989) that Norwegians are interested in home improvements. But it is not reflecting what home upgrade work is actually done in "the home as a place for project" and if the upgrades result in a better technical condition of the house or energy efficiency. The "home as a place for activities" dwellers give priority to have a functional home that fits their needs and believe that the fewer projects the better. It is not shown whether this means that this group of homeowners do not renovate or if it includes that renovation is done when it is necessary. The two home categories are rather related to the motivation to do home upgrades. The "home as a place for projects" occupants enjoy to do home upgrade tasks while the "home as a place for activities" homeowners do not appreciate such tasks and keep them at a minimum level.

Priorities of home upgrades can also be influenced of other cultural aspects. The different rooms in a dwelling have different functions and meanings (Sørby, 1992, Block Watne AS, 1986). The bathroom has become a place for self-enjoyment and luxury (Clapham, 2005, Craik, 1989). The kitchen is the control centre for domestic space and family life (Clapham, 2005, Craik, 1989).There is a lack of knowledge if these strong cultural values for bathrooms and kitchen results in priority for renovating these rooms. In Norway there are special shops with studios presenting kitchen and bathroom interiors, thus further influencing homeowners to do improve these rooms (Leather et al., 1998).

The market influence and cultural aspects are drivers for redecoration. Knowledge on the gains from energy efficiency can be a driver for renovation(Mills and Rosenfeld, 1996). However, the real life situation is that lack of knowledge among house owners identified as an existing barrier to energy efficiency(BarEnergy, 2011, Enova, 2012, Nair et al., 2010). The private homeowners also need knowledge on the technical condition of their houses to make the better decisions on renovation. Leather *et. al* (Leather et al., 1998) found that British homeowners living in houses in a poor condition were generally aware of the house defects, but homeowners living in houses with few defects were generally unaware of the existing problems. The houses in this study are from the 1980s and fall into the category of dwellings with few defects. It might therefore be the case that the owners are unaware of defects. Such a situation will most likely result in a situation of redecoration rather than renovation.

The literature shows that Norwegians love to redecorate and renovate their homes. And that they spend a lot of resources on this work. But the literature does not say if the efforts actually result in a better technical condition of the building. This study aims to gain knowledge on the Norwegian private homeowners' priorities regarding home upgrades and to what degree their effort improve the technical condition of their house.

Research methods

The case study

Single family houses built in the 1980s are chosen as a case for the study. The 206,920 houses (Thyholt et al., 2009) built in the 1980s, represent 10 % of the Norwegian dwelling stock and are found all over Norway. These houses are bigger and more diverse in architecture than houses from previous periods (Sørby, 1992) and floor areas up to 300 m^2 were not uncommon. Gable dormers, hipped roofs and bay windows were typical architectural elements. Open layouts between floors and arched openings between rooms were common (Block Watne AS, 1986) giving large volumes to be heated. Norwegian dwellings from the 1980s have the highest annual energy needs compared to dwellings from other time periods (Bøeng, 2005). The size of dwellings, the open layouts and the poor insulation standard compared to new dwellings are probable reasons for the high energy need. These houses are therefore a national target group for energy efficiency.

Table 1 shows that building components such as roofing, windows, drainage, ventilation have lifetime expectancies down to 15-30 years. The houses built in the 1980s are from 20 – 30 years old, and major renovation tasks should be expected. If the work is not already done, it is a possibility to combine the renovation with energy efficiency measures limiting the cost for the energy improvement(Martinaitis et al., 2007). If the results from this study show that renovation already is carried out without energy efficiency, the chance for energy efficiency may be lost until it is time for the next replacement(Vanhoutteghem et al., 2011).

Sampling

The houses built in the 1980s represent diversity in architecture, size, financial value, and, location, and this should be reflected in the sample. A sales report for a dwelling includes a financial value assessment of the dwelling and the site, describes the location and shows the floor plan as well as photos of most rooms. The reports also include a technical condition survey made by a trained assessor (NITO, 2011) as well as a homeowner declaration on the technical condition of the house and technical systems. It was therefore decided to use sales reports as the data source as the reports give data on the home upgrade status and the technical condition of the house.

The condition surveys are based on visual observations of the house as well as non-intrusive moisture measurements according to NS 3424(Standard Norge, 1995). Hidden damages related to moisture such as condensation inside basement walls and rain leakages around windows are known damages on wood frame constructions (Lisø et al., 2007a). It is therefore likely that the actual number of defects is somewhat higher than what is found in a visual and non-intrusive technical condition survey.

Ninety-one sales reports for single family houses built in the period from 1980 to 1989 were downloaded from the Internet (www.tinde.no, www.finn.no) in June 2010 and June 2011. The smallest house in the sample is 95 m^2 and the largest is 317 m^2. The average size is 189 m^2. Sixty of the houses are located in the southeast, twenty-five in the southwest, seven in the middle and eight in the northern parts of Norway. The geographical locations thus cover the different climatic zones in Norway(Lisø et al., 2007a).

Registration of data

Registration of home upgrades is based on the condition surveys and the homeowner declarations. The condition surveys give some information on whether the upgrade is visual, technical or both. The analysis of home upgrades versus defects for the houses shows if the measures are strictly visual or have resulted in an improved technical condition after the upgrade. Due to the cultural significance of the kitchen and the bathrooms in a home (Clapham, 2005, Craik, 1989, Gullestad, 1989, Leather et al., 1998) it was decided to register if upgrades have been done for these rooms. Registrations of defects are based on the homeowner's declaration and the condition survey. Most building damages in Norway are related to moisture (Lisø et al., 2007a) and therefore both the upgrade status and the occurrence of defects for the moisture-exposed building parts was registered, see table 2. The registration is shown as 1 if an upgrade/defect was found or 0 if there was no finding. The findings for each house regarding home upgrades and defects are summarized in a defect and home upgrade score. A high home upgrade score means that the house has gone through several improvements. A high defect score means that the house is in a poor technical condition from neglected maintenance/repairs or wrongly executed work. The example in table 2 shows a house where the bathroom and kitchen is upgraded giving an Upgrade score of 2. Defects were found in three building element: the basement, exterior walls and in a laundry room. The concept 'wet rooms' is used for all rooms in a house with floors that are frequently exposed to water such as bathrooms, laundry rooms and toilets(European Organisation of Technical Approvals, 2007).

Table 2: Example of registrations from the sales report for the house "Dapalo"

Basic data							
Short name	Region	Floor area	Construction year		Declared energy label		
Dapalo	South east	156	1980		E orange		
Home upgrades							
Kitchen	Bathroom	Windows	Surfaces	Roof	Basement	Other	**Upgrade score**
1	1	0	0	0	0	0	**2**
Defects							
Basement	Floor	Exterior walls	Windows	Wet rooms	Roof	Other	**Defect score**
1	0	1	0	1	0	0	**3**
Comments							
Bathroom upgraded in 2010, kitchen upgraded in 2007. Moisture in basement walls, moisture and damage in wall due to a leaking water tap in the basement laundry room, some rot in exterior cladding.							

House defects

Figure 1 presents the percentage of houses with registered defects. 60% of the houses have defects in bathrooms and laundry rooms. Severe defects such as no water membrane were found in both upgraded and original bathrooms. 45% of the houses had observations of defects in the basement floor or walls, in most cases related to moisture. Only seventy-six of the ninety-one houses had a basement, meaning that more that 53 % of the houses with a basement had defects.

35% of the houses had defects on windows, and 30% had roof defects. Other defects include areas of rotten wooden cladding and defects in the technical systems such as leakage from the hot water boiler.

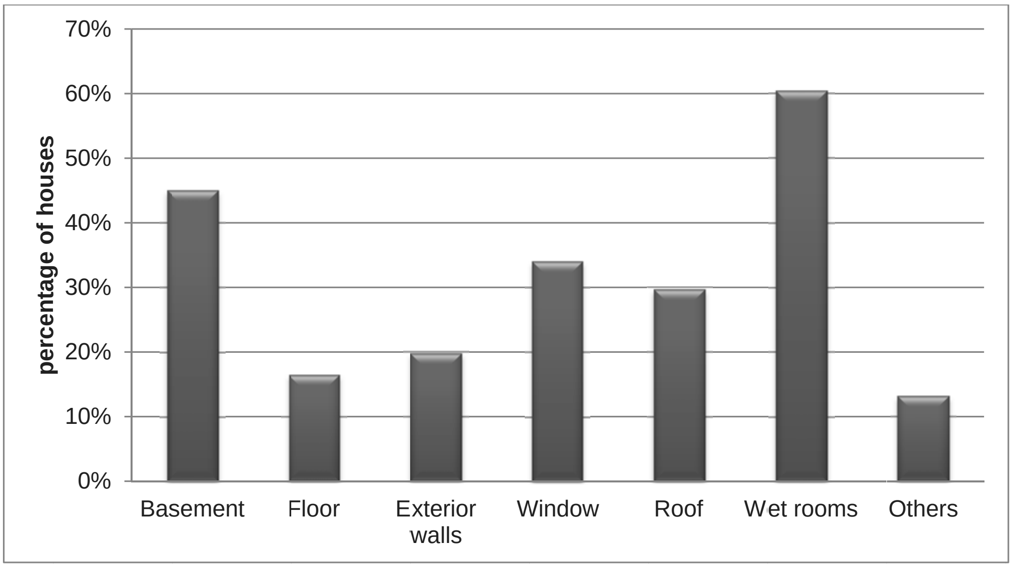

Figure 1: The percentage of 1980s' houses with defects on building elements

Home upgrades

No home upgrade measures were found for 27 houses. Figure 2 shows that 50% of the houses have one or more upgraded bathrooms and 40% have an upgraded kitchen. Building renovation measures such as replacing one or more windows occurred in approximately 10% of the houses. A renovated drainage was only reported for three of the ninety-one houses.

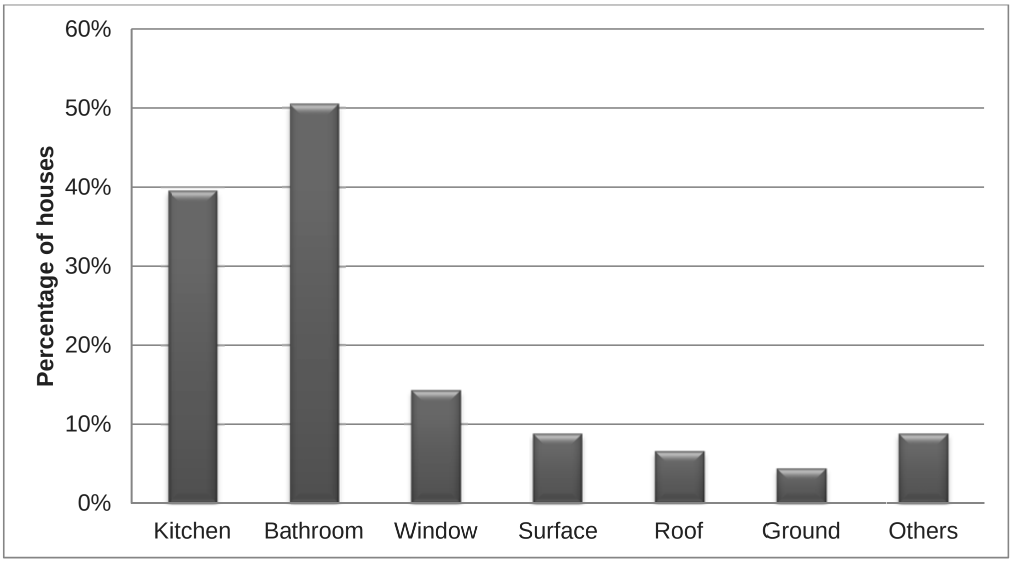

Figure 2: The percentage of the 1980s' houses with upgraded building elements

Home upgrades versus house defects

The number of home upgrade and defect registrations per house is summarised in a home upgrade and defect score, see section 4.2. A high upgrade score means that the house is highly redecorated, renovated or both. A high defect score means that the house is in a poor technical condition. The scores are plotted in Figure 3, each mark representing one house. An R-value of 0.0017, shows that there is no correlation between the scores. As an example, Figure 3 shows that the houses in the sample with three observed home upgrade measures have zero, one, three or five defects.

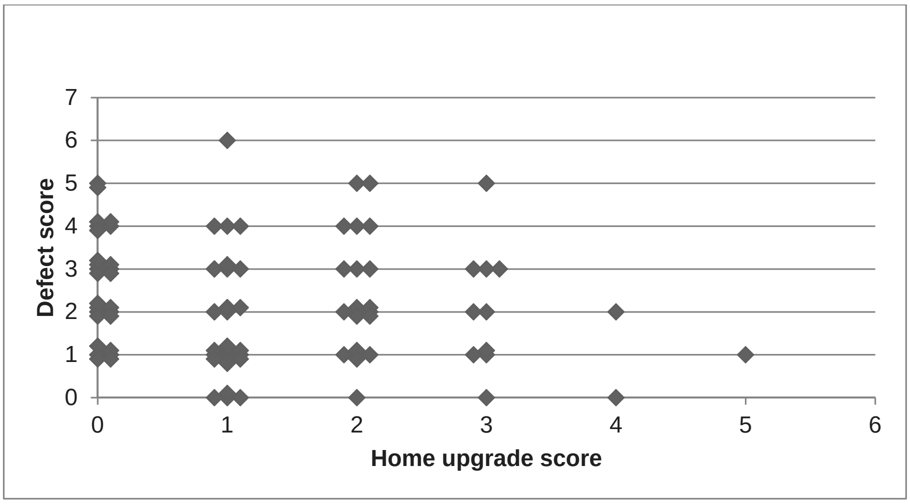

Figure 3: The defect and home upgrade scores for 91 single family houses built in the 1980s

The analysis was a lso done to identify houses with common characteristics regarding home upgrades and technical condition. Four categories of houses were identified, see Figure 4. The categorization reflects the home upgrade findings and the relation between the home upgrade score and the defect score for each category.

- The 'as built' houses have not been maintained, redecorated or renovated. These houses are also characterized of a high number of defects and are in a poor technical condition.24 of the 92 houses were categorised as 'As built'.

- The 'do-it-yourself' houses have been redecorated and/or renovated by the homeowner and their social network. The resulting technical condition depends on their knowledge and skills, and the defect score in the sample varied from zero to six. The majority of the 18 houses in this category are classified as "Normal" regarding technical condition
- The 'aesthetic upgrade' houses have been redecorated. Some have also been renovated and might also be in the 'well-kept' category. The homeowner might have done the work so that the house might also fall into the 'do-it-yourself' category. 27 of the houses are categorised as 'Aesthetic'. The common features for these houses are the strong focus on visual improvements. The defect scores of these houses ranges from zero to five, with an average score of 3.
- The 'well-kept' houses are renovated and are in a good technical condition. They may also be redecorated and aesthetically upgraded. The homeowner

might have done the renovation so the houses may also be in the 'do-it-yourself' category. 23 of the 92 houses are mainly characterised as 'Well kept'.

The technical condition refers to defect score. It must be noted that this does not consider the severity of the defects. A more refined categorization of the technical condition was not possible due to limitations in the empirical data.

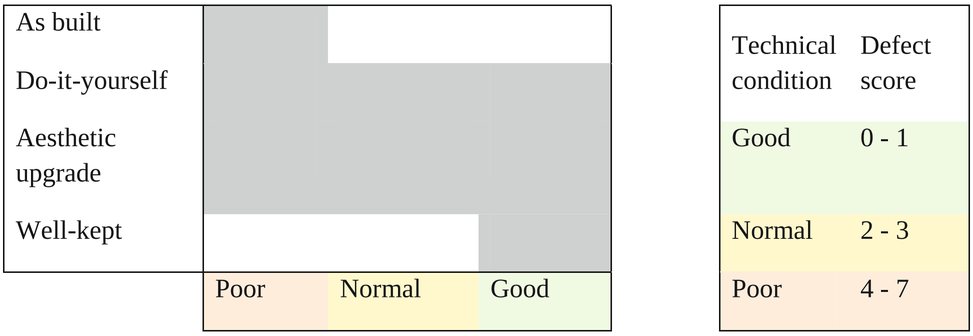

Figure 4: Four categories of 1980s' houses and the technical condition of the houses in the categories.

Discussion

The main research task was to investigate if the resources spent on home upgrades result in a better condition of the houses. The findings in figure 3 and 4 imply that this depends on the homeowner. It is just as likely that a highly upgraded house is in a poor condition as it is in a good technical condition. But before discussing the main finding, there is a need to verify that the findings on defects and home upgrade are reliable.

Regarding defects, table 1 shows that the shortest lifetime expectancies are for the ventilation systems, the bathrooms, the drainage, the windows and the roofing. The results in Figure 1 verify this as there are numerous observations of defects in these building envelope parts. It must also be noted that the condition surveys are based on visual inspections, so in reality a higher number of defects than registered are likely (Standard Norge, 1995). A high defect score should also be expected for the ventilation. However, the condition surveys focus on the structure and surfaces of the building more than on the technical systems. That might explain why there were few registrations of defects in the ventilation systems.

Bathroom and laundry room defects are most frequent, observed for 60 % of the houses. The houses have more than one such room. Figure 2 show that 50 % of the houses have one or more upgraded bathrooms, but many of the renovated bathrooms also have defects. The end of life situation, the number of bathrooms and unskilled renovation are probable causes for the high percentage.

Most registered basement defects are related to moisture. A poor construction of basement walls, a lack of watertight membrane or malfunctioning drainage are likely reasons for the observations. But clearly the homeowners are unaware of the risk for moisture damages in the basement as only three of the 91 houses hade renovated the drainage. Windows and roof defects were also found in many houses and such defects may also not be visible for the untrained observer. A homeowner can therefore be inattentive to symptoms of defects (Leather et al., 1998). The owners of the houses from the 1980s might be unaware of the situation as Figure 2 displays low occurrence of renovation of windows, roofs and drainage.

The defect results document the renovation need and the energy efficiency potential. Energy efficiency can be combined with other renovation tasks increasing the cost effectiveness of the energy saving measures(Martinaitis et al., 2007). Typical energy efficiency measures for these houses will be to install balanced ventilation system with heat recovery, to install windows with three layered glazing, to add on thermal insulation of exterior wall when replacing the drainage or when replacing the damaged wooden cladding (Bøhlerengen et al., 2009, Thyholt et al., 2009, Dokka et al., 2009). The calculations of the potential energy saving of 8 TWh of renovation of detached houses assume that none of the1980s houses are already renovated (Thyholt et al., 2009). The data in this study confirms this assumption. Figure 1 shows that only a small percentage of the houses in the sample has an upgraded building envelope components and technical systems.

The found results on defects presented in figure 1 are thus in accordance with what can be expected for houses that are from 20 – 30 years old. What is also evident from figure 1 is that these houses are in need of major renovation tasks within few years. In contrast to this, the home upgrade findings do show that the houses are being upgraded and that the kitchens and bathrooms are most likely to be upgraded. Wet installations have short lifetimes and require renovation after 25 – 30 years thus being a technical factor influencing the percentage. The high numbers for kitchen and bathrooms upgrades are most likely a result of a combination of the technical condition and the cultural meaning of these rooms (Clapham, 2005, Craik, 1989). In addition comes influence from the market and the network that gives a strong incentive for upgrading these rooms.

The home upgrade scores and defect scores for each house plotted in Figure 3 show no correlation. It simply means that even if a house is highly upgraded, it is not necessarily in a good technical condition. There are more reasons for this. Home upgrades can be purely aesthetic not including the need for maintenance and repair. Priorities can be made for renovations only dealing with visual defects. Another factor is that renovation can be done by unskilled labour, resulting in defects. The bathroom upgrades can be used to illustrate. Twenty-two of the fourty-six houses with an upgraded bathroom also had a defect in such a wet room. The upgraded bathrooms have defects due to unskilled work, due to only partly renovation or due to a purely aesthetic upgrade. The non-correlation of technical condition and home upgrades are therefore not directly linked to a priority of redecoration over renovation as found by Leather et al (Leather et al., 1998). It is also linked to skills and knowledge of the homeowner and the craftsmen involved in the renovation.

In each home upgrade project, it is the homeowner who decides on what measures are carried out. Most Norwegians have a high standard of living which is reflected in the annual spending on home upgrades(P4, 2010, Dagbladet, 2010). The priorities of each homeowner decide if they choose to spend money on redecoration, renovation or both. The four categories of houses and home upgrade identified in this study correspond to different redecoration and technical condition levels, see Figure 4. The houses that fall into the category ‘as built’ are generally poorly maintained. The opposite is the ‘well-kept’ category. These houses are well-maintained and upgraded throughout the years. There is no correlation between the upgrade efforts and the technical condition of the ‘do-it-yourself’ and ‘aesthetic upgrade’ houses. The majority of the ninety-one houses in this study fall into these two categories explaining the lack of correlation between home upgrades and defects. If the ‘do-it-yourself’ or "aesthetic" homeowner has the knowledge and the skills, the technical condition of the house can be good. The human factor representing a random variable (Sterner, 2011) is decisive for the outcome of the renovation.

The ‘as built’ houses can be seen as examples of a "home being a place for activities" as described by Aune (Aune, 1998, Aune, 2007). The dwellers are not interested in doing work on their house; it simply needs to be functional. Gullestad (Gullestad, 1989) presents the Norwegians' interest in redecoration, which is reflected in the 'aesthetic upgrade' category. The three categories of ‘well-kept’, ‘do-it-yourself’ and ‘aesthetic upgrade’ all fall under the category "the home as a place for projects" as found by Aune (Aune, 1998, Aune, 2007). The motivation for doing the upgrade depends of different factors for the three categories; the technical condition, the ability to do work yourself or the visual performance.

Marketing of energy efficiency and policy instruments should be targeted towards homeowners that are in a phase of making home improvements as they are the ones most likely to invest in energy efficiency (Tommerup et al., 2010). The three groups of homeowners identified as doing work on their dwelling are potential target groups for such energy efficiency marketing and incentives. But since the motivation for doing renovation and priorities regarding the renovation solutions differ, this should be reflected in the policy strategies. The single family houses are also a potential market for actors in the building industry offering energy efficiency. Business models for nearly zero energy renovation of single family houses are developed, demonstrated and evaluated in the international projects OneStopShop and SuccessFamilies(Mahapatra et al., 2012, Haavik and Aabrekk, 2012).

Conclusion

Norwegians spend time and money on upgrading their home and the upgrade of bathrooms and kitchens are most common. Regarding the observed defects, bathrooms and basements dominate. Defects were observed for both upgraded and original bathrooms. Most of the defects in basements are related to moisture.

There is no correlation between the observed technical condition of the house and the home upgrade level. Significant resources may have been used for redecoration and renovation not dealing with the need for maintenance and repair. Homeowners' and dwellers' knowledge, priorities and resources are decisive. Four different categories of homes were identified: The 'as built', The 'well-kept', The 'aesthetic upgrade' and The 'do-it-yourself'.

The detached houses built in the 1980s should be a target group for energy efficiency marketing and incentives because the houses are high energy spenders and are at a stage in the lifetime where major renovation tasks are needed. The knowledge on house categories and homeowner's priorities regarding renovation should be used to tailor policy instruments, renovation solutions and marketing strategies to overcome barriers to energy efficiency.

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SUCCESS FOR ENERGY EFFICIENT RENOVATION OF DWELLINGS. LEARNING FROM PRIVATE HOMEOWNERS (PAPER 5)

Submitted for review in the scientific journal Energy Policy

SUCCESS FOR ENERGY EFFICIENT RENOVATION OF DWELLINGS
-Learning from private homeowners

Birgit Risholt and Thomas Berker,

Abstract

Large scale energy efficient renovation of buildings is one of the most important tools to realize the society's need of a more sustainable building stock. Most Norwegians own their own homes. Therefore private homeowners are a focus group for the government urging to accelerate the dwelling energy efficiency rates. Success factors were identified in the in-depth study of the decision process of eleven homeowners. Large differences in energy use due to the building's condition and the occupants' behavior was encountered in the sample. Only homeowners who were conscious consumers and did not trust expert advice or that had special knowledge due to their professions succeeded in realizing energy efficiency by renovation. Lack of knowledge, bad advice from craftsmen or priority to work that they can do themselves stopped other homeowners from implementing energy efficiency. Increased knowledge on all the gains from energy efficiency, the availability of attractive products and services as well as easy access to reliable advice on the better renovation solutions have a large potential to get more homeowners to make energy efficient choices in the process of renovation. Coordination of more of policy strategies including specific information and incentives are needed to facilitate this.

Keywords: dwelling, renovation, energy efficiency

Introduction

Homeowners are most likely to improve the energy efficiency of their homes when they are already in a process of making changes(Enova, 2012, Strandbakken, 2006). Therefore, every engagement with the building that does not include energy efficiency improvements is a missed opportunity. What is even worse, those who renovate without including energy efficiency measures, are likely to experience an energy lock-in since it is not likely that *any* changes to the building will be made until the next time renovation is needed.

We know from earlier research that homeowners wanting to renovate energy efficiently face several barriers related to low energy prices, lack of attractive products and services, priority to comfort and other non-energy aspects, and insufficient coordination of initiatives, incentives and regulations (Reddy, 1991, Strandbakken, 2006, BarEnergy, 2011). In this contribution, which of these barriers actually influence the decision process leading to home improvements is analyzed in depth. These decisions are made as part of a stepwise process constituted by initiation, planning, designing, contracting-/bidding process, financing and ordering the work or doing the work themselves. Different complications can emerge at the different steps of the decision process (Enova, 2012).

In the present paper we focus on those homeowners that have overcome the barriers towards energy efficiency. After an introduction into the Norwegian context in the next chapter and a general description of the studied buildings' condition and energy use, success criteria are identified. Finally, policy strategies are discussed based on the identified success criteria to demonstrate how policy instruments can facilitate large scale energy efficient renovation of dwellings.

The Norwegian context: World champions in home improvement

Every year when new statistics is published, Norwegian newspapers celebrate Norwegians as the world champions of home improvement. A steady influx of revenue based on oil and gas exports combined with an active welfare state and low unemployment rates has made the average Norwegian a wealthy home owner. A significant part of this wealth, more than €6.2 billion in 2011, is spent on upgrading the 2.3 million Norwegian dwellings (Statistisk sentralbyrå, 2010).

These upgrades are not primarily motivated by energy or climate related concerns. They include redecoration such as new floors/wall coverings and bathroom fixtures, but also renovation including repairs and replacement of components and improvement of the qualities of the dwelling. Whereas the redecoration measures result in an aesthetical upgrade of the home and do not have a direct energy saving potential, renovation deals with the technical condition of the dwelling and are directly relevant. In fact, a recent report concluded that incremental renovation and especially improvements of the building envelope can explain 37% of the stabilization of Norwegian household energy use since the 1990s (Hille et al., 2011). However, this stabilization has been achieved on a high level of electricity use placing Norwegians after Iceland on second rank in per capita electricity use.

30 TWh of the Norwegian energy use in 2009 was related to the 1.2 million single family houses (Statistisk sentralbyrå, 2010). Sustainable renovation of single family houses has huge potential to reduce Norway's energy use if it is done on a massive scale (Dokka et al., 2009, Thyholt et al., 2009).

Norwegian dwellings from the 1980s have the highest energy use compared to dwellings from other construction periods (Bøeng, 2005) probably due to the large areas of these dwellings compared to dwellings from previous periods. Buildings built in the 1980s are also at a stage in their lifetime where major renovation actions, such as new windows and ventilation system, are needed during the next 10 years (SINTEF Building and Infrastructure, 2010).

In a previous study effective measures to reduce the heating requirement in this type of building were analyzed: improved insulation of the facades, better windows, improved air tightness of the building envelope and installation of ventilation with heat recovery were identified to be the most interesting candidates for energy efficient renovation (Risholt et al., 2011). It was also demonstrated that a net or nearly zero energy balance for operation of this kind of renovated 1980s single family house is theoretically possible even in Norwegian climate. Improvement of facades, new windows with three layers glazing, ventilation with heat recovery and installation of renewable heat production have been shown to potentially be cost effective for such a 1980s house if it has high heating loads(Risholt and Time, 2012).

Research approach

The research presented here was done as a case study (Flyvbjerg, 2011, Yin, 2003, Stake, 1995) of Norwegian privately owned single family houses from the period 1980-1990.

In a first step, the energy efficiency status for 102 dwellings was mapped. Condition reports from visual examination (Standard Norge, 1995) were analyzed for 91 single family houses. The technical condition and the home upgrade status of the 91 houses were analyzed and categorized (Risholt et al., 2012). In addition, energy efficiency data of eleven buildings was studied through a detailed analysis of the technical condition of the houses, the dwellers' energy behavior, their renovation decision processes and their experiences from renovation. These buildings were chosen by contacting home owners in a suburban location outside of Trondheim and selecting houses with a large floor area requiring substantial energy quantities for heating in the cold season. Houses were chosen to represent different renovation status and different owner occupancy periods.

This data, which is reported here, was obtained from in depth interviews (Kvale and Brinkmann, 2009, Tjora, 2010) of the homeowners and visual observation (Standard Norge, 1995) of the inside and the outside of the dwelling. The interviews took place in November 2011. An interview guide including questions on energy use, energy efficiency, the quality of living in the house, the technical condition of the house and the renovation experiences was the basis for the semi-structured interviews. The interviews were transcribed, coded using an inductive scheme, and grouped according to contents and associated concepts.

Table 1 summarizes the renovation status for the eleven dwellings and table 2 shows the constructional details.

Table 1 Renovation status for eleven Norwegian single family houses built in the period 1986 - 1990

Dwelling	Floor area [m2]	No. of dwellers	Renovation and energy efficiency status
A	190	4	Balanced ventilation with heat recovery, air-air heat pump, Interior partition wall, new windows, renovated bathrooms, upgraded kitchen, new flooring, redecorated and insulated basement
B	150	2	Renovated bathroom, new roof windows, upgraded outside entrance area
C	200	2	Air-air heat pump, new flooring in basement, upgraded outdoor area
D	200	2	Air-air heat pump, some new windows, renovated bathroom, interior surface renewal
E	250	2	Air-air heat pump, some new windows, new flooring in basement, new roof
F	180	3	As built
G	180	2	Air to air heat pump, renovated bathroom
H	220	4	Renovated laundry, renewal of interior surfaces
I	200	3	New windows, repaired moisture damages, renovated bathroom, new fireplace and chimney
J	230	4	Two air-air heat pumps
K	260	5	100 m2 extension, major renovation including new floor plans, balanced ventilation with heat recovery, new windows

Table 2 Constructional details for eleven single family houses built in the period 1986-1990

Building element	Wall	Roof	Floor	Window	Venti-lation	Heating system
Constructional details	Wood frame construction with 15 cm mineral wool	Wood frame construction with 20 cm mineral wool 1)	Concrete slab on ground with 5 cm polystyren insulation	Wooden window with 2-layered glazing 2)	Exhaust venti-lation 3)	Direct electric and fire wood

1) House E is built with 25 cm mineral wool in the roof
2) House A and I has new windows with 3-layer glazings. House B has original windows with 3-layered glazing.
3) House A and K have installed balanced ventilation with heat recovery

Variations in energy use in the sample

One of the eleven interviewees had no knowledge of the energy use and did not have access to the households' electricity invoices. Table 3 shows the energy use of the other ten inspected dwellings based on the homeowner's own information. The numbers give an average energy use of 150 kWh/m^2 with a standard deviation of 40 kWh/m^2. 140 kWh/m^2 average energy use for single family houses from the 1980s was found in a study by Enova (Enova, 2012). These real life energy use numbers are lower than those obtained from nominal calculations. The Norwegian norm for energy calculations in dwellings NS 3031(Standard Norge, 2007d) assumes an indoor temperature of 21^{o}C in all occupational rooms, including bedrooms, in the heating season. This is not the case in real life where bedroom temperatures often are kept lower than 21^{o}C. NS 3031 also set nominal values for air exchange rates and domestic hot water production that are higher than a real life situation for a single family house built in the 1980s.

Five of the eleven informants could document their energy use in the summer months. The summer use represents the base load which is the season independent electricity specific need for domestic hot water, ventilation, domestic appliances and home electronics. The good access to daylight in summer results in hardly any energy use for lighting (Mysen, 2008, Standard Norge, 2007d). The winter loads include lighting and space heating in addition to the base load. The annual base load in table 3 differs from 12000 to 15000 kWh constituting from 40% to 60% of the overall energy use. The winter loads for the ten houses in table 3, assuming a base load of 13000 kWh for those not documenting it, ranges from 9000 kWh (dwelling G) to 25000 kWh (dwelling I).

Table 3 Energy use for operation of ten Norwegian single family houses built in the period 1986-1990

Dwelling	A	B	C	D	E	F	G	H	I	K
Annual electricity use [kWh]	25000	35000	22000	25000	35000	24000	16000	28000	36000	25000
Annual energy from fire wood [kWh]	5000	1000	3500	0	1000	3000	5000	3500	2000	2000
Annual energy use [kWh]	30000	36000	25500	25000	36000	27000	21000	31500	38000	27000
[kWh/m2]	159	240	128	125	144	149	118	143	189	103
Base load [kWh]	12000			12000		14000	12000	15000		
Space heating and lighting [kWh]	18000			13000		13000	9000	16500		

[1] before replacement of damaged windows

Based on the interviews and visual observations, the differences in energy use in these otherwise comparable buildings are related to the condition of the building's heating system, the building envelope and the interior floor plan.

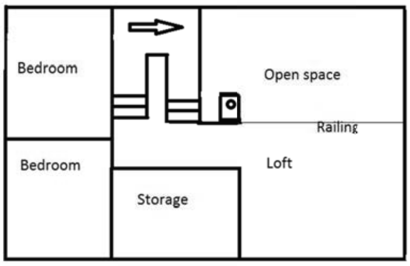
Homeowner D, for instance, uses electricity for heating and has installed an air to air heat pump and has experienced annual electricity savings of 8000 kWh. This illustrates his willingness to invest in renewable heat production. However, his willingness to do work on the building envelope to reduce the heat loss was low which is in accordance with the findings of Gireesh et al (Gireesh et al., 2010). To add on insulation to walls and the roof was looked at as negative due to the inconvenience and also uncertainty on the actual resulting energy savings.

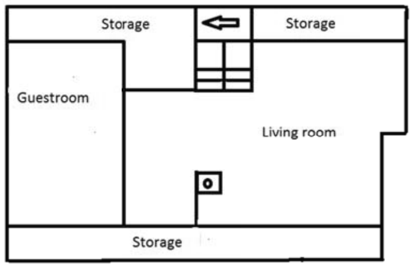
"Obviously I would have used less electricity for heating if we had 5 cm more insulation in the walls. But so what? It is just the way it is. I can not start tearing down the roof to add 20 cm. Because I don't believe in it. The same for the walls. So I have no potential for saving energy, within reason." Homeowner D

The energy saving due to a renovated air tight building envelope, depends on the as built air tightness. The air tightness of the building envelopes differs between the ten houses shown in table 3. Seven of the homeowners stated that the air tightness of their house was good and three stated that the airtightness was poor, as in this example:

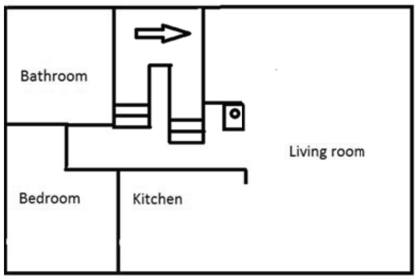
"The house is an open shell/hull. The need for heating is higher when it is 0 degrees and wind than in calm weather and minus 20. We have a leaking house and that's a fact. And yes, it is a 1980s house, because of the large volume. And they did not have focus on air tightness back then."

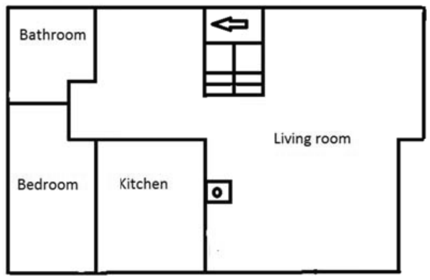
The heating needs also differed due to the interior floor plans of the houses. The houses B and F were quite similar in size and exterior architecture, but house B had a much higher heating load than house F even though house B had windows with 3-layered glazings. The indoor temperatures were the same in the two houses. The crucial difference was in the floor plans of the houses. House B had one big open volume from the basement to the roof, see figure 1. The living rooms in the 1st floor and the loft were connected by an open stairway and only separated by a railing constituting one big volume. House F also had an open stairway allowing some heat convection between the floors, but not to the same degree as house B. The very open room plan of house B allowed the heat to rise up to the loft and there was no forced circulation or recovery of the air. This gave a constant need for heating of the basement and first floor in the cold season.



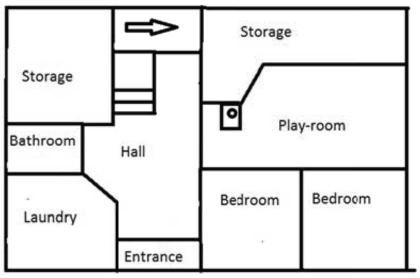


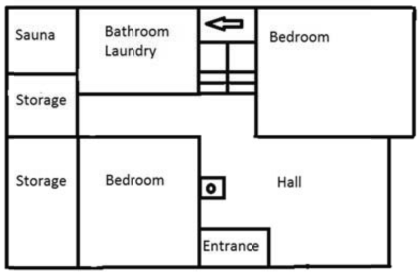
House B	House F
2[nd] floor	2[nd] floor





House B	House F
1[st] floor	1[st] floor





Basement	Basement
House B	House F

Figure 1 Floor plans for houses B and F

The energy saving potential of every day life: What is "appropriate" energy use?

It is necessary to look at the cultural and social meaning of the homes of Norwegians to understand the energy behavior. The Scandinavian and particularly the Norwegian home has an important cultural and social function (Aune, 1998). The home is a place for family life and entertaining guests (Garvey, 2005, Garvey, 2003). The interior is a symbol of uniqueness and the exterior is a symbol of uniformity with society (Støa, 1996, Gullestad, 1989). Norwegians use energy to have a comfortable indoor temperature, good air quality, an abundance of light in the dark seasons as well as to have the electrical appliances that are deemed necessary for their standard of living. Table 3 shows that 40 – 60 % of the energy use for the ten dwellings was related to electric appliances and domestic hot water production. It is evident that for saving energy and electricity, notice should also be given to the user aspects and all the appliances in a home, not just reduced heat loss and renewable heat production.

A certain indifference of Norwegians to energy use has been documented earlier (Enova, 2012, BarEnergy, 2011, Strandbakken, 2006) but could not be confirmed in this study. All eleven informants were very conscious about their own energy use. They implied unanimously that they only used the amount of energy necessary to reach an appropriate comfort level. But what “appropriate level” means was described very different from household to household.

The comparison of two households in the same neighborhood and their efforts to save energy illustrates this. Both were two person households being retired couples. The first couple was asked whether they want to save energy, they say:

"We do try. And I don't think we use that much electricity. If the weather is nice I dry the clothes outdoor. Except from that it is not that much to do. Refrigerator, freezer and such things have to be on. And I normally keep the TV on. The bedroom windows are always open. We want to keep it cold there. But the rest of the house needs to be nice and warm."

This couple does not succeed in their energy saving efforts, as they don't see possible ways of saving energy without affecting their quality of living in the house. The house needs to be warm and comfortable and all the appliances are indispensable. The personal loss of saving energy is emphasized stronger than the gains for society. On the other end of the spectrum is the other couple:

"We have found out that we use much less than most people... I think we save energy because it's not so warm inside the house. When we visit others, I think it is so warm, 23 and 24 degrees. But that is too warm for us. We like 21. Now it is 20.6. But somewhere between 21 and 22 is appropriate. I think you can get used to having one or two degrees lower"

Compared to the other households, this couple has had great success in saving energy. They have the same appliances as the other households, but use much less electricity for heating. They have installed an efficient air to air heat pump and uses firewood for peak load heating. But the main reason for their low heating need is that they keep the indoor temperature lower than the others. They don't see the lower indoor temperature as a loss of quality of living. It is the others that have too warm homes.

Another way of describing the difference between both households is as being locked into different practices. Practices, the nexus between what people are doing and thinking on a regular basis (Reckwitz, 2002), in the first case leave no room for less energy use. In turn, the second couple could not use more energy on space heating, even if someone would want them to, because they have become used to a lower temperature.

Within daily practices of cooking, eating, sleeping, playing etc energy per se is usually invisible (Shove, 2002). In theory there are good possibilities for saving energy by using energy efficient appliances and energy labeling is meant to make these possibilities visible. As the following quote shows – homeowners do assess energy labeling when purchasing appliances, but it is only one of many factors being evaluated:

"It is a part of the totality you get presented. But it is not the deciding factor for our choices. Then we have rather looked for. We just bought a washing machine. And we bought a Miehle machine because we thought it was of good quality. And it was silent. But energy is a part of it."

The informants want to save energy. But they don't want this to have negative influence on their quality of living. This quality is an effect of a complex variety of factors related to daily practices. Even though our informants state their willingness to change, the benefits of energy efficiency are not a strong enough motivator, therefore the non-energy benefits related to cost, comfort, aesthetics and convenience should be promoted to show all the gains from energy efficiency (Mills and Rosenfeld, 1996).

The renovation initiation: When is it necessary to renovate?

Given the adversity to change described in the previous section, the question arises why there are people that implement energy efficiency measures at all. Current energy prices are perceived as being to low to make energy efficiency investments attractive for the homeowner (Reddy, 1991, Strandbakken, 2006). Therefore, many energy efficiency measures can only be cost effective if they are done when repair or renovation is going to be done anyway (Martinaitis et al., 2007). Exterior insulation of underground basement walls when a new drainage is installed is one example of this.

This resonates well with what our informants say about when their specific renovation needs emerged. The overall common feature stated by the homeowners in this survey, is that renovation was done when it was "necessary". Moderation is an appreciated value in Norwegian culture (Gullestad, 1989) and to do renovation when it is “necessary” is in compliance with this cultural value. As with the word “appropriate” above, the word "necessary" has different meanings for different homeowners. One non-controversial understanding of the word is to renovate when an element is at the end of its technical life. The extreme end of life situation is a damaged pipe in a bathroom leading to a water leakage that need urgent repair. But for the sneaking damage, the assessment of when an element is at the end of its technical life varies greatly:

"It all started with a couple of punctured windows. That we had to do something about"

"I have a couple of punctured glazings. Two or three that I probably ought to replace. And it cost almost the same to replace the window as two replace a glass pane. When it's not unavoidable, you can do replacements little by little. "

"The quality of the windows was catastrophic. There was a plastic glider where the sash should glide. That was worn out and also the locking handle. So the window slipped open. The water poured in because of the poor construction."

A punctured glazing means that the insulating properties are degraded. But more importantly it means that you have condensation between the two glass sheets with loss of transparency, view and daylight. For the first homeowner this was considered a damage that is severe enough to initiate renovation. The second does not share this opinion. Only when it is unavoidable, as in the third example where the window is a safety risk, it is necessary to do a replacement.

The end of life assessment was also done based on aesthetic qualities or on a combination of more factors as in the following quote:

"We worry and focus on certain parts of the house. Such as the bathroom. Is the membrane defect? Plus functional aspects. And there are other things, such as windows. And there are other factors than improving insulation. We observed rotten frames in some of the old windows. And we could see out through openings between the windows. There was no sealing of the joints. And there are visual factors, aspects of the house that we appreciate."

Functional requirements due to change in family situation was also found to be a common reason for initiating home improvements

"The motivation for the changes in the basement was to get the room plan we wanted. We wanted to replace a long and narrow hallway and inconvenient small bedrooms. We also needed to do something with the entrance area and get more space for storage. It was a complete chaos with three small children. The house had no defects before the renovation. A larger kitchen was also a motivation. We also needed a guestroom because of the family living far away."

Another factor considered by some homeowners was the ability to do-it-yourself. The threshold to initiate works that you can do yourself was lower, than to decide to do work that require assistance of professional craftsmen.

"I am hurt from my experience from the roof. I am very skeptical. I almost cry when I have to get a plumber or an electrician. I am very skeptical. But then it's not. It's something about my feeling of command, to manage something. In that aspect, I am like a farmer. A farmer does most tasks himself. He doesn't know everything, but still he manages to do it."

The final aspect to initiate renovation that was encountered in the interviews was some mandatory requirement from the authorities. An inspection of the chimney in one of the dwellings resulted in a ban to use the fireplace. The homeowner had to install a new steel chimney and at the same time they installed a more energy efficient fireplace.

The findings of this section can be summarized in that Norwegians initiate home improvements and renovation when it is "necessary". Necessities may include damages or mandatory requirements that result in the need to repair or replace building elements. The concept also includes end of life assessments of building elements made by the homeowner based on technical, aesthetical, functional and comfort performance criteria.

From initiation to renovation project: Knowledge is power

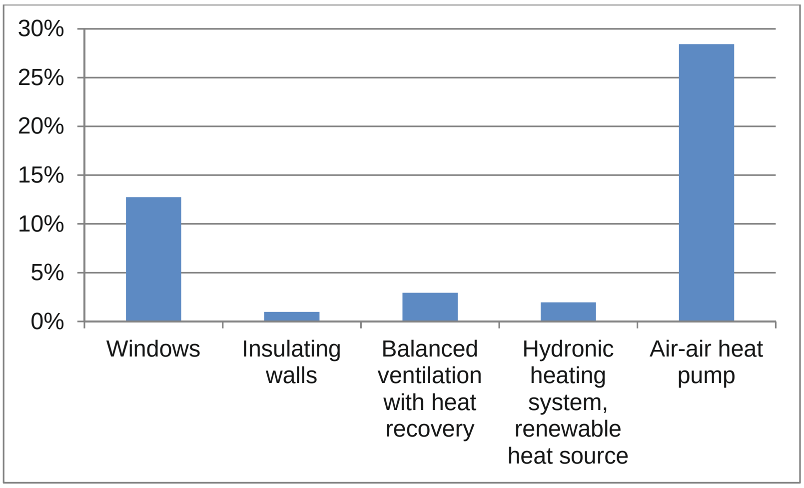


Figure 2 Energy efficiency measures for 102 Norwegian single family houses built in the period 1980-1990.

One important factor for success is the availability of products and services (Reddy, 1991). An example of this is the mass market success for air to air heat pumps in Norway. The heat pumps are available for the consumer from supermarkets and even door salesmen. An analysis of the energy saving status for 102 houses from the 1980s showed shows that 28 % of the houses in the sample had installed an air to air heat pump (see Figure 2).

In terms of efficiency, installation of balanced ventilation with heat recovery would have been a very good energy efficiency measure for the 1980s houses (Risholt et al., 2011). But in contrast to air to air heat pumps, ventilation aggregates are not marketed towards the end consumers. Only three of the 102 houses in this study had installed balanced ventilation with heat recovery. The two interviewed homeowners that have made this investment were both mechanical engineers with expert knowledge in ventilation. For homeowners without this expertise, there was an absence of awareness and also a lack of availability of services.

"I have tried to get someone to come and check the bathroom ventilation. And I have sat with the telephone book for days. Most seem to be working on large projects, something different than inspecting a house or answering my call. I did call a few, but they were busy and were going to return my call, but they never did. This was today. And I don't know who to ask. So it is the availability for the regular person."

Without expert knowledge and without someone ready to offer this knowledge as a service, the question of risk becomes an important barrier towards energy efficiency. Risk is associated with new technology in several ways: will the energy saving be achieved? Will there be negative side effects? Additionally, there is social risk associated to innovative choices (Christie et al., 2011). Technical risk evaluation related to severity of damages was found in the interviews by priorities to renovate bathrooms that may cause damage to the wood frame construction over renovating bathroom in the masonry basement. Risk assessment was also done when professionals were hired. Many homeowners did tasks as painting and carpenter works themselves or by using their network, while they hired professionals for plumbing or electrical works:

"Those parts of the house where we think the requirements are strict, there everything is done according to the book. It is done by certified companies. We are consistent in that. So we file reports from electricians and that kind of documentation. We try to have an updated house regarding documentation. So things are traceable to avoid conflict."

So prior to all renovation decisions are made, many factors are at play (Faiers et al., 2007). Possible energy saving is only one factor. Even for cost effective measures with short payback time, homeowners were reluctant due to other technological drawbacks as aesthetics and noise. The cost of renovation was evaluated against the known gains and drawbacks. In this phase after the initiation and before someone is hired to do the work homeowners evaluate risk and decide on which measure will be taken. This is an important time to influence the homeowners and to guide them to make the right choices.

Despite a far-reaching lack of information some homeowners still managed to make better choices than others. The decision process of homeowners A, D, I and K was analyzed to find why they were able to overcome the barriers against energy efficiency.

A common element in these four cases was that these informants were heavily involved in the design and planning of the renovation measures. None of them was indifferent to renovation and technical aspects and just hired someone to come and do a job. These homeowners realized the need to renovate and to do the wanted improvements. They searched for information, planned and decided what to do and finally got the work done by hiring professionals or they did it themselves. They shared a strong commitment to the decisions to optimize the result in relation to the efforts and resources spent.

In addition to these commonalities, there were differences regarding what these homeowners actually decided to do, even though the reasons and needs for the renovation were similar. Window replacement was one example:

"I knew there was something called three layered. But then I tried to check. And those who sold me the windows took it for granted that I should buy two layered. But if there had been any discussion, I would have checked it further." Homeowner D

"In the basement we bought two layered. We have three layered on this floor (1st floor). Here we have seating close to the windows. And there are large glazed surfaces everywhere. When we finally decided on that's what we wanted. But it was not an easy choice. The window manufacturer and the carpenters were indifferent. There was little advice on what where the better choice regarding energy and economy. They said that a two layer window is so good that it's more than you need." Homeowner I

Both homeowners were told by the experts that windows with a two layered glazing would be a good choice for their home. Homeowner I, being the conscious consumer, did not take the advice for granted and ended up with a better product after making her own investigations. Homeowner D trusted the carpenter, being the expert, and got the worse product. This example shows the importance of being a conscious consumer in order to succeed in making innovative choices. It also identifies a structural barrier (BarEnergy, 2011). Carpenters have the role as experts on renovation of single family houses, but according to our informants they have little access to information on innovative products and little knowledge on the gains for the homeowner from energy efficiency. The carpenter's role is to fit the new windows in the wall. He earns no more money from installing a window with three layer glazing than a window with a two layer glazing. But the three layered windows weigh more and are heavy to handle. The better energy efficiency measure is therefore actually less attractive for the carpenter making him an important barrier towards energy efficiency.

The lack of knowledge on the experts' side has to be compensated with knowledge on the side of the homeowner. As was indicated above, some homeowners are competent buyers due to their profession. Homeowners A and K are mechanical engineers and have installed balanced ventilation with heat recovery to save energy and to get cleaner indoor air. Homeowner D had calculated the savings meticulously to purchase an air-air heat pump that would work under the local climatic conditions:

"I made a spreadsheet before I bought this heat pump. What pump should I buy? I looked into it and calculated. So I found out that I ought to buy this pump. It gave the best. And when I calculated, that was based on hourly, no day average temperatures for a couple of years that I found on the web. And I compared them with the characteristics of the different heat pumps and adjusted to our need. I calculated that I could save approximately 9000 kWh annually with this pump." Homeowner D

This is the same person that trusted the carpenter and ended up with two layered windows. This illustrates the case that a homeowner can have special knowledge regarding one element or technical system, but may lack knowledge on other parts. This also shows that the complex interplay between the components of an energy efficient house poses great challenges to homeowners who cannot rely on external expertise.

A preliminary taxonomy of renovation styles

Based on the interviews four categories of homeowners can be distinguished among the eleven informants (see table 4). These categories represent typical combinations of

- how the renovation is initiated,

- how information is sought, and

- how the renovation is executed.

The conscious consumers do not trust experts, but make their own investigations to make optimal decisions. They are open for advice and new technology, but need to verify the effects themselves before deciding. Different from this group is what we call the category of confident homeowners. They trust their own assessments and choose solutions based on their existing knowledge and advice from their network and craftsmen. Within this group we find different degrees of knowledge, ranging from ignorance to a sufficient amount. Informants within the "handy" category trust in their on assessment and give additionally priority to work they can do themselves. This group of homeowners will most likely renovate using traditional technical solutions.

The unaware category corresponds to The ignorant category defined by Reddy (Reddy, 1991) thus representing a information barrier. As the example of the homeowner D showed above a homeowner might belong to both the informed and unaware category depending on the situation and the renovation task.

Only the conscious and the informed have sufficient knowledge and make the optimal choice which reduces the risk for energy lock in. Both the unaware and the "handy" homeowners, however, have a high risk for energy lock-in since they risk ending up with outdated energy efficiency technology.

Table 4 Categories of private homeowners and their ability to realize energy efficiency in renovation

The conscious	The confident		
	The informed	The unaware	The handy
-looks for more information, using internet and their network - open for advice and new solutions -low/medium risk for energy lock-in	- repair and replace - aware of the condition of elements -aware of energy efficiency possibilities -low risk for energy lock-in	-does not have valid knowledge -unaware of own lack of knowledge -unaware of real condition of elements -high risk of energy lock-in	-give priority to do it yourself tasks -risk assessment if necessary to do works and hire professional -high risk for energy lock-in

Policy discussion

The renovation project is a window of opportunity for the homeowner to realize energy efficiency and also to gain from the following non-energy benefits. In this contribution we have identified strong barriers for these opportunities to become realized. A set of strategic efforts is needed for market success for energy efficiency including regulatory, financial and communicative instruments (Reddy, 1991, Weiss et al., 2012).

Private homeowners need to be able to plan, design and order the renovation works. In this study, only conscious consumers or those that have knowledge in buildings and technical systems were successful. These groups are innovators, but not representative for the average homeowner. Information and knowledge on the possibilities and gains from energy efficiency is a key factor to make more homeowners successful in realizing energy optimal choices.

Efficient Guidelines

According to the interviews, the information needs to be trustworthy, easily accessible and specific. Information from the government and public institutions of today is often on a generic level. Previous research has shown that the and the effect of information on this level is positive in short term but diminishes after few weeks (Henryson et al., 2000). The positive sides of being more specific are well documented (Desmedt et al., 2009, Ellegaard and Palm, 2011).

The present study underlines the need for publicly supported guidelines for energy efficient renovation of dwellings, showing the specific gains and possibilities from a stepwise sustainable renovation process.

The present study contains four lessons that should be included into these guidelines to make them more successful.

First, it was shown that daily routines and practices and concerns for the overall quality of living are able to choke energy efficiency measures altogether. Therefore, these guidelines should also show the non-energy benefits of the renovation measures such as aesthetics, comfort, sound insulation, safety, maintenance, climate robustness, better functionality, flexibility and universal design (Mills and Rosenfeld, 1996).

Second, home owners have different renovation styles. The “handy” category of homeowner wants to be involved in the planning, design and execution of the renovation. Other groups such as the “conscious” category only wants to control the planning and design. Therefore, the guidelines for energy upgrades should offer different degrees of engagement.

Third, in order to destabilize established notions of “appropriate” energy use levels, demonstration of very ambitious energy standards can be effective (Reddy, 1991). Based on objections mentioned in the interviews, these demonstrators should focus on making homeowners experience low noise levels from modern balanced ventilation systems, the aesthetics of a solar collector and feel the comfort of a window with three layered glazing.

Fourth, for the initiation of renovation, it was demonstrated above that home owners mean very different things when they unanimously say that they start renovation when it is “necessary”. To associate a lack of energy efficiency of components with a state of necessity for renovation should be a crucial message of the guidelines proposed here.

Mediating actors

Nine out of eleven home owners said that the Internet was their most important source for information in the renovation process. Guidelines published online can only be specific up to a certain point since they address an unknown recipient. As mediating actor between products, possible renovation measures and the specific end user, craftsmen play an important role. As was shown above, craftsmen feature in the interviews as barrier rather than as enabling mediator. Today, the craftsman has no gains from energy efficiency. What should be looked into is if the craftsman could be the one assessing the dwelling and preparing the plan for energy saving renovation. This would be a new service that would give the craftsman an economic incentive in energy efficiency. Training courses in energy efficiency of houses for carpenters could be a good strategy to make this possible. Moreover, the role of project managers for energy efficient renovation is a new business model that are being introduced in the Norwegian market (Tommerup et al., 2010). The concept is a one-stop-shop where the homeowner has one contact point the project manager. The project manager plans and designs, is the manager of the building works, contracting and coordinating the craftsmen. Homeowner J used a project manager for their major renovation and experienced a smooth building process with little inconvenience for the family.

Conclusion

Large scale ambitious energy efficiency renovation of buildings is one tool to realize the society's need of a more sustainable building stock. Most Norwegians own their own homes. Therefore private homeowners are a key group to accelerate the dwelling energy efficiency rates.

Private homeowners identify the renovation need and decide upon renovation based on their needs, desires and capabilities. Homeowners that are conscious consumers or that have special knowledge due to their professions are the only ones that have succeeded in realizing energy efficiency. Lack of knowledge, trust in bad advice from craftsmen or priority to work they can do themselves stop other homeowners from energy efficiency.

Those homeowners that have decided to do renovation, and are in a planning phase on what to do, are in a window of opportunity for energy efficiency. Increased knowledge on all the gains from energy efficiency, the availability of attractive products and services as well as easy access to reliable advice on the better renovation solutions for their home can get more homeowners to choose energy efficient solutions. Today, due to a lack of knowledge and incentives, craftsmen are an important barrier to energy efficiency. But they could play an important role as mediators between available products and the specific building that has to be renovated.

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6.4 SUSTAINABILITY

The main research question is if it is possible to renovate a single family house to become a zero energy building and at the same time fulfil requirements related to cost and improved home qualities. The papers 1 – 5 look at the individual factors of energy demand, lifecycle costs and homeowners preferences regarding renovation and home qualities. But, to be able to find an answer to the main research question, there is a need to see if there are renovation strategies that fulfil all the stated requirements. The three aspects energy, lifecycle costs and home qualities can be seen as indicators of sustainability. It was therefore decided to use a method for multicriteria sustainability analysis to find an answer to the main research question.

More sustainability assessment methods are described in the literature, and there are methods especially designed for assessment of buildings and building renovation. Paper 6 give a short summary of some of the methods and an evaluation of if they are suitable for analysing the research question in this PhD. It was not a task for this research to develop a new sustainability assessment method, but rather to investigate the existing methods and identify one ore more methods that could be used for assessing dwelling renovation.

Paper 6 presents a method from the British Institute for sustainability (Institute for Sustainability, 2012) as a preferred tool for the multicriteria evaluation. The method is revised based on the findings in paper 1 – 5, and the revised method is used to analyse the sustainability of two nearly zero energy renovation strategies.

SUSTAINABILITY ASSESSMENT OF ZERO ENERGY RENOVATION OF SINGLE FAMILY HOUSES. BASED ON ENERGY, ECONOMY AND HOME QUALITY INDICATORS (PAPER 6)

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Sustainability assessment of nearly zero energy renovation of dwellings
-based on energy, economy and home quality indicators

Birgit Risholt, Berit Time and Anne Grete Hestnes

Abstract

A case study of a Norwegian detached house is used to evaluate the sustainability of two nearly zero energy renovation strategies. Energy demand, life cycle cost and home qualities are assessed as sustainability indicators. The Façade renovation strategy is an energy upgrade of the façade supplemented with high renewable energy production on site. The Ambitious renovation strategy is a total building envelope upgrade using passive house components and a lower on site renewable energy production. Both renovation strategies result in a 50 to 85 % reduction of the heating requirement depending on the renewable energy production. The sustainability assessment was done as an iterative process including qualitative and quantitative parameters. The Ambitious renovation strategy is more costly than the Façade alternative over a 30 year period. However, homeowners do not base their decisions to renovate strictly on cost evaluations and homeowner categories influence the assessment. The Façade strategy is suitable for homeowners that do the retrofit themselves and homeowners prioritizing to keep the existing architectural qualities of their house. The Ambitious strategy is more suitable for the homeowners seeking to change the aesthetics of their home as well as for the homeowners emphasizing the overall technical performance after renovation.

Keywords: sustainability, renovation, energy, lifecycle cost, social indicators

Introduction

> *"I have considered installing balanced ventilation with heat recovery. My bedroom is so cold in winter. The heat recovery would give me tempered inlet air. I could have the bedroom temperature I prefer in winter. I would really like to install balanced ventilation, not to save energy, but for the comfort."*

The quote was made by a Norwegian private homeowner in an interview about renovation preferences. It illustrates that a homeowner has different priorities and does not always base decisions on cost effectiveness. The indoor comfort and fresh tempered air following of balanced ventilation with heat recovery are the decisive factors in this case, not the energy and economic gains. In a zero energy renovation context, this means that the renovation measures need to be tailored to the building, but the solutions must also be attractive for the homeowner who is deciding whether to renovate or not. The renovation must result in energy efficiency, and at the same time increase home qualities due to energy and non-energy benefits(Mills and Rosenfeld, 1996).

Private homeowners seeking energy efficiency face several barriers related to lack of knowledge, low cost effectiveness for the investment, lack of attractive products and services, priority to comfort and other non-energy aspects (Reddy, 1991, Strandbakken, 2006, BarEnergy, 2011, International Energy Agency, 2010). The barriers prevent market success for renovation with ambitious energy saving targets. One approach to overcome the barriers and to assist the homeowner in renovation planning and design is to facilitate evaluation of the sustainability of renovation alternatives. Sustainability assessment includes social, economic and environmental aspects. In a dwelling renovation context, energy efficiency, economic properties and improved home qualities can be included in sustainable planning (Baek and Park, 2012).

This article deals with sustainability analysis of dwelling renovation. The analysis includes energy, economic and home quality impacts. The article gives a review of existing methods for multicriteria sustainability analysis and discusses the relevance of sustainability indicators for renovation of privately owned dwellings. A case study of a nearly zero energy renovation of a dwelling built in the 1980s will demonstrate how a multicriteria sustainability analysis can be used to find the better renovation strategy for different homeowner categories.

Indicators for Sustainability

A sustainability analysis of building renovation can include many factors; the energy performance, material efficiency, environmental impact, durability, affordability, and social benefit (Mwasha et al., 2011). An even more exhaustive listing of indicators can be found in the norms NS-EN 15643-1 to 4 'Sustainability of construction works. Assessment of buildings.' (Standard Norge, 2010a, Standard Norge, 2011, Standard Norge, 2012a, Standard Norge, 2012b). What indicators are actually evaluated in a renovation project depend on the planner and the decision maker(Risholt and Berker, 2012, Botta, 2005).

Sustainability assessment of buildings and renovation should be based on a lifecycle analysis(Standard Norge, 2010a). Regarding building material and products, the lifecycle assessment is done for the specific manufacturer, preferably resulting in an environmental product declaration (EPD) (Standard Norge, 2006, Standard Norge, 2010a). This study focuses on renovation strategy, not including an optimal choice of construction products. It is therefore chosen not to include environmental aspects such as embodied energy and CO_2 equivalents of materials as indicators, but rather focus on the energy performance of the building after renovation (Alsadi et al., 2012, Chang, 2011, Diakaki et al., 2008).

This article deals with nearly zero energy renovation of dwellings meaning renovation of an existing building to a nearly zero energy building as defined in the EU Directive 2010/31(European Parliament and The Council, 2010). The definition comprises a low energy performance of the building envelope and production of renewable energy on site to achieve a nearly zero energy operation performance of the building. The definition (European Parliament and The Council, 2010) does not quantify the energy performance or the renewable energy production of a nearly zero energy building. This work focuses on a retrofitting standard reducing the need for delivered energy for space and domestic hot water heating by a minimum of 60 %.

Technical performance indicators are added to the environmental performance indicators in a sustainability assessment (Institute for Sustainability, 2012, Standard Norge, 2010a). Durability of renovation measures is one example of a technical performance indicator (World Commission on et al., 1987, Institute for Sustainability, 2012). Durability of a building envelope component depends on more factors such as constructional and material properties, maintenance and climate robustness(International Organization for Standardization, 2008). The choice of indicators of technical performance in a sustainability analysis will depend on the goal of the project and the detailing of the analyses (Botta, 2005).

In a sustainability perspective, the economic performance should be evaluated as life cycle costs (World Commission on et al., 1987). The life cycle costs include current and future investment and operational costs (Anastaselos et al., 2009, Juan et al., 2010). One way to present the life cycle cost is as a global cost that sums the total occurring costs throughout the calculation period(Standard Norge, 2007a). A homeowner investing in renovation most likely has a timespan for his ownership. Global cost is linked to the calculation period and will give the homeowner knowledge on all costs that will occur during his expected ownership period, and thereby making it possible to identify the most cost effective renovation strategy.

Indicators of home qualities are of special importance when assessing retrofitting privately owned dwellings(Institute for Sustainability, 2012). Private homeowners are involved in planning and decide on upgrade solutions based on their own assessments, and they are concerned with the outcome of the renovation and the impact for the home qualities such as indoor comfort and aesthetics(Vanhoutteghem et al., 2011). A Norwegian study of the renovation status of dwellings showed that there are four categories of homes; the 'As built', the 'Aesthetic', the 'Well kept' and the 'Do it yourself' (Risholt et al., 2012). The owner of an 'As built' house has not done any renovation or major maintenance tasks throughout their ownership. The 'Do it yourself' homeowner prioritize renovation tasks they can do themselves. The 'Aesthetic' house owner has finances to do major renovation tasks, but gives priority to aesthetic upgrades. The 'Well kept' houses are in a good technical condition, and the house owner does the needed renovation and maintenance in a stepwise process.

The energy efficiency results in a dwelling renovation project depends on the knowledge and skills of the homeowner (Risholt and Berker, 2012). The studies of Norwegian homeowners (Risholt and Berker, 2012, Risholt et al., 2012) imply that social indicators should include self involvement in planning and execution of work in addition to non-energy benefits such as aesthetics and improved indoor comfort.

Methods for analysis of sustainability

A framework for sustainability assessment of construction work is described in 'NS-EN 15643-1 Sustainability of construction works. Sustainability assessment of buildings. Part 1: General framework' (Standard Norge, 2010a). When assessing the sustainability of strategies for zero energy renovation of a house, it is the zero energy performance that represents the functional equivalent for the different strategies. The norm states that the social, economic and environmental performance shall be evaluated over the lifetime of the building. The sustainability assessment shall also include criteria on building functionality and technical characteristics. The assessment is based on quantitative indicators (Standard Norge, 2011, Standard Norge, 2012a, Standard Norge, 2012b). The norm defines a framework of the overall approach and possible indicators to assess sustainability. But it does not give a method for how to actually perform the assessment and how to analyse possible conflicting performance criteria such as increased insulation levels and higher investment cost.

More methods are described in the literature as decision making support tools for sustainability assessment. Quantitative multicriteria models are the engineering approach for sustainability evaluation. Models with linear functions on thermal comfort and cost effectiveness are used to evaluate renovation measures such as heat insulation levels of walls, window types and on site renewable energy production (Alsadi et al., 2012, Diakaki et al., 2008, Chang, 2011). Other models focus on optimizing energy needed for operation with environmental properties such as CO_2 equivalents and cost effectiveness (Anastaselos et al., 2009, Juan et al., 2010, Allen and Shonnaard, 2012). A prerequisite for a quantitative analysis is that the parameters can be modelled. In addition, the evaluator must have sufficient knowledge and defined goals and priorities to do the assessment. Bearing in mind that the decision maker is a private homeowner, both the lack of knowledge and goals makes the multicriteria numerical models inappropriate for optimizing the choice of renovation solutions.

Quantitative multicriteria assessment of environmental properties of a building is also the basis for certification in BREEAM and LEED (Breeam, 2012, Leed, 2012). Both systems give rating of environmental performance based on factors weighting related to energy, material and water use as well as indoor environment. The weighting of factors replaces the numerical processes and also includes a priority of which factors are more important for the environmental performance. The homeowner might have other priorities or motivation for renovation than what is decided in a normative assessment scheme that should fit all buildings. A more adaptive system including personal priorities would be preferable for evaluation of dwelling renovation.

While quantitative models are based on numerical and physical rules, the human factor in a renovation project is difficult to model. The renovation process can be seen as a complex system of related activities that can have many possible outcomes, due to a random human factor (Sterner, 2011). In an evaluation process of sustainable renovation of a privately owned dwelling, the homeowner priorities are not strictly logical or mathematical, but they are a mixed set of quantitative factors such as investment costs and thermal comfort and also qualitative factors supporting home qualities such as aesthetics and safety. A sustainability analysis of dwelling renovation should therefore encompass both quantitative and qualitative data.

The British Institute for sustainability has published a retrofit guide for sustainable renovation of domestic buildings (Institute for Sustainability, 2012). Chapter 3.10 of the guide gives an iterative method for evaluating the sustainability of renovation solutions, see figure 1. The sustainability indicators are divided into the categories economic, performance, social and usability impacts. The analyses of the different sustainability impacts are quantitative or qualitative depending on the indicator to be assessed. Social impact and usability impact are related to home qualities as they strongly depend on homeowner preferences. The Performance category includes energy savings, environmental and technical performance. The Economic category encompasses current and future economic situations through life cycle cost analysis. This method is used for the case study as described in section 4.

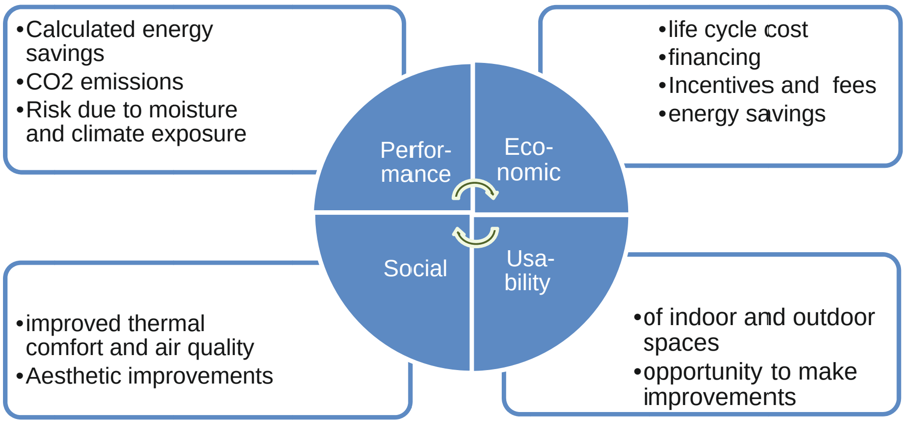

Figure 1 Iterative method with impact categories for sustainability assessment of dwelling renovation (Institute for Sustainability, 2012)

The case study of the house 'Block 180'

Norwegian dwellings built in the 1980s have the highest energy use compared to dwellings from other construction periods(Bøeng, 2005). Houses built in the 1980s are at a stage in their lifetime where renovation actions, such as new windows and ventilation system, are needed within the next decade. It was therefore decided to use renovation of dwellings built in the 1980s as case for a sustainability analysis. 'Block 180' was a popular detached house model in Norway in the 1980s(Sørby, 1992). By analysing a popular house model, the results will be applicable for many houses. 'Block 180' was chosen as a case because the floor area is larger than for many other popular models. A larger house is a worse case scenario when the goal is to achieve a nearly zero energy building after renovation. Table 1 presents some basic information on the house 'Block 180'.

The floor is made of concrete cast on site. Basement walls are in light weight masonry. Exterior walls, interior walls, interior floors and roofing are wood frame structures insulated with mineral wool. The exterior walls are clad with wood panels. Table 2 shows thermal properties represented by U-values of the building envelope, normalized thermal bridge coefficient and air tightness of the house before and after renovation to two different energy performance levels, *Façade* and *Ambitious*.

Table 1 Basic data for the house model Block 180

No. of floors	2.5	
Total floor area	262 m^2	
Window area	45 m^2	
Heated volume	565 m^3	
Location	Oslo	
Orientation	Main façade oriented 30^o to southwest	

Renovation scenarios

Two renovation scenarios are analysed in this paper, see table 2. Scenario Façade encompasses new windows, adding on insulation to the exterior walls of the house and improving the air tightness. The scenario Ambitious is a deep renovation of the whole building envelope using passive house components. Both renovation scenarios require installation of a ventilation system with heat recovery as well as a hydronic heating system for energy storage and distribution. Renewable heat production for space heating and domestic hot water is included for both scenarios. Two alternatives, an air to water heat pump and a 20 m^2 solar collector are evaluated. An all electric reference is included to verify if installation of renewable energy production is cost effective compared to direct electric heating(National Office of Building Technology and Administration, 2010b). Results from calculations of energy outputs from the renewable energy production are shown in table 3 and 4.

Table.2 Thermal properties and the annual heating need for Block 180 before and after renovation

Energy scenario	U-values [W/m^{2}K]				Thermal bridge [W/mK]	Air tightness n50 [1/h]	Ventilation [m^3/hm^2]	Heat recovery efficiency	Annual space heating demand [kWh/m^2]
	Window	Wall	Roof	Floor					
As built	1.75	0.47	0.21	0.37	0.07	3.0 1)	0.4	0	145
Façade	1.0	0.21	0.21	0.37	0.03 2)	2.0 2)	1.2	0.86	49
Ambitious	0.77	0.14	0.11	0.21	0.03	0.6 2)	1.2	0.86	24

1) The air tightness and ventilation values are nominal values based on Thyholt et al(Thyholt et al., 2009)
2) These values are not documented and depends on workmanship and details in solutions

The global costs are calculated for the two scenarios according to 'EN 15459 Energy performance of buildings. Economic evaluation procedure for energy systems in buildings' (Standard Norge, 2007a). Global costs are calculated for a 30 year period. The ownership of a house might be longer as more Norwegians live in single family houses until old age. Statistics Norway (Statistisk Sentralbyrå, 2011a)shows that the inflation rate from September 2010 – September 2011 is 1.6%. An inflation rate of 2 % is used in the calculations. The real interest rate used is 4 % according to the guidelines for the Norwegian Building Code(National Office of Building Technology and Administration, 2010b). The annual rise in electricity price in Norway in the period 1999- 2010 was 5.5 % (Statistisk Sentralbyrå, 2011b) and a rate of 5 % is used in the calculations. Only costs related to energy efficiency are included in the global costs calculations(Martinaitis et al., 2007, Jakob, 2006). Costs for renovation measures are gained from offers given by Norwegian product manufacturers and contractors in 2011.

Knowledge on homeowner preferences is obtained from a previous study on technical condition and renovation status for 91 Norwegian single family houses (Risholt et al., 2012). This is supplemented by interviews of 11 homeowners to gain more in depth knowledge on home qualities indicators for choice of renovation measure. Other results from the interviews, including energy use and decision processes, can be found in(Risholt and Berker, 2012).

Results

Performance Indicators

The performance indicators include the energy demand, climate exposure resistance and moisture robustness, see figure 1. The annual calculated energy demand for space heating and domestic hot water before and after renovation is shown in table 3. The electricity for heating in table 3 is the supplementary energy required in addition to the renewable energy produced on site. Direct electric heating using cables in the floors or by wall mounted boards are traditional heat sources for a dwelling in Norway (Bøeng, 2005) and the all electric situation is included as reference(National Office of Building Technology and Administration, 2010b).

Table 3 Annual on site renewable heat production for space and domestic hot water heating before and after renovation of a single family house for two renovation scenarios calculated according to NS 3031(Standard Norge, 2007d)

Heat production technology	As built	Façade		Ambitious	
	Electricity for heating [kWh]	Renewable heat production [kWh]	Electricity for heating [kWh]	Renewable heat production [kWh]	Electricity for heating [kWh]
Solar collector [1)]		4.700	12.300	4.400	7.100
Air-to water heat pump [2)]		7.600	9.400	5.300	6.200
Electricity	40.000		17.000		11.500

1) 20 m^2 flat plate solar collector. Energy output calculated in PolySun(Vega Solaris, 2011)
2) COP= 3.3 for hot water production, system loss 1000 W, COP= 2.8 for Façade and COP = 3.0 for Ambitious regarding space heating. 30 % of the space heating are covered by 100 % electricity due to low outdoor temperatures

Both strategies can be realized using traditional wood frame construction techniques with a ventilated wooden cladding(SINTEF Building and Infrastructure, 2010). An exterior wall U-value of 0.21 W/m^2K will require 250 mm of mineral wool with a thermal conductivity of 0.037 W/mK, and an U-value of 0.14 W/m^2K will require 350 mm(SINTEF Building and Infrastructure, 2010). Both strategies should allow both stepwise and one-step major renovation

Economic Indicators

Investment costs for the envelope upgrade and the energy distribution system are presented in tables 4 and 5. The overall costs in table 4 include cost for general renovation, e.g. a new wooden cladding, and the energy related costs. The energy related costs in table 4 include costs for thermal insulation and other building materials as well as labour costs. The floor cost includes interior work as for example replacement of doors due to change of floor height. The table also includes financial support from the Norwegian public enterprise Enova (Enova SF, 2011). Table 5 shows investment costs and annual maintenance costs as well as operational energy costs.

Table 4 Investment costs for renovation of the Block 180 building envelope including costs for installation of hydronic floor heating distribution system. The overall cost include cost for renovation and for energy efficiency measures

Building component	Expected lifetime[years]	Area [m^2]	Façade		Ambitious	
			Overall cost [€]	Energy cost [€]	Overall cost [€]	Energy cost [€]
Basement walls	60	130	17,900	1,600	38,500	15,600
Wood frame walls	60	146	18,000	7,100	24,700	14,300
Windows and doors	30	45	41,100	3,400	47,000	9,300
Roof	30	180			35,600	11,900
Floor	60	99			20,500	13,900
Floor heating -hydronic - electric	60 15	55/95	7,100 (5,800)	7,100 (5,800)	4,100 (3,900)	4,100 (3,900)
Enova financial support		272			20,400	20,400
Investment cost for envelope upgrade [€]			84,100	19,200	150,000	48,700

The dimensioning outdoor temperature for Oslo, which is -20 ^{o}C, is used to calculate the heating power. The calculation show a minimum requirement of 7.3 kW for the Façade scenario and 4.3 kW for the Ambitious scenario. There are not many suppliers in the Norwegian market offering air to water heat pumps with a power as low as 4 kW. Due to this, the same heat pump is used for both scenarios. Table 5 shows the investment costs for heat production and storage as well as running energy costs. The numbers include space and domestic hot water heating.

Table 5 Investment costs, operational costs and expected lifetime for energy production and storage. Maintenance costs and expected lifetimes are from(Standard Norge, 2007a)

Production unit	Investment costs [€]	Financial support from Enova [€]	Cost for annual maintenance in % of investment	Expected lifetime [years]	Energy costs [€/kWh]
Ventilation with heat recovery	9,400	0	2	15	0.125
Solar collector	9,900	1,250	2	20	0
Air to water heat pump	11,700	1,250	2	15	0.125

Figure 2 presents the global costs for a period of 30 year for the two renovation scenarios and the selected heat production technologies. Only energy related costs are included(Martinaitis et al., 2007, Kragh and Rose, 2011), see tables 4 and 5. The final value of the energy upgrade of the envelope, ventilation system and energy system is subtracted from the investment costs. The results show that the Façade strategy gives lower global costs than the Ambitious strategy. The Façade alternative with an air to water heat pump for renewable heat production is the better choice from an economic point of view.

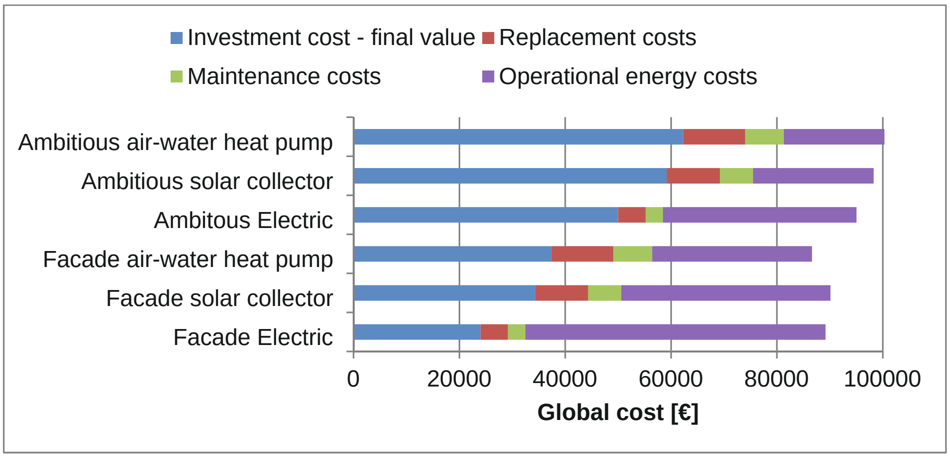

Figure 2 Global cost in € for two zero energy renovation strategies of Block 180 and 3 heating alternatives. The final value is subtracted from the investment cost. The global costs are calculated according to EN 15459(Standard Norge, 2007a) for a 30 year period.

Social and usability Indicators

According to the assessment method of the Institute for sustainability, home qualities indicators are divided in the categories social and usability impacts(Institute for Sustainability, 2012). Usability indicators include the possibilities to do home improvements. A change in life situation is one aspect affecting usability(Clapham, 2005). Five of the eleven households in the study were two person households. The quotation below is from one of the homeowners where the children had left, and the remaining couple living in the house only uses parts of the house in their daily life.

> *"There are bedrooms we only use when we have guests. Not for our daily use. We only use two of the bedrooms, and one of them we only use parts of. So we actually have two vacant bedrooms."*

In a situation like this, where only parts of the house are used, the heating and ventilation system needs to be flexible, only supplying a minimum temperature to prevent moisture damage in areas not in use. The floor plan of the house should be flexible, allowing rental of a part of the house. This implies that flexibility is a usability indicator.

The aesthetic homeowner is focused on the visual quality after renovation. The aesthetic houses can be modernized and appear as a new house on the inside(Risholt et al., 2012). Two of the homeowners interviewed were interested in keeping the visual qualities of their house and would not make visible changes. One of the homeowners stated this clearly:

> *"We had an architect helping us to choose colour for our living room because we found it difficult to decide. We want to keep the character of our house. And it was her advice, that this is a house built in the 1980s, and it should never be changed to appear as anything else."*

The findings verify that aesthetics should be kept as a social indicator. But what visual qualities that are appreciated depend on the homeowner.

Analysis and discussion of sustainability

Figure 3 illustrates an revised iterative method for sustainability assessment of Norwegian privately owned dwellings. The method is based on the retrofit guide of (Institute for Sustainability, 2012) and revised based on the findings from this study. This study is focused on zero energy renovation, and Performance is defined as step 1 in the process. However, other projects with other goals might alter the order of the steps. Regarding Performance, Risk of failure is linked to execution of work and the finding that some homeowners carry out the renovation with lack of skills in renovation. Maintenance and durability are relevant aspects for the homeowners that emphasize technical performance. Personal involvement includes involvement in planning, design and execution of works. The options of a one-step major or a stepwise retrofit are included as these retrofit processes are relevant for dwelling renovation. Flexibility is based on the findings of changes in family situation and resulting housing needs. In the following the revised method will be used to analyse the sustainability of the two renovation strategies Façade and Ambitious, see table 2 and 3. The analysis includes evaluation of the priorities of different homeowner categories regarding renovation.

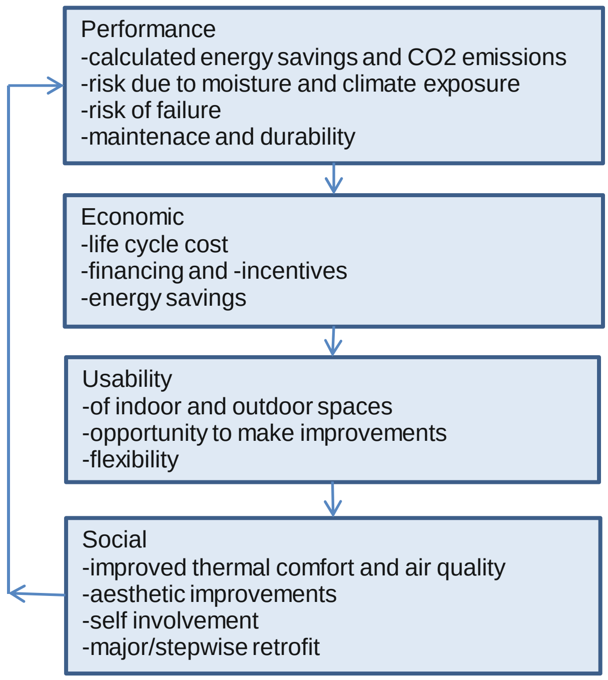

Figure 3 Iterative method for assessing sustainability of dwelling renovation based on performance, economic, usability and social impacts based on (Institute for Sustainability, 2012) and studies of Norwegian homeowners (Risholt et al., 2012). Homeowner probability scores are used to evaluate the priorities of different homeowner categories in renovation projects

Step 1 Performance assessment

Performance impact includes environmental and technical factors, see figure 3. Embodied energy and related CO_2 emissions for construction products should be calculated for each manufacturer. This study focuses on strategies rather than optimal choice of products. It was therefore decided not to include embodied energy and CO_2 emissions in the analysis. Annual energy for heating and the demand for delivered energy were chosen as environmental indicators as low energy requirement and renewable energy production are according to the nearly zero energy building definition in the EU Directive 2012/31(European Parliament and The Council, 2010). The Ambitious strategy is preferable considering the annual demand for heating. The demand for heating is reduced by 70 % compared to the as built situation. However, both the Façade and Ambitious strategies fulfil criteria as nearly zero energy heating renovation when including renewable heat production on site. The need for delivered energy is reduced by 65 – 85 % compared to the as built situation, see table 3. The Ambitious scenario with a heat pump installed has the least demand for delivered energy for heating. So, considering energy performance both renovation strategies are satisfactory as fulfilling the definition of a nearly zero energy renovation.

Other Performance indicators are moisture safety, robustness towards failure, maintenance and durability. Both strategies can be realized using traditional wood frame construction techniques with a ventilated wooden cladding(SINTEF Building and Infrastructure, 2010). However, in a thicker wall and roof construction, as in the Ambitious case, built in moisture will dry out more slowly, and it is important to prevent moisture from entering the wood frame construction in the retrofit period (Geving and Holme, 2010). The robustness towards moisture and defects depends on the skills of the persons executing the works. The Do it yourself homeowner lacking knowledge and skills should choose the most robust strategy considering moisture safety, and the Façade strategy may be a better choice. Regarding maintenance and durability the Ambitious strategy will involve an upgrade of all building envelope parts. The owners of Well kept houses focus on the technical performance of the building components and may prefer the Ambitious strategy.

Step 2 Economic Assessment

The life cycle cost evaluation shows that the Façade strategy gives a lower life cycle costs than the Ambitious scenario, see figure 2. The main reason is the higher investment costs for the Ambitious scenario. The Façade heat pump alternative gives lowest global cost over a 30 years ownership period (€ 81 000), while the Ambitious scenario with a heat pump is the most costly (€ 101.000). Less extensive energy effective renovation has also previously been found to be more cost effective than more extensive renovation (McKinsey & Company, 2009, Galvin, 2010). The payback time for the initial Façade and heat pump investment is 12 years, and the renovation may also be attractive from a strictly cost evaluation for homeowners with long perspectives on their investment. When establishing a score for the probability of homeowners finding the economic impacts attractive, the Façade strategy is rated positive for all homeowners and the Ambitious strategy can also be attractive for the Aesthetic homeowners as this group invest in upgrading their home(Risholt et al., 2012).

But it must be noted that the analysis in this paper is based on a nominal heating demand. The payback evaluation should be based on the measured heating of the house (Martinaitis et al., 2007). The calculations are also sensitive to the electricity and energy prices (Amstalden et al., 2007, Kragh and Rose, 2011, Jakob, 2006). Future price variations will affect the results. Increased government financial incentives for energy efficiency would also stimulate the market. If a market for energy efficient renovation is established, this will, over time, possibly lead to a reduction in prices that might favour ambitious renovation(Amstalden et al., 2007). It should also be noted that the cost calculations in this article is valid for the house model 'Block 180' and the received offers for renovation. Other suppliers, contractors and house models might give different investment costs.

Step 3 Usability assessment

Usability is linked to functionality and flexibility of indoor and outdoor spaces, see figure 3. There might not be big differences between the two strategies considering usability. But the Ambitious strategy includes indoor works and can be combined with more home improvements only resulting in low additional cost.

Step 4 Social assessment

The Aesthetics is an important home quality indicator (Gullestad, 1989, Støa, 1996) and is closest linked to the Aesthetic homeowner category(Risholt et al., 2012). The Façade strategy changes the visual appearance of the house less compared to the Ambitious strategy. The Aesthetic homeowner wishing to keep the qualities of their house may prefer the Façade strategy while the innovators of this category seeking modernization may prefer the Ambitious strategy.

Indoor comfort is a also a Social indicator(Martinaitis et al., 2007), see figure 3. The Ambitious strategy includes improved insulation of floors and roof as well as better air tightness than the Façade scenario and will result in warmer floor surfaces and less draught. The Well kept homeowners are focused on technical performance and gains from renovation. The better indoor comfort will be important for this category, favouring the Ambitious strategy.

The As built homeowner is not interested in renovation or does not have the resources to get the work initiated(Risholt et al., 2012).

Self involvement in planning and design is possible for both renovation strategies. In nearly zero energy renovation there is a need for special knowledge in energy planning. The project SuccessFamilies describes the gains from using professional project managers to assist the homeowner in renovation planning (Tommerup et al., 2010). The Do it yourself homeowner also wants to be involved in the execution of works. As discussed above, for this category it may be better to choose the less extensive Façade strategy to minimize the risk for moisture defects.

Regarding the retrofit process, both strategies are suitable for both a stepwise and a major renovation. The cost effectiveness of energy efficiency depends on the retrofit being done when the component is at the end of its lifetime(Martinaitis et al., 2007, Vanhoutteghem et al., 2011). The As built houses are in a poor technical condition and in need of major renovation (Risholt et al., 2012), while the Well kept houses are in a good condition and renovated in a stepwise process. A suitable process to prevent moisture damages and to improve indoor air quality would be to install balanced ventilation following improvements of the building envelope elements and installation of renewable energy production (Vanhoutteghem et al., 2011).

Step 5 Evaluate sustainability and repeating steps 1-4

The next step in the analysis is to go back to the performance and economy indicators. The annual energy savings are too small to make the more ambitious renovation of the building envelope cost effective. The Aesthetic innovators and the Well kept homeowners are the ones likely to prefer the Ambitious strategy due to its social impacts. The probability for the homeowners finding the two renovation strategies attractive are illustrated in figure 4. The question to evaluate is if the non-energy benefits of comfort, maintenance and aesthetics are that much better for the Ambitious strategy to justify the higher investment costs. The SuccessFamilies project has come to the conclusion that that this will depend on the individual homeowner and his resources and financial situation (Vanhoutteghem et al., 2011). This is also illustrated by the quote in the introduction of this article. The homeowner wants to install balanced ventilation to gain indoor comfort in winter. The installation is not economically motivated, but motivated by non-energy benefits(Mills and Rosenfeld, 1996).

This analysis shows that the homeowner category is decisive for the optimal zero energy renovation strategy in a sustainability analysis taking energy, economy and home qualities into account.

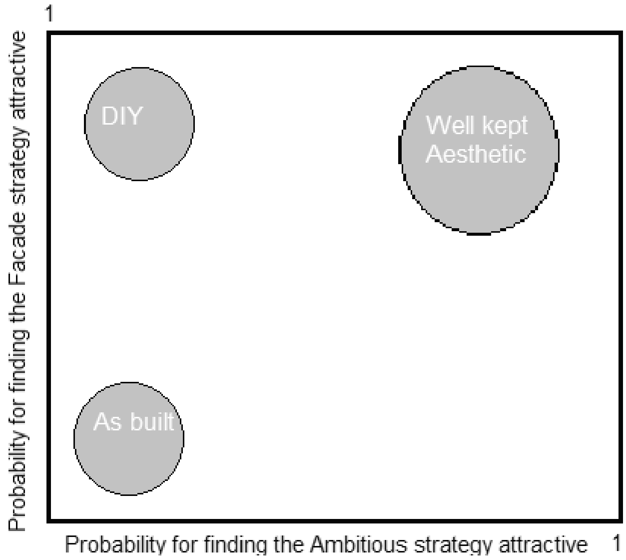

Figure 4 Different homeowner categories have different renovation preferences resulting in different probability for evaluating the zero energy renovation strategies as attractive

Conclusion

The homeowner decides upon renovation for privately owned dwellings. Market success for zero energy renovation of dwellings depends on homeowners' priorities for improved home qualities. Both quantitative indicators of environmental and economic performance and qualitative indicators of social aspects and usability are required when evaluating renovation of dwellings to enable homeowners to make sustainable choices.

Two strategies for nearly zero energy renovation of a single family house are analysed in this work. The Façade strategy includes new windows, adding thermal insulation on the exterior walls, and improvement of the air tightness of the building. The Ambitious strategy is an upgrade of the entire building envelope to Passive house energy standard. Both strategies require installation of balanced ventilation with heat recovery. Two alternatives for on site renewable energy production, a solar collector and an air-water heat pump, are analysed for both strategies. The renewable energy production covers from 30 to 45 % of the heating demand for the Façade strategy and from 40 to 45 % for the Ambitious scenario, resulting in an annual nearly zero energy balance.

An iterative method for sustainability analysis including energy and technical performance after renovation, lifecycle cost and homeowner preferences was proposed, and it established that the optimal choice of renovation strategy depends on the homeowner category. For the Do it yourself homeowner, the owner of a Well kept house and the Aesthetic homeowner that intend to keep the architectural qualities of their home the Façade renovation strategy might be the optimal choice. The Aesthetic homeowner wishing to modernize their home and also the owner of Well kept houses might prefer the Ambitious strategy. The Ambitious strategy is a more costly alternative, but homeowners do not base their decisions solely on a quantitative basis, also the qualitative preferences might be decisive.

The knowledge gained is that there are human factors that will influence the choice of renovation strategy for private homeowners. A decision guidance on renovation and technical solutions should be based on the resulting effects that are specific for each dwelling, the homeowner and the occupants(Henryeson et al., 2000). Nearly zero energy budgets for heating are possible with more or less energy efficiency and renewable energy production on site. The sustainable balance point between reduced energy demand and renewable energy production on site is best assessed in a multicriteria analysis that includes both qualitative and quantitative methods and data.

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7 DISCUSSION AND CONCLUSIONS

7.1 MAIN FINDINGS AND CONCLUSIONS

The results are presented and discussed in the papers 1 – 6, see sections 6.1-6.4. Ten main findings and conclusions are extracted from the papers and are listed below:

1. Dwelling renovation utilizing existing building technologies can result in substantial energy savings (paper 1). The thermal properties of the building envelope may be improved by external insulation, improved air tightness and energy efficient windows. For the house 'Block 180' built in the 1980s, façade improvement has higher impact on the heat loss than improvements of the roof or floor constructions (paper1). The windows' air tightness influences the overall air tightness of the building envelope (paper 2).

2. The energy use in a dwelling depends on the energy performance of the building envelope, the technical systems, the floor plan and the residents (paper 5). In a dwelling with low energy demand, the user loads dominate the energy budget (paper 1). A low energy demand may result from building envelope improvement (paper 1), from installing a ventilation system with heat recovery (paper 1), from installation of renewable energy production on site (papers 3 and 6) or from users minimizing the heating of the dwelling (paper 5).

3. A nearly zero energy budget can be realised with different strategies for renovation. Two nearly zero energy renovation strategies, Façade and Ambitious, are investigated. The Façade strategy includes upgrade of the thermal properties of the façade, installation of a ventilation system with heat recovery and renewable energy production. The Ambitious renovation strategy includes renovation of the whole building envelope to passive house performance, installation of a ventilation system with heat recovery and renewable energy production. For both renovation strategies, the annual energy demand for heating, lighting and appliances can to a significant extent be covered by on site renewable energy production , but where the higher heat loss for the Façade strategy is compensated with more renewable heat production on site (papers 3 and 6).

4. The more extensive building envelope renovation strategy, Ambitious, imply higher lifecycle cost than the less extensive upgrade. The Façade strategy with an air to water heat pump is the cost optimal alternative (papers 3 and 6).

5. Non-energy technical, functional, economic and legal requirements influence the energy efficiency renovation measures (paper 6). Windows are installed to let

daylight enter the room and to allow the resident view to the outside. Increased glass area may be required to fulfil daylight requirements after renovation (paper 2).

6. Norwegians spend huge sums of money on upgrading their homes. Upgrading kitchens and bathrooms are most common for houses built in the 1980s. Many of the houses have defects as moisture damages in basements and wet rooms. There is no correlation between the number of defects and the renovation status of the houses (paper 4). It is just as likely that a renovated house is in a poor technical condition as that it is in a good condition

7. Four categories of houses with common characteristics regarding technical condition and renovation status are identified. The categorization is based on a study of ninety-one houses built in the 1980s (paper 4):
   - The ‘as built’ houses have not been maintained, redecorated or renovated.
   - The ‘do-it-yourself’ houses have been redecorated and/or renovated by the homeowner and their social network, but the technical condition of the houses may not be good.
   - The ‘aesthetic upgrade’ houses have been redecorated and the visual qualities are upgraded, but the technical condition of the houses may not be good.
   - The ‘well-kept’ houses are maintained and renovated and are in a good technical condition.

8. Market success for zero energy renovation of dwellings depends on homeowners' priorities for improved home qualities. However, the homeowners face barriers such as lack of knowledge, lack of services and attractive products and poor advice from craftsmen when they want to do energy saving renovation measures (paper 5). The homeowners that succeed are either conscious consumers or they have the required knowledge from their profession (paper 5).

9. A sustainability assessment of dwelling renovation should include quantitative factors on energy savings and life cycle cost as well as qualitative factors on social and usability impacts of the renovation. A method from (Institute for Sustainability, 2012) is revised based on the main findings 1 – 8. The revised method is proposed as a tool for sustainability assessment (paper 6)

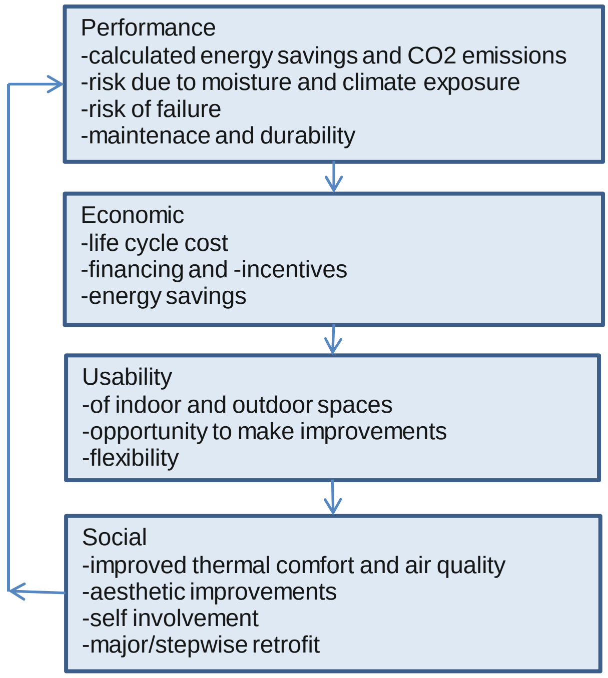

Figure 6.2 An iterative method for assessing sustainability of dwelling renovation based on (Institute for Sustainability, 2012) and studies of Norwegian homeowners

10. For privately owned dwellings, the optimal sustainable zero energy renovation strategy can be identified using energy performance, lifecycle cost and home qualities indicators. The optimal renovation strategy depends on the homeowner priorities for home quality improvements (paper 6). The 'As built' homeowners do not renovate. The 'Aesthetic' innovators and the 'Well kept' homeowners are the ones likely to prefer the Ambitious strategy due to its social impacts, while owners of 'Do it yourself' houses and the owners of 'Aesthetic' houses wanting to keep the qualities of their house are most likely to prefer the Façade strategy.

7.2 DISCUSSION

The results in Chapter 6 are already discussed in the six papers. The conclusions in the papers are listed in section 7.1. This section discusses how the findings relate to the research questions stated in Chapter 2 and how the gained knowledge influences the theory, practice and policy regarding energy efficiency and dwelling renovation.

One of the research questions is to investigate if it is possible to renovate a single family house to become a zero energy building. The findings in paper 3 show that it is possible to renovate a single family house built in the 1980s to become a net or a nearly zero energy building. The house studied is a large house and represent a worst case for zero energy renovation. The positive answer to the research question therefore implies that it should be possible for more houses to be renovated to a zero energy performance.

First considering a net zero balance after renovation, paper 3 is based on a theoretical study. In a real life situation, the net zero energy balance after renovation will be a combined result of reduced heat loss due to building envelope improvements, energy efficient ventilation, on site renewable energy production and reduced user loads. The maximum annual electricity output from the 98 m^2 solar cells presented in paper 3 is 8,600 kWh, representing a technical upper limit of how much electricity it is possible to produce onsite for the house Block 180. The number is based on no shading of the solar cell covered roof, and therefore the number may not be realistic in real life where trees and neighbouring buildings can shade parts of the roof.

The annual base load for five Norwegian households was found to be from 12,000 kWh – 15,000 kWh, see paper 5. This base load includes the energy demand for electrical appliances, ventilation and domestic hot water production. Subtracting 5,000 kWh for domestic hot water production (Mysen, 2008), this gives an annual electricity demand of 7,000 – 10,000 kWh for electrical appliances and ventilation. The electricity for lighting comes in addition to these numbers. The prerequisite for the net zero energy balance in paper 3, is an annual maximum electricity use of 5,400 kWh for appliances and ventilation and less than 3,000 kWh for lighting. This means that for all the five households in the study substantial measures are required to reduce the electricity specific loads if a net zero energy renovation should be realized. The net zero energy balance will therefore require investments in energy efficient appliances, LED lighting and control systems for operation of technical systems as well as a change in the residents' energy behaviour. These investments and efforts come in addition to the investments on building envelope upgrades and installation of ventilation and renewable energy production. Very high investment costs (paper 3), high electricity spending in the Norwegian households (paper 5) and technical limitations of electricity production on site (paper 3) document that currently, the net zero energy balance for the house 'Block 180' is very challenging in practice.

Regarding nearly zero energy renovation, the results in paper 3 and 6 shows that more than one strategy is possible. According to the findings in paper 1, thermal improvements of the façade are especially important to reduce the heating requirement for the house 'Block 180'. This research has focused on two strategies for renovating the building envelope, Façade and Ambitious, and five commercially available renewable heat producing technologies. The Façade strategy gives a higher annual energy need for heating and thus requires a higher on site heat production than the Ambitious strategy. But it is possible to achieve a nearly zero energy balance for both strategies (paper 3 and 6).

The theoretical analysis of the possible net and nearly zero energy renovation strategies in the papers are based on calculations according to standardised methods (Standard Norge, 2007d, Standard Norge, 2010b). As for the net zero energy renovation, it is also important to discuss the practical aspects of nearly zero energy renovation. In a real life situation both the electricity use and the total energy use in a dwelling are highly dependent on the residents. When the thermal properties of the building envelope are improved, the user loads including domestic hot water, electrical appliances and lighting dominate the total energy budget, see paper 1. Calculations according to the norms may therefore not be relevant for the real energy use because they are based on standardized values not taking residents and use patterns into account. Domestic hot water production is one example of this. NS 3031 and NS 3700 require that 29.8 kWh/m^2 is to be used to calculate the energy requirement for domestic hot water production (Standard Norge, 2007d, Standard Norge, 2010b). This gives an annual energy requirement of 8000 kWh for domestic hot water production for the house Block 180. The number is most likely much higher than what is realistic even for a large family. Mysen reports 5,000 kWh to be realistic for a family of five and the SINTEF Building Design sheet 553.121 state a value of 3,500 kWh for a Norwegian household of four persons (Mysen, 2008, SINTEF Building and Infrastructure, 2010). The space heating depends on the thermal properties of the building envelope and also on the indoor temperature. Some homeowners were found to prefer an indoor temperatures of 23^{o}C in the living rooms, while the nominal calculations use a temperature of 21^{o}C, see paper 5. The norms state that all rooms shall have 21^{o}C in the calculations, while in real life the residents keep bedroom temperatures lower in the heating season. The Norwegian Building Code (National Office of Building Technology and Administration, 2010b) requires calculations according to NS 3031 for Oslo climate, not the climate for the location where the building is constructed. NS 3031 calculations are thus valid for assessing the legal requirements, but are not a good tool for estimating the real energy load of the household. The nominal calculations may therefore not be relevant for the design of technical and heating systems. To be able to forecast a realistic real energy use for the residents and to dimension heating and ventilation, other calculation procedures are required. The energy analysis in this study is based on calculation according to norms and building regulations. A more detailed analysis taking the energy behaviour of users into account is not included. This is a limitation for the study and a possibility for further research on optimization of zero energy renovation strategies.

The research question related to economy is whether there are cost optimal strategies for zero energy renovation. The results from papers 3 and 6 indicate that the cost optimal strategy is the Façade strategy, where the nearly zero energy balance is achieved by high on site energy production. The extensive Ambitious renovation strategy gives very high investment costs for the building envelope upgrade, and the investments are not compensated by the annual energy savings. Another clear finding on cost is that the net zero energy renovation currently will require investments that make the renovation very unlikely. So of resent, there are practical, technical and economic barriers preventing net zero energy renovation.

The lifecycle cost calculations in papers 3 and 6 are based on a 2011 electricity price of 0.125 € and an annual price rise of 5%. The experienced 2012 electricity prices have been approximately half of the 2011 level (Statisktisk Sentralbyrå, 2012) and are much lower than the estimates in the lifecycle cost calculations. A lower energy price gives an even more favourable economic status for the Façade versus the Ambitious strategy. Future electricity and energy prices can not be predicted with a great accuracy because they depend on a multitude of national and international market factors.

Even though the Façade strategy is to be preferred considering cost, it is still not cost effective with a short payback period of three - five years. Cost effectiveness with such short payback times is one crucial factor for products that succeed in the mass market (Jakob, 2006 , Strandbakken, 2006, Enova, 2012). The Façade strategy discussed will only be cost effective for homeowners having large energy bills for heating. The calculations in papers 3 and 6 are based on a pre renovation energy use of 22,000 kWh for heating, while in paper 5 it was found that the investigated households had heating requirements of 11,000 – 20,000 kWh (assuming 3,000 kWh annually for lighting and 5,000 kWh for domestic hot water).

A third research question is how the homeowner priorities regarding home qualities influence the design of an attractive zero energy renovation strategy. Homeowners' priorities on dwelling renovation are described in papers 4, 5 and 6. The core finding presented in paper 6 is that there is a clear link between the different homeowner categories and the zero energy renovation strategy that the homeowner is likely to prefer.

The human factor in renovation has been characterized as a random factor (Sterner, 2011). This PhD research has showed that it is possible to identify homeowners with common characteristics regarding renovation preferences and priorities, limiting the random effect due to human nature. The knowledge gained on homeowner priorities give us a more predictable situation regarding decision making and attractiveness of renovation measures. However, the data in this research is only valid for houses built in the 1980s, investigating a limited number of 102 samples of a total number of 1.2 million Norwegian single family houses.

The homeowner priorities for home improvements are decisive for which zero energy renovation strategy is most likely to be preferred in practice. The knowledge gained is that the homeowner preferences should be included in zero energy renovation planning and design. There are human factors, cultural and individual differences that influence the home upgrade priorities and what is assessed to be attractive.

Another finding is that homeowners do not base their decisions on only cost effectiveness. The social and non energy benefits from renovation and energy efficiency might be the decisive factor. A cost calculation only includes quantifiable numbers. The calculations do not include indoor comfort, future less work hours for the homeowner in maintenance, visual upgrades or better indoor air quality. The energy performance and economic evaluation should therefore not be presented alone, but be a part of an overall analysis of energy savings, costs and gains. The homeowner can then base the renovation decisions on the presented positive and negative effects from the renovation to find a renovation strategy that fits the needs and wishes of the household. The sustainability evaluation method demonstrated in paper 6 can be used as a tool for assessment of domestic renovation and the results form the assessment can be used for presenting the energy savings, costs and benefits for the homeowner.

The practical impact of the findings on homeowners and decision processes are clearly that a successful renovation implies the use of different construction products, retrofit processes and renovation strategies for the different homeowners as well as for the different houses. Policy instruments as well as construction products and services ought to be tailored to the different segments in the market defined by the categories of houses and homeowners. The categorization can also make it possible for actors in the building industry to supply an assortment of different solutions for houses of a specific age and construction, with products and services meeting the preferences of each homeowner category. The homeowner could buy the solutions that fit for their home.

In the following, the findings' impact on policy instruments is discussed. The national and international ambitions to reduce the energy demand for operation of buildings is the background for this research. The Norwegian government has several policy instruments to accelerate energy efficiency and renovation rates.

The Norwegian Building regulations set requirements for normalized energy calculations for new buildings, but the current legal context for renovation is limited to requirements for energy performance of buildings undergoing major renovation. However, the findings presented in papers 4 and 5 show that most single family houses are upgraded in a stepwise process. In my opinion, the regulations ought to be revised to set requirements on building measures with a large impact on the energy use of the building. For the house 'Block 180', the upgraded façade and ventilation system is of great importance for the energy efficiency. The government states that there will be regulatory requirements for components to be used in renovation from 2015 (Kommunal- og regionaldepartementet, 2012). The only specific reference made is to windows. However, the energy saving potential of installing balanced ventilation with heat recovery and adding on thermal insulation to exterior walls should also be reflected in the future building regulations targeting houses with features similar to those of Block 180. And, since user behaviour and user loads are dominating factors of the energy use after renovation (papers 1, 5 and 6), the regulations could also take into account the installation of energy efficient appliances with a correlation to the requirements of the Ecodesign directive and energy labelling of appliances (European Parliament and The Council, 2009).

Paper 4 shows a renovation backlog for single family houses that were built in the 1980s. This can also be used for setting regulatory energy performance requirements for dwelling renovation. The results show that the houses built in the 1980s need renovation of the building envelope, where defects in the basements dominate. It is therefore likely that these houses will need a new drainage in the coming years. This is a window of opportunity for energy efficiency that could be reflected in the policy instruments making or urging homeowners to add on insulation to the exterior basement walls when they install a new drainage.

Legislative requirements are one policy strategy, and financial incentives such as green loans and economic support for energy efficiency investments are other policy tools. As discussed in Paper 5, the availability of reliable information is also a policy strategy that can contribute to accelerate the renovation rates. In Norway the National Office of Building Technology and Administration is responsible for building regulations, The Norwegian State Housing Bank is responsible for financing and the public enterprise Enova is offering subsidies for energy savings. Currently, there are no publicly available studies on the interaction and effects of the total available policy instruments. In my opinion, there is a need for a detailed study of the effect of possible policy instruments and how they work together to make sure that the better instruments are preferred and effectuated, if society is to achieve the national targets on energy savings.

The society needs to reduce the energy use for domestic purposes, while the homeowners are more neutral to energy savings (BarEnergy, 2011, Nair et al., 2010). The main research focus in a future study on policy instrument should be how to make homeowners decide to carry out renovation and energy efficiency and how to enable them to get the renovation done. Regulations can push the market, while financial incentives and information campaign can build awareness and attractiveness. At the same time I think it is unlikely that there will be a mass market for dwelling renovation if there is a lack of attractive construction products, services and skilled craftsmen.

8 RECOMMENDATIONS FOR FUTURE WORK

The results in Chapter 6 give knowledge on renovation, energy savings, cost and home improvements that make it possible to design better products, services and policy instruments. However, a PhD study is limited in time and resources. I therefore like to recommend some topics of special interest for further studies to gain more knowledge on zero energy renovation of single family houses:

1. This study focuses on houses built in the 1980s, the owners of these houses and the possibilities and effects of zero energy renovation. Houses built in other time periods might have additional demands for renovation, and the owners of these houses might have other priorities for home upgrades than the owners of the 1980s houses. This research ought to be supplemented with a study of houses built in the 1960s and 1970s, as these houses also are quite uniform in construction and architecture and represent a mass market for renovation and energy savings. The study should focus on what measures are most effective for energy savings and what measures are the more sustainable. The knowledge gained from the study can also be used to set effective legislative requirements for components and renovation measures.

2. The current practice in ambitious renovation projects is to design the renovation strategy in each case. But to meet the society's need for energy saving, there is a need for mass market renovation of single family houses. In such a situation, it should not be required to tailor the renovation strategy to every single case. The gained knowledge on energy behaviour from this study and other studies (Våge et al., 2010, Wigenstad, 2007, Strandbakken, 2006) should be used to develop design guidance tools based on real life use situations, user patterns and home quality preferences. The revised method for sustainability assessment suggested in this research can be used as a starting point for developing the tool. Such a design tool could give homeowners better guidance on suitable renovation strategies for their house.

3. As discussed previously, the user loads are highly important for the overall energy use when you reach a low energy performance after renovation. It should therefore also be evaluated in a lifecycle cost perspective, if the investment in energy efficient appliances and lighting has a shorter payback time than the investments in building and technical system improvement for similar energy savings.

4. One of the dilemmas discussed in paper 6 is the lifecycle cost versus non energy benefit. How will the individual homeowner evaluate the investment in non energy benefits such as aesthetic, indoor air quality and comfort? Further studies

are needed to get a better conclusion on this subject. One approach is to renovate pilot buildings to demonstrate visual qualities and other non-energy benefits from nearly zero energy renovation. The work could also verify if the suggested method for sustainability analyses in paper 6 is a suitable tool for sustainability analysis of dwelling renovation.

5. Another subject that needs further investigation is to study the potential effect of coordinated policy instruments. If the Norwegian government is to succeed in its goals on energy savings, policy instruments such as building regulations and financial incentives are needed to reach the required renovation rates. The study on policy instruments should also evaluate if the better strategy is to aim for massive scale renovation to a low energy standard or if it is a better strategy to aim for more ambitious renovation on a smaller scale.

6. The final subject suggested for further studies is to go deeper in the analysis of market barriers in dwelling renovation. A special focus should be on the role of the small contractor companies and local carpenters that are the ones actually doing renovation of single family houses. How can we facilitate a market and business change so that these actors become mediating actors in energy efficiency?

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