

# Method for planning extensive energy renovation of detached single-family houses



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PhD Thesis

Department of Civil Engineering  
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# PREFACE

This thesis is submitted as a partial fulfilment of the requirements for the Degree of Doctor of Philosophy at the Technical University of Denmark, Department of Civil Engineering. The thesis is the result of approximately 3.5 years of full time study over a period of 5.5 years in the field of the energy renovation of single-family houses in Denmark.

I would first like to thank my main supervisor, Professor Svend Svendsen, for his indispensable support and interest in my project, and for always being constructive and believing that it would be successfully completed. I also want to thank my co-supervisor Associate Professor, Alfred Heller, for his useful comments and ability to see the big picture. In addition, I would like to thank Lawrence White from the Language Support Centre for his always positive and tireless work to improve my writing.

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And I would like to thank my friends for their continued friendship; it means a lot to me that you are still there, even though I may have been somewhat absent lately. I would also like to thank my amazing family for their interest and support in my project. I would especially like to thank the babysitting grandparents for their love and attention to my little girls while their mother was busy.

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Matilde Grøn Bjørneboe

Kgs. Lyngby, April 21<sup>st</sup> 2017

# ABSTRACT

It has long been a political aim to reduce the emissions caused by energy consumption, and in Denmark politicians aim to make Denmark a society independent of fossil fuels by 2050. To achieve this, it is necessary to increase sustainable energy production and reduce energy consumption. This will take time, so both areas must be considered already now, but it will be beneficial to work on reducing the consumption before the sustainable energy supply is fully developed, so that we can avoid expensive over-production.

Some 30% of the total energy consumption in Denmark takes place in households, and 22% occurs in single-family houses, making this the largest single contributor to the total consumption after road transport (DEA, 2015a). There is a large potential for achieving energy savings in this sector, especially among the large number of single-family houses built in the 1960s and 1970s. Many of these were built before the introduction of actual regulations for energy consumption in buildings, and many will soon need considerable renovation due to their age.

However, despite the potential for achieving savings and updating these houses built about 40-60 years ago, the renovation of the building stock is proceeding very slowly. This is partly due to problems with the process, in which the initiative rests very much with the house owners, and partly due to barriers to renovation that are currently unaddressed by policy makers.

One of the problems addressed in this thesis is the process. In the hope that this could be improved, the use of a One-Stop-Shop (OSS) was investigated and tested. With an OSS, one contact person guides the house owners through all five phases of renovation: initial planning, thorough analysis, deciding on specific solutions, implementation, and verification through measurements. Although the case study suffered from a very high dropout rate, one renovation was successfully completed, and a second followed the project until the start of the fourth phase. While the study did not find evidence that the use of an OSS concept would motivate people to renovate, it did find that the use of this approach produced a better renovation with a larger energy saving. The initial evaluation helped the house owners identify a maintenance backlog, and the use of an independent advisor helped ensure quality throughout the process.

Renovations are too often carried out for just one purpose: maintenance, to update functions or to reduce energy consumption. But a lot can be gained by combining these efforts, which can reduce expenses for planning and execution and avoid doing things twice. Research for this thesis demonstrated this approach by carrying out a renovation based on maintenance, but including the owners' wishes for functional improvements and better than mandatory energy improvements. The

renovation resulted in increased comfort, a reduction of 53% for heating, and an increase in the value of the house corresponding to 77% of the investment.

There are a lot of barriers that discourage people from embarking on a renovation, and one way to deal with these barriers is through targeted policy. The research created an overview of current policy in this field in Denmark and compared it with the known barriers and motivations, which were collected in a framework to make it possible to identify the areas where current policy falls short. Four points in need of improvement and attention were identified: focus, finance, plans and regulation. The focus must be moved to improving comfort instead of energy renovation as an investment, because this is doing the field a serious disservice. There is a need for more financial support in the form of cheap loans and non-symbolic subsidies, which can overcome the barrier of lack of finance and motivate more extensive renovations. House owners should receive long-term renovation plans for their house, which inform them of their maintenance backlog and inspire energy improvements. And finally, it will be necessary to use regulation to reach those who are not planning to renovate. This could be done for example by setting a maximum allowed energy consumption per m<sup>2</sup> in houses, though this would have to be backed up by subsidies to avoid creating major social imbalance.

# RESUME

Det har længe været et politisk mål at reducere udledningen af drivhusgasser bl.a. fra energiproduktionen, hvilket har ledt til et mål om at gøre Danmark uafhængig af fossile brændsler i 2050. for at opnå dette er det nødvendigt både at øge produktionen af vedvarende energi og at mindske energiforbruget. Det er en langsom proces, så det er nødvendigt at kigge på begge områder allerede nu, men det er vigtigt at nå målet om at reducere forbruget inden man er færdig med at udbygge energiproduktionen, da man ellers kan risikere dyr overproduktion.

Ca. 30 % af det totale energiforbrug i Danmark finder sted i husholdninger, og hele 22 % i enfamiliehuse, hvilket er det største enkeltbidrag udover vejtransport (DEA, 2015a). Der er et stort potentiale for at finde besparelser i denne sektor, specielt mht. de mange enfamiliehuse der blev bygget i 60erne og 70erne. Mange af disse er bygget før der blev lavet egentlige regler for energiforbruget i bygninger, og i kraft af deres alder nærmer mange af dem sig en større renovering.

Men på trods af det store potentiale for at opnå besparelser og opdatere de efterhånden halvgamle huse, så går det kun langsomt fremad med renoveringen. Dette er til dels pga. problemer med processen, hvor initiativet ligger næsten udelukkende hos husejeren selv, samt pga. barrierer der i øjeblikket ikke bliver imødekommet igennem politiske tiltag.

Et af de problemer der ligger til grund for denne afhandling er processen. I håb om at denne kunne forbedres er brugen af en såkaldt One-Stop-Shop (OSS) blevet undersøgt og testet. I en OSS har husejeren en kontaktperson der hjælper dem igennem alle 5 faser af processen; indledende evaluering, grundig analyse, vælge løsninger, udførelse samt opfølgning og verificering gennem målinger. Selvom projektet var ramt af meget stort frafald, lykkedes det at gennemføre en renovering til enden og yderligere én der kom gennem hele processen frem til udførelsen. Studiet kunne ikke påvise at brugen af OSS motiverede folk til at påbegynde renovering, men fremgangsmåden resulterede i en bedre renovering med en større energibesparelse. Den indledende evaluering fik husejer til at opdage et vedligeholdelses efterslæb, og brugen af en uafhængig vejleder hjalp til at bibeholde kvaliteten gennem hele processen.

Alt for ofte er en renovering kun baseret på ét formål, enten vedligehold, opdatering af husets funktioner eller energibesparelser. Men der kan være store fordele ved at kombinere disse og på den måde reducere udgifter til planlægning og udførelse samt undgå dobbeltarbejde. I denne afhandling blev denne tilgang demonstreret, ved at udføre en renovering baseret på vedligehold, men som stadig inkluderede funktionelle forbedringer og energiforbedringer udover lovkrav.

Resultatet af renoveringen var bedre komfort, en reduktion i energiforbruget til opvarmning på 53 %, og en værdistigning i huset svarende til 77 % af investeringen.

Der er en række barrierer der afholder folk fra at gå i gang med en renovering. En måde at imødekomme dette problem er gennem målrettet politik. Ved at danne et overblik over de nuværende politiske tiltag på området og sammenligne dem med kendte barrierer og motivationer er det muligt at identificere områder hvor der kræves en større indsats. Der blev fundet fire områder der havde behov for ekstra opmærksomhed: fokus, finansiering, planer og regulering. Der er behov for at flytte fokus over på de komfortforbedringer der kan opnås. I dag er fokus næsten udelukkende på selve energirenoveringen som en investering, hvilket er at gøre området en bjørnetjeneste. Herudover er der en behov for at tilbyde mere finansiel støtte i form af billige lån eller reelle tilskud, der kan hjælpe folk der ikke har råd til en større renovering. Det kunne være gavnligt hvis husejere havde en langtidsplan for hvordan deres hus burde blive renoveret for at blive vedligeholdt, så man undgår vedligeholdelseefterslæb og giver inspiration til energiforbedringer. Og sidst men ikke mindst, vil det være nødvendigt at bruge lovgivning hvis man skal nå dem der ikke har planer om at renovere. Det kunne f.eks. være i form af et loft for hvor meget energi et hus må bruge pr. m<sup>2</sup>. Her er det dog meget vigtigt sideløbende at lave støtteordninger, så man ikke skaber en stor social slagside.

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# ABBREVIATIONS

BEA	Building Environmental Assessments
BB	BedreBolig (A Better Home), a Danish energy renovation scheme
BBR	Register of Buildings and Homes in Denmark
CCE	Cost of conserved energy, the cost of saving 1 kWh [DKK/kWh]
DACC	Danish Association of Construction Clients
DEA	Danish Energy Agency
DIY	Do-it-yourself
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
EU	European Union
GI	Landowners' Investment Foundation
LCA	Life-cycle assessments
OSS	One-Stop-Shop
PV	Photo-voltaic (solar panels)
SFH	Single-family houses built in Denmark in the period between 1960 and 1980

# 1 INTRODUCTION

For many years, it has been a political goal to reduce energy consumption and to increase the share of the production covered by sustainable sources with a view to reducing the human impact on the climate. In Denmark, 22% of all energy consumption takes place in single-family houses, which makes this the largest single contributor after road transport (Bjørneboe et al., 2017; DEA, 2015a). Most of the single-family houses in Denmark were built during the period from 1960 to 1979. Many of the 450,000 houses from this period are in need of renovation due to their age, and although they may not be the most energy-consuming houses in Denmark, their sheer number makes this one of the housing segments with the highest potential for energy savings. However, despite the potential, the renovation of this segment is only proceeding slowly.

## 1.1 Aim

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This study focuses on developing methods for improving and increasing the number of renovations of Danish single-family houses, taking the typical single-family houses built during the 1960s and 1970s as a specific case.

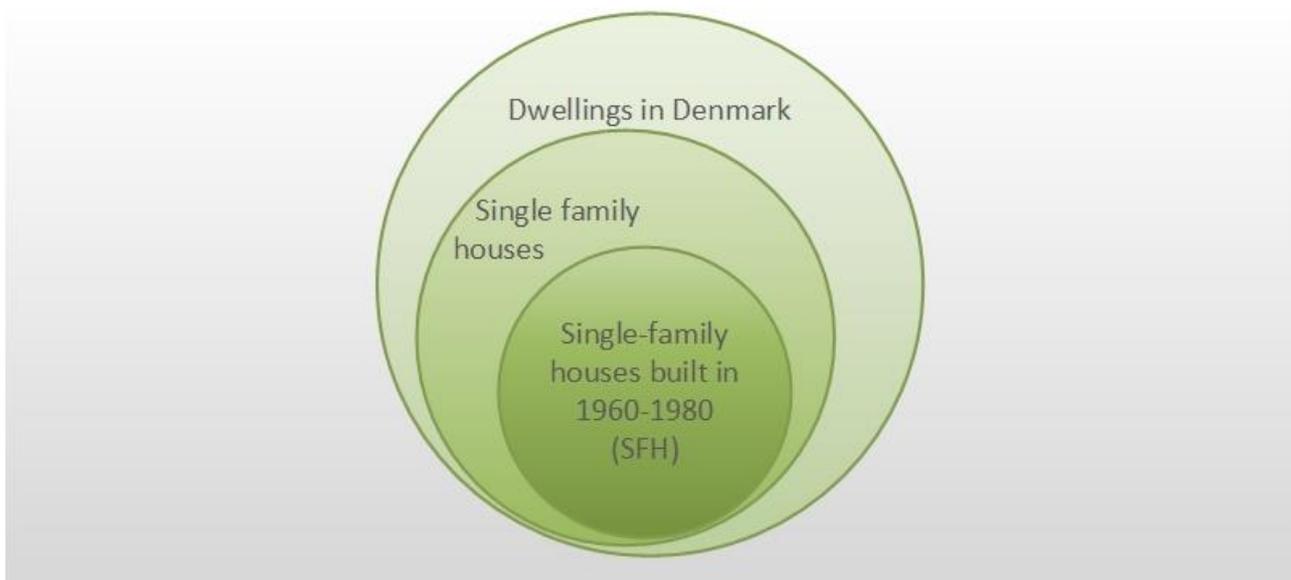
Although there are many good reasons and solutions available for increasing the energy efficiency of existing single-family houses, very few houses receive major renovation due to barriers and lack of motivation. The aim of this project was to study the barriers, incentives, and the process of renovation to identify possible improvements in public policy. The research included carrying out renovation on case houses to evaluate the process and its complications in real life.

## 1.2 Scope

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The scope of this thesis is limited to the renovation of single-family houses built in Denmark during the period 1960–1980, see Figure 1. Nevertheless, many of the findings will also be applicable for other owner-occupied houses and locations.

The research did not go into depth on the question of whether to renovate or replace, because the main point was to study renovation. The subject is, however, briefly discussed in section 2.3.2 page 30.



*Figure 1 - Scope of the study is single-family houses built in 1960-1980. The size of the circles is not representative of the number of buildings in each group.*

## 1.3 Hypothesis

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This study is based on one main hypothesis (H), which is further divided into three sub-hypotheses (SH), see Figure 2. For all these, the research object is limited to Danish single-family houses and the process of renovation. This limitation is implicit in the following statement of the hypothesis to avoid it becoming too long and unclear. The sub-hypotheses lead to the research questions. The work carried out to answer these questions is described in Section 3 of this thesis and in Papers I-III, in the appendix to this thesis.

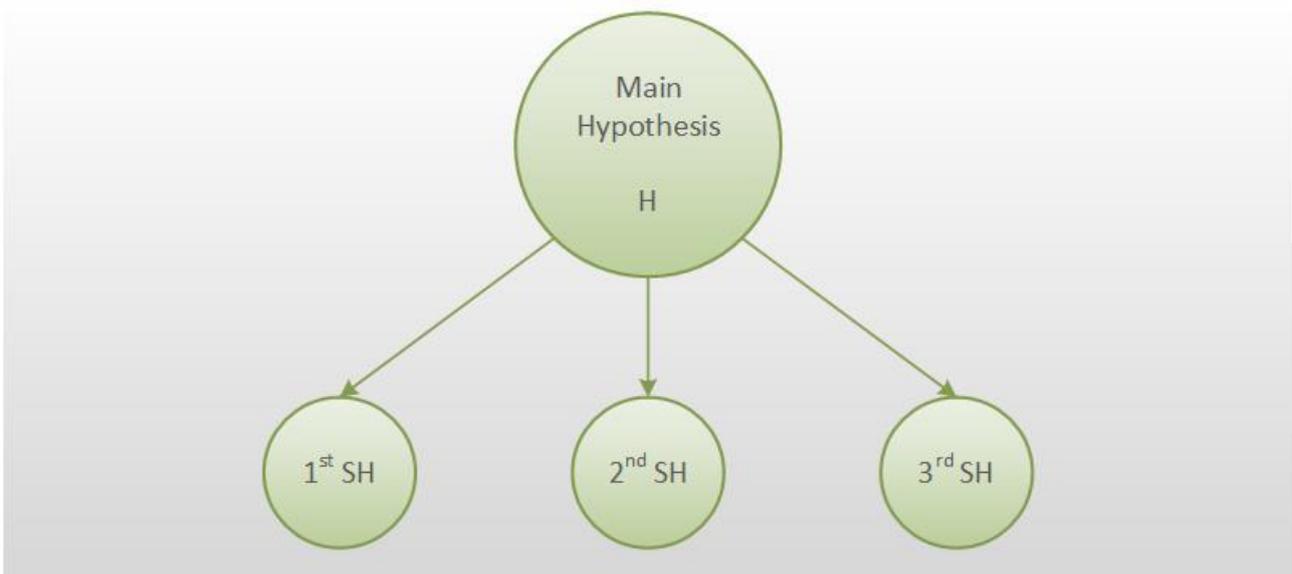


Figure 2 – The main hypothesis H is further divided into three sub-hypotheses (SH)

**H:** *The number and level of energy renovations of Danish single-family houses may increase if the process of renovation is improved to motivate house owners to act and policies are adopted to remove barriers.*

This overall hypothesis is decomposed to the following three sub-hypotheses:

**1<sup>st</sup> SH:** *The use of a One-Stop-Shop concept to guide their decision-making will motivate house owners to add energy renovation components to comfort or maintenance renovations, and their house will receive a more energy-efficient and extensive renovation than with an unsupervised renovation.*

In this context, an unsupervised renovation refers to a renovation where the house owners include necessary maintenance and comfort improvements, e.g. a new kitchen, with no intention of

including more energy improvements than required by the regulations. In this way, synergetic savings are lost and energy efficiency is not improved.

**2<sup>nd</sup> SH:** *Energy consumption for heating can be significantly reduced if energy efficiency work is carried out together with maintenance renovation to update design and functionality in accordance with the house owners' wishes – and it can all be done within a feasible budget.*

A significant reduction in this context is a decrease in the energy consumption for heating of at least 50%. The energy efficiency work refers to improvements that go beyond those required by the Building Regulations (Danish Transport and Construction Agency, 2015) when renovating.

**3<sup>rd</sup> SH:** *The documentation of barriers and motivators for house owners to initiate energy efficiency improvements on their house can identify deficiencies in current Danish policy, so that relevant recommendations for improvements can be made.*

### 1.3.1 Research Questions

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#### 1.3.1.1 1<sup>st</sup> Research Question

*Will the use of the One-stop-shop-concept improve the process of renovating and result in better renovations with a lower energy consumption because the house owners are guided through the process?*

The work on answering this research question is described in Section 3 Part I – Decision-making and the renovation process, and in Paper I in the appendix:

Bjørneboe, M. G., Svendsen, S., and Heller, A. (2017). "Case study: Using a One-Stop-Shop concept to guide decisions when single-family houses are renovated." *Journal of Architectural Engineering*.

The paper describes a case study on the process of an extensive renovation of a Danish single-family house, where a One-Stop-shop (OSS) concept is used to guide the decision-making of the house owners. The study found that using an OSS concept is not enough in itself to motivate people to renovate, but its use has probably helped to expand and improve the renovation.

#### 1.3.1.2 2<sup>nd</sup> Research Question

*When a renovation is based on necessary maintenance and includes energy improvements and functional upgrades, is it possible to improve the house and reduce the energy consumption for heating by 50% within a feasible budget?*

The work on answering this research question is described in Section 3 Part II – Result of a renovation, measurements and simulations, and in Paper II in the appendix:

Bjørneboe, M. G., Svendsen, S., and Heller, A. (2017). "Evaluation of the renovation of a Danish single-family house based on measurements." In press, *Energy and Buildings*.

The paper describes a case study in which a house was renovated with regard to durability of building elements, functional improvements, and reducing heating energy consumption. The energy consumption and indoor climate was measured for a year before and after the renovation, and the results were analysed and compared to dynamic simulations. The house achieved a more comfortable indoor climate and a saving of 53% on the energy consumption for heating. The house increased in value by an amount corresponding to 77% of the investment.

### 1.3.1.3 3<sup>rd</sup> Research Question

*Can documenting the known barriers and motivators for energy renovation be used to identify shortcomings in current schemes, leading to concrete suggestions for improvements?*

The work on answering this research question is described in Section 3 Part III – Policy to support renovation of houses, and in Paper III in the appendix:

Bjørneboe, M. G., Svendsen, S., and Heller, A. (2017). "Initiatives for the energy renovation of single-family houses in Denmark evaluated based on barriers and motivators." Submitted for peer-review.

The paper collects the acknowledged barriers and motivators for the energy renovation of homes found in the literature and puts them into in a framework. Danish initiatives that are currently effective in the field are mapped and evaluated in this the framework. This makes it possible to identify gaps in current policies, and on this basis and experience from other countries, four suggestions for improvements are made. These are making relevant renovation plans, providing a lot more financial support, putting the focus on non-energy benefits rather than energy renovation as an investment, and introducing regulations on the maximum allowed energy consumption.

## 1.4 Structure of the thesis

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Section 1 of the thesis contains the introduction, the hypothesis, and the research questions to be investigated in this thesis. The background and state of the art for the study is described in Section 2, which presents the motivation for investigating this subject, its current status, and methods in the field. Section 3 contains an overview of the investigations carried out to answer the research questions and evaluate the hypothesis. Each of the three parts in Section 3 describes work to answer one of the research questions. The work described in this section is also the content of the three papers, which can be found in the appendix. Section 4 contains a discussion of the results obtained during the investigations, and section 5 concludes on the work and the hypothesis. Finally, section 6 presents perspectives and recommendations for future work.

## 2 BACKGROUND

### 2.1 Motivation

#### 2.1.1 Political targets

The European Union (EU) has a priority to reduce the energy consumption spent on heating and cooling, and to make the remaining supply sustainable (EU Commission, 2016). The three main goals are to reduce the necessity for energy imports, thereby reducing dependency; to achieve economic savings for households and businesses; and to meet the commitments to reduce the greenhouse gas emissions of the EU agreed within the United Nations Framework Convention on Climate Change (UNFCCC) at the COP21 (Conference of the parties) in Paris (United Nations Framework Convention on Climate Change, 2016, 2015).

The energy strategy for the EU was originally formulated in 2007 and has been expanded in the following years. To achieve the goals of security of supply, competitiveness, and sustainability a number of targets for the EU as a whole were established, see Table 1.

*Table 1 – EU energy targets (European Union, 2017)*

EU ENERGY TARGETS			
Year	2020	2030	2050
Reducing greenhouse gas emission (compared to 1990)	20%	40%	80–95%
Energy from renewable sources	20%	27%	
Energy efficiency improvement	20%	27–30%	
Electricity interconnection (infrastructure to transport electricity within the EU)		15%	

As an EU member country, Denmark must contribute to meet these goals. However, in Denmark there is a political wish to push the goals further. This could be beneficial, not only because it would give the country a further edge with regard to independence and sustainability, but also because of the possibility of gaining new knowledge and finding new solutions that can be exported to other countries later.

In 2012, a political agreement was made for the Danish energy policy during the period 2012–2020 (Danish Government, 2012). In addition, the government set goals that would mean a reduction in

## 2 Background

greenhouse gas emissions of 35% by 2020; to cover all electricity and heat supply using renewable sources by 2035; and to be completely free of fossil fuels by 2050 (Danish Government, 2011). Since then, the government has changed, and the goals have been modified, but it remains a goal to become independent of fossil fuels by 2050 (DEA, 2016a).

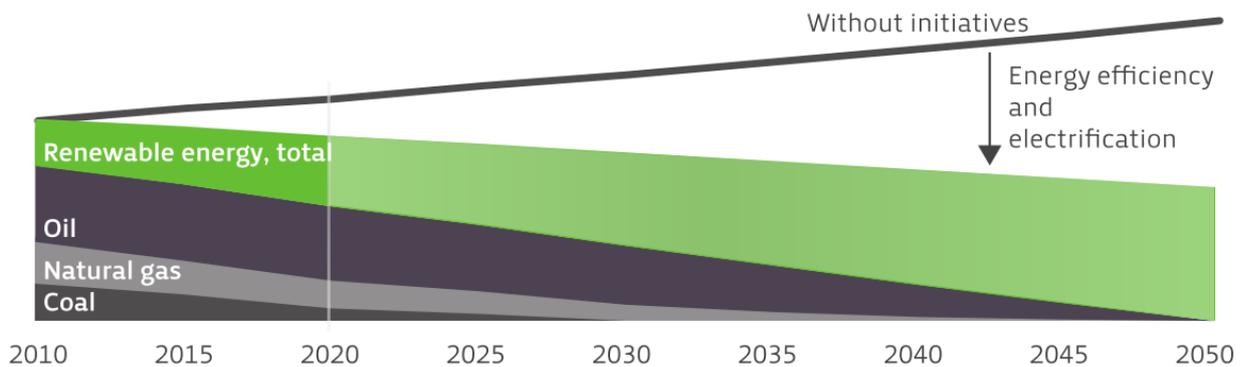


Figure 3 – Illustration of the energy consumption up to 2050 as pictured by the Danish Government (2011)

To become independent of fossil fuels, it will be necessary to find a balance between increasing the production of sustainable energy and reducing the total energy consumption, see Figure 3. After transport, households are the most energy-consuming sector, and more than 20% of the total energy consumption in Denmark takes place in single-family houses (DEA, 2015a). The most dominant types of single-family house in Denmark are the many houses built in the period 1960–1980. This particular group of houses (in this report referred to as SFH) are the main focus of this project.

### 2.1.2 The renovation potential

If houses are not maintained, they will deteriorate over time and thereby lose their function and value. So it is not just a question of postponing an investment, it can also be a case of creating a maintenance backlog, eventually resulting in larger expenses for restoration. According to DACC and GI, there was a maintenance backlog of about DKK 27 000 million (about EUR 3 6000 million) in the stock of Danish single-family houses in 2011 (DACC and GI, 2011).

In a report mapping the stock of single-family houses and their owners, SBI Danish Building Research Institute et al. (2016) makes a rough estimate that at least 78% of single-family houses in Denmark are either in need or very much in need of renovation. This figure includes 26% where there are significant challenges, such as a lack of finances. Many sources back up the statement that there is a large potential for energy renovation in SFH (DEA, 2014; Gram-Hanssen, 2014; Kragh and Rose, 2011; Vanhoutteghem and Rode, 2014; Wittchen, 2009).

Tommerup and Svendsen (2006) calculated the savings achievable in a typical SFH. They estimated that the initial heating consumption of 167 kWh/m<sup>2</sup> a year could be reduced by 13–75% depending on the scale of the renovation. The least ambitious renovation was just improving the roof insulation, and the most ambitious extended to improved windows, external wall insulation, and ventilation with heat recovery.

Kragh et al. (2010) produced a report estimating the amount of energy that would be needed to supply buildings in Denmark in 2050. The report estimated the current energy consumption in buildings of all types and ages. For example, the average energy consumption in the SFH<sup>i</sup> in 2010 was estimated to be between 111 and 136 kWh/m<sup>2</sup> a year, depending on whether they were built late or early in the period. Since they make up about 17% of the total built area in Denmark (based on data from BBR, an official Danish database of buildings, presented by Kragh et al. (2010)), this is a significant place to search for possible reductions in energy consumption. The report (Kragh et al., 2010) estimates the total consumption in the SFH to be 27 665 TJ a year, corresponding to 17% of the total consumption in buildings. They introduce 3 scenarios for the renovation of the building stock. Here they use varying percentages of renovation implemented for each major building element, ranging from 50% (scenario A, one in two houses receive external wall insulation) to 100% (scenario C, all houses has windows replaced) for all buildings where the current thermal transmittance is below a certain value. Using this method, they find a saving potential in the SFH of 46-66 %, depending on the scenario. In total for all building types and ages, the least ambitious scenario would bring the building stock up to the level of new houses in 2010, and reduce the total energy consumption in buildings by 52%, whereas the most ambitious would reduce the consumption by 73%. All 3 scenarios show a potential for a significant contribution to the reduction of energy consumption in the building stock by 2050.

Another report (SBI Danish Building Research Institute, 2016) presents a number of renovation scenarios for the Danish building stock on the basis of different assumptions concerning regulation in the field. The scenarios range from 'business as usual' to levels of compliance with the regulations and strengthening the requirements in the building regulations. They estimate energy savings ranging from 24.3% to 35.2% across the whole building stock.

### 2.1.3 Energy performance gap and the Rebound effect

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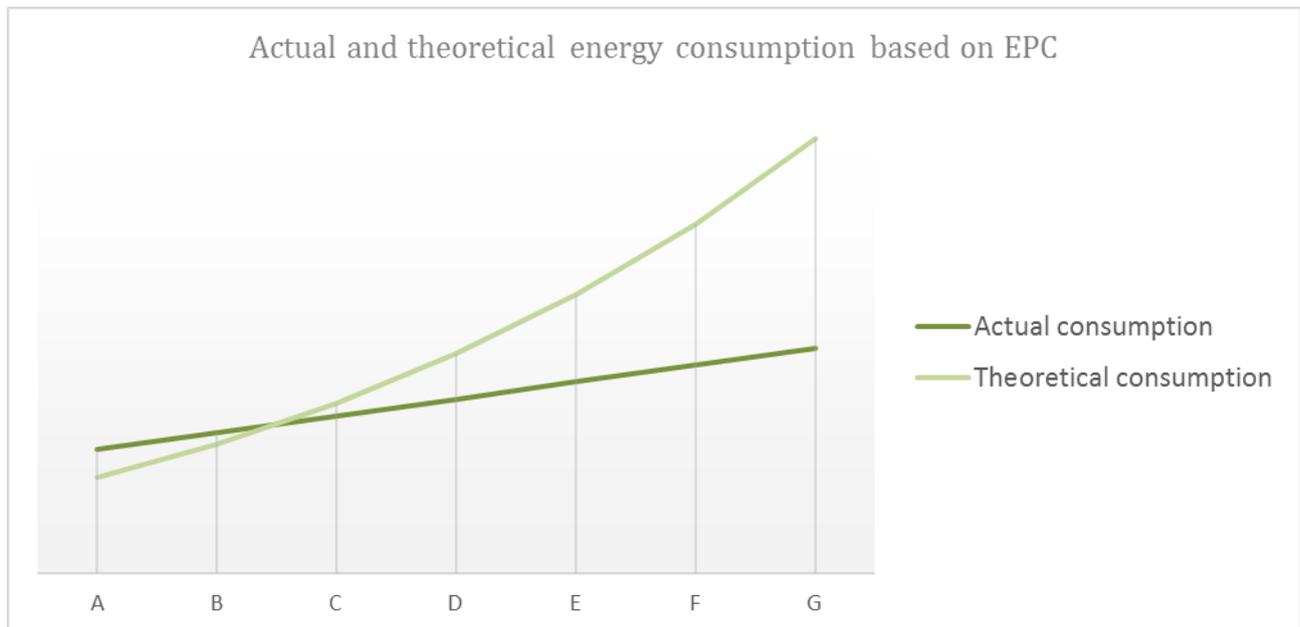
It is however, not always straight forward to estimate the energy saving after renovation. There are often large differences between the energy consumption found through simulations and what is achieved in reality. This difference is known as the Energy Performance Gap (Burman et al., 2014;

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<sup>i</sup> The numbers in (Kragh et al., 2010) are based on a different division of the houses based on age, which is why the SFH here only covers the houses build in the period from 1961-1972 and 1973-1978.

## 2 Background

Calì et al., 2016; Galvin, 2014). It can be a very big problem on a national scale, because it makes it very difficult to achieve the energy-saving goals set on the basis of potential savings according to simulations and calculations. Figure 4 shows an estimation of the difference between the actual and the theoretical energy consumption based on EPC rating. The estimation is made on the basis of results from a study in the Netherlands (Majcen et al., 2013).



*Figure 4 – Estimation of the actual and theoretical energy consumption of houses based on their EPC rating. Inspired by Majcen et al. (2013).*

One reason for this difference is the rebound effect, which is caused by changes in user behaviour, whereby the potential energy saving is instead used to increase comfort (Audenaert et al., 2011; Galvin and Sunikka-Blank, 2013; Vivanco et al., 2016). Often houses with a bad EPC rating will have a lower energy consumption than calculated, because people compensate for the large heat loss by maintaining a lower temperature (e.g. 19°C) and maybe not heat the whole house all the time. In houses with a good EPC rating, it is easy to keep a comfortable temperature in the whole house, which is why people may heat it to a higher temperature (e.g. 22°C) than the standard value (e.g. 21°C) used in the calculations. While these temperature differences can have a significant impact on actual energy consumption, they can be difficult to predict, because people react differently to the same situation. In a study featuring the renovation of a Danish multi-storey building, the space heating consumption was found to vary by a factor of 80 between apartments, due to the differences in occupant behaviour (Harrestrup and Svendsen, 2015).

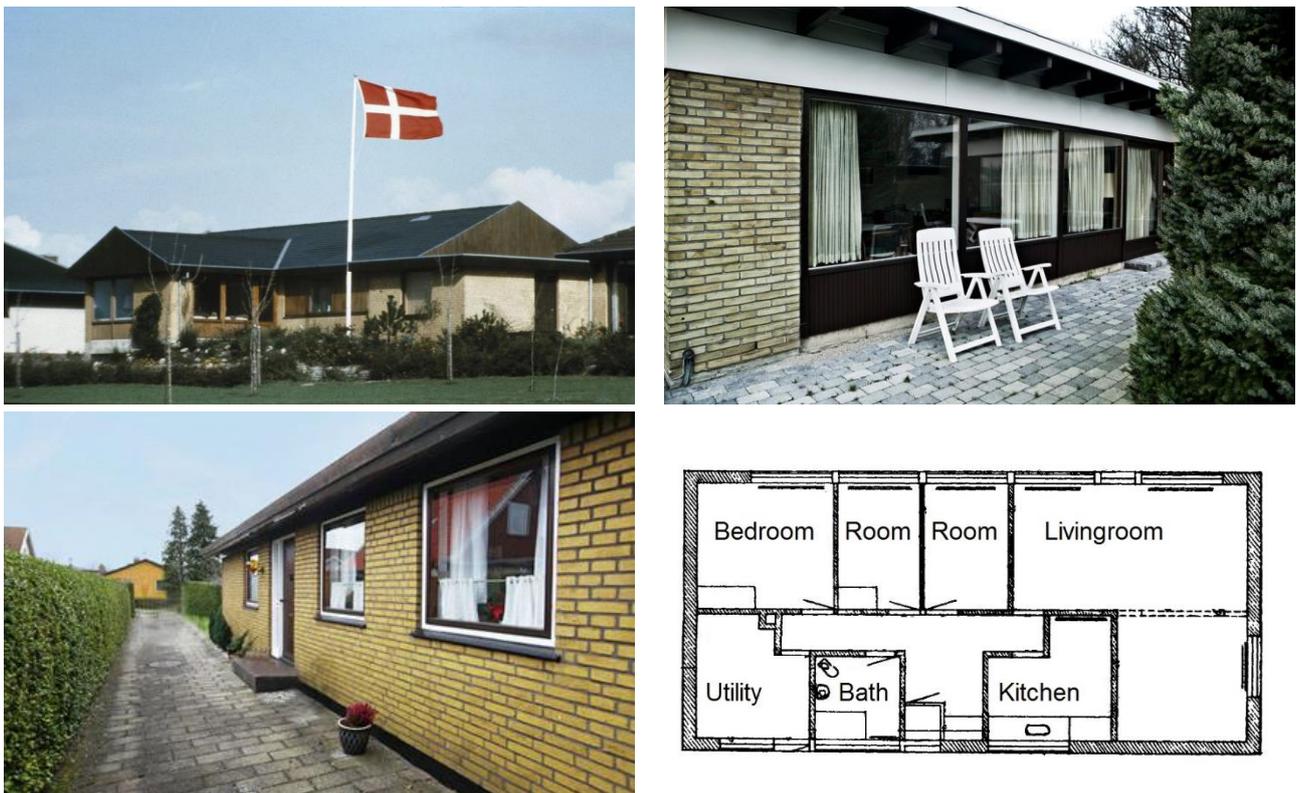
From one perspective, the rebound effect is simply a solution for house owners who used to live in cold houses. But it can also be a problem. When a policy scheme includes solutions for financing

energy renovations, they often include a degree of “Pay-as-you-save”, where the savings on the energy bill are used directly to cover the expenses of the renovation. However, this is a problem, if the saving predicted is much larger than the actual saving achieved, so that the saving is unable to cover the cost. The difficulty in predicting the saving can also cause people to lose faith in energy renovation, preventing them from starting a renovation at all, because they stop believing they “work” (Tænketank om Bygningsreovering, 2012).

## 2.2 Status

### 2.2.1 Danish single-family houses built 1960–1980 (SFH)

The history of the Danish single-family houses from 1930–1980 is described by Bolius (2004). During the 1960s there was wealth and prosperity in Denmark, enabling a lot of people to move out of the city centre and into their own house in one of the newly built neighbourhoods. Several standard-house building companies offered pre-drawn houses at a fixed price. In the period from 1960–1980, about 450 000 houses were built in Denmark, corresponding to the amount built during the previous 100 years. However, the large increase in building projects created a need for increased efficiency and simple solutions to reduce labour intensity and construction time. As one example, houses began to be built with a loadbearing back wall of wood or light concrete blocks, and prefabricated brick elements were used as facing to give the appearance of a brick house. Many other elements were also being prefabricated for the houses, such as windows and doors.



*Figure 5 – Examples of typical houses from the period and a typical layout of an original house. Pictures from (Bolius, 2015) and (DEA, n.d.). Layout from current project.*

The houses built during this period (SFH) have many similarities, see Figure 5. The house is usually one storey high (late in the period, some houses were built with 1½ storeys) and very few have a

basement. The roof was double-slanted with an angle of 25–30 degrees (in the early period some houses were built with a flat roof covered in asphalt roofing). The early houses of the period were about 100 m<sup>2</sup>, while the houses built during the 1970s had an average size of about 140 m<sup>2</sup>. Some of the smaller houses have later been extended. The houses usually have one side with small windows, one or two entrance doors, a utility room, kitchen and bathroom. The other side is more open, with large windows towards the garden. This is where the main occupied spaces are, such as bedrooms and living rooms. In the other direction, the house was often split into a 'day-zone' with kitchen and living room, and a 'night-zone' often with a small L-shaped hallway, bathroom and the bedrooms.

The constructions and materials were often based on prefabricated elements (Tommerup et al., 2015). The roof was usually clad with tiles or fibre-cement boards. The façades were brick on the outside and with bricks, concrete or a wooden construction on the inside. The outside brick often only went to the top of the windows, the rest was wood. Many houses also had areas with a light wooden wall construction, especially in connection with the windows. From 1960, it became more common to use double insulating glazing units. Ground slab and foundation were most often made of concrete. In some houses from this period, slag was used as a filling under the concrete in the ground slab. Later this turned out to be a big potential problem, because slag expands if it gets wet, pushing the wall foundations out, and compromising the stability of the whole house (BYG-ERFA, 1997).

## 2.2.2 Renovation of SFH

The renovation of a house can be divided into 3 types, depending on the purpose. An overview of the three renovation types including examples of improvements is shown in Figure 6.

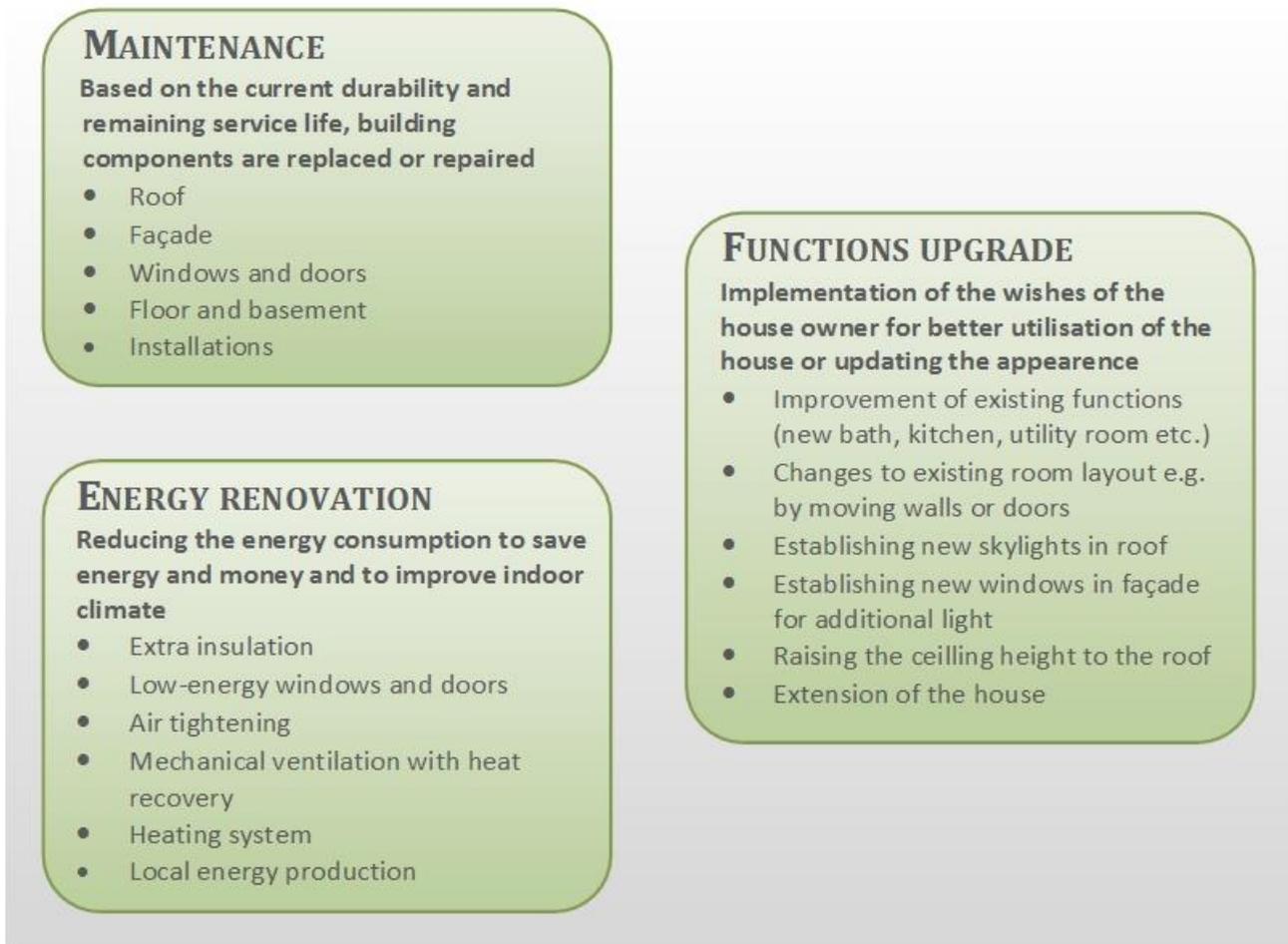


Figure 6 – Overview of the three main types of renovation, based on purpose.

A maintenance renovation includes replacing building elements or installations that have reached the end of their service life to increase the durability of the house. This type of renovation extends the functional lifetime of the house, without improving it in other ways. This is the most important type of renovation, because the building will in fact deteriorate and lose both value and its basic functions if maintenance is not carried out.

The purpose of a renovation can also be to update the functions and/or the design of the house. This could include extension, moving internal walls, a new bathroom or kitchen, painting the walls a new colour or installing skylights. This is often a very visible type of renovation, but it does not in itself lengthen the service life of the house or reduce energy consumption.

The third type of renovation is the energy renovation. Here the purpose is to reduce the energy consumption of a house, which often also results in a more comfortable indoor climate. The energy effectiveness of a house can be improved in two ways (DACC and GI, 2011):

- Reducing the energy consumption through renovation
- Installing energy production, such as photo-voltaic (PV) panels

Both solutions will reduce the amount of energy supplied from the outside and improve the energy benchmarking of the house. However, energy production will not improve the building itself, either with regard to its maintenance status or its indoor climate. The energy improvements can further be divided into two groups: active (installations) and passive (building envelope) measures. Often it will be beneficial to either improve installations and the building envelope at the same time or start with the building envelope. Although significant savings can be achieved by improving installations, these active measures should be dimensioned on the basis of the energy consumption of the house, which changes during renovation of the building envelope. The energy part of renovation in this report will focus on improvement through passive measures and will not include the installation of local energy production.

#### **2.2.2.1 Current renovation practice**

Due to their age, much of the SFH stock is now in need of major renovation. Often renovation is not seen as a whole, and too often an improvement will only concern one of the three mentioned renovation types due to a lack of holistic thinking (Tænketank om Bygningsrenovering, 2012). Examples could be adding plaster to the façade of a house without considering external insulation, installing PV-panels on the roof without considering when the roof tiles will need to be replaced, or replacing a roof without considering the possibility of installing skylights. It is often an advantage to combine different types of renovation in one process. The house will still benefit in the same way, but the total cost will often be reduced because, for example, scaffolding and building site costs will only be paid once (DACC and GI, 2011).

In general, the renovation of single-family houses is dominated by a do-it-yourself (DIY) culture, where individual improvements are made one project at a time (Tommerup et al., 2010b; Vanhoutteghem and Rode, 2014). A survey made among SFH owners showed that very few carried out larger renovations, while most implemented smaller improvements, such as new windows (Mortensen et al., 2015). According to another survey of more than 3000 Danish house owners (Bolius, 2016), more than half of them carry out minor maintenance work themselves, about 40% receive some help from friends and family, while only 8% use building professionals. For major maintenance work, however, 63% hire building professionals. But even with major renovation

## 2 Background

projects, people will often just ask the craftsmen for advice, rather than hire a professional adviser, such as an architect or an engineer (Vanhoutteghem and Rode, 2014).

To get some indication of the amount of renovation currently taking place, the changes in the energy level of houses sold between July 2010 and November 2016 were analysed. The data for 50,000 houses was provided by Boligsiden.dk, and it covers about 22% of all houses sold in the period (Statistics Denmark, 2017). The houses were rated on the basis of their energy performance certificate (EPC) level, which is further described in section 2.2.4.2, page 22. The number of houses sold during this period increased gradually for all energy levels, see Figure 7. However, the percentage distribution shows a clear change in the distribution between the levels. To make this tendency even clearer, the various EPC levels were collected into four groups: A2010–A2020: “new buildings”; B–C: “good or renovated buildings”; D: “average buildings”; and E–G: “un-renovated buildings”. Figure 7 shows that the share of houses with very high energy consumption is decreasing, while the share of houses with average or low energy consumption is increasing. Houses are often improved by one to two steps on the EPC scale when renovated. The figure suggests that a lot of houses are being renovated from D-G to B-D.

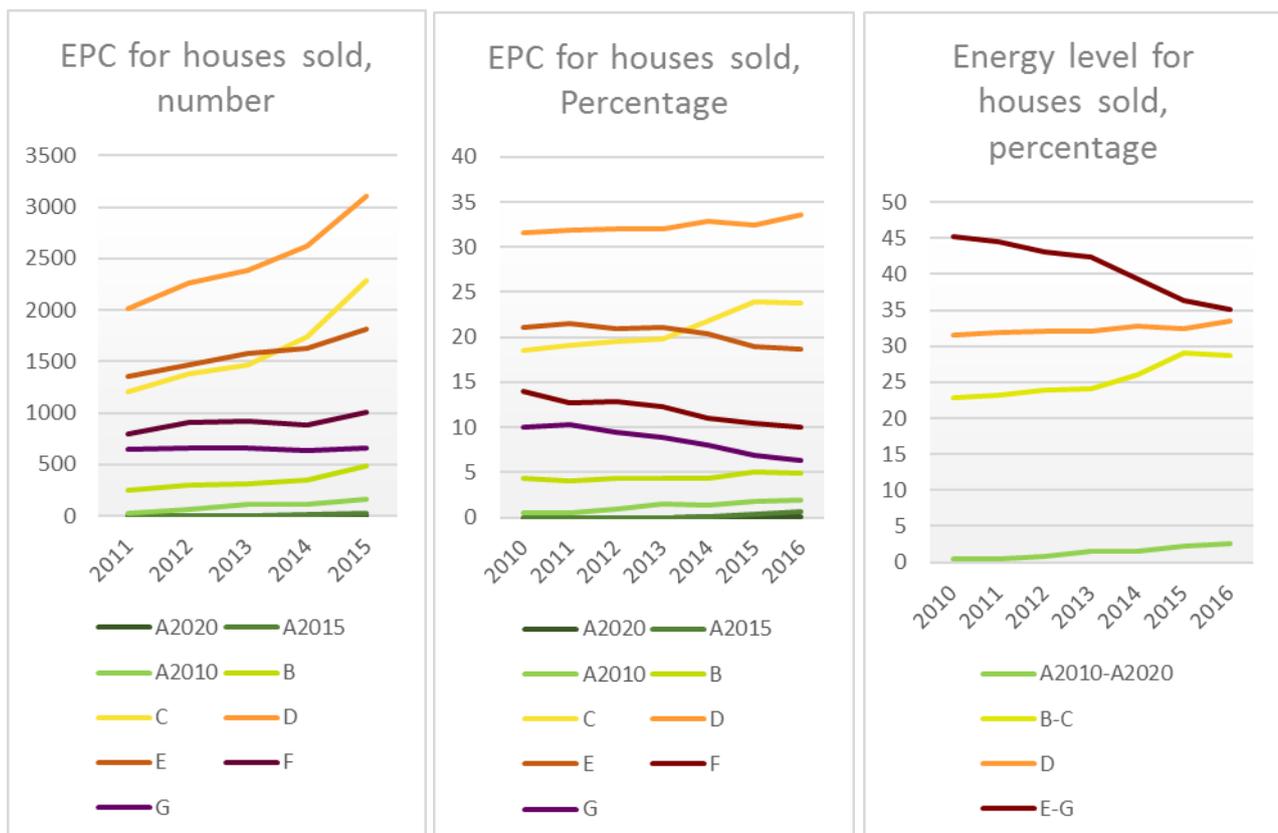


Figure 7 – Distribution of EPC labels among the 50,000 houses, shown by numbers, percentage and grouped. A2020 has the lowest energy consumption G has the highest. Data from Boligsiden.dk.

### 2.2.2.2 Energy improvement of building envelope

The building envelope is the term describing all parts of the building that divide inside from outside, and every part can be the subject of an energy renovation. The building envelope usually consists of roof, walls (and foundation), floor, windows (possibly also skylights) and doors. In the following, some of the most common constructions in SFH are described, including some possible improvements (DEA, 2016b; Tommerup et al., 2015).

The roof can either be flat or with a slope. Depending on the construction, insulation can be added inside or outside. If the house has an unused attic, it can be relatively easy to apply more insulation. However, irrespective of the construction, the workload is reduced a lot if insulation is added in connection with a replacement of the roof cladding. The Danish Energy Agency (DEA) suggests that insulation should be added up to a total thickness of 300–400 mm if there is currently less than 200 mm (DEA, 2016b).

SFH usually have cavity walls with or without insulation. If there is no insulation this can be added by blowing granulated insulation into the cavity. It is also possible to replace the cavity insulation if the old insulation no longer works properly. For light walls or to decrease heat loss further, it is necessary to add insulation internally or externally. Internal insulation can result in moisture problems and should be avoided if another solution is possible. External insulation has the benefit of reducing cold bridges more than internal insulation. The DEA suggests that insulation should be added up to a total of 125–225 mm for brick walls and 200–300 mm for concrete walls, if there is currently less than 100 mm. When insulating the wall, it is also important to consider insulating the footing of the house, although this requires digging around the house.

SFH do not usually have a basement. When there is no basement, it can be a very large and expensive job to insulate the ground slab, because the whole floor has to be removed. So although insulation here can help reduce the heat loss, it is only economically advisable when the floor is removed for another purpose, such as installing floor heating or refurbishment after water damage. The DEA recommends insulating if there is less than 100mm insulation, to 300–400mm insulation in total.

The windows in this type of house are usually two-layer with a thermal transmission (U-value) of about 2.8 W/m<sup>2</sup>K. To reduce heat loss, either the glass panes or the whole window can be replaced, depending on the quality and remaining lifetime of the existing frame. New 2-layer energy windows can have a U-value of about 1.0–1.3 W/m<sup>2</sup>K, and 3-layer windows have a U-value of about 0.5–0.7 W/m<sup>2</sup>K (Tommerup et al., 2015).

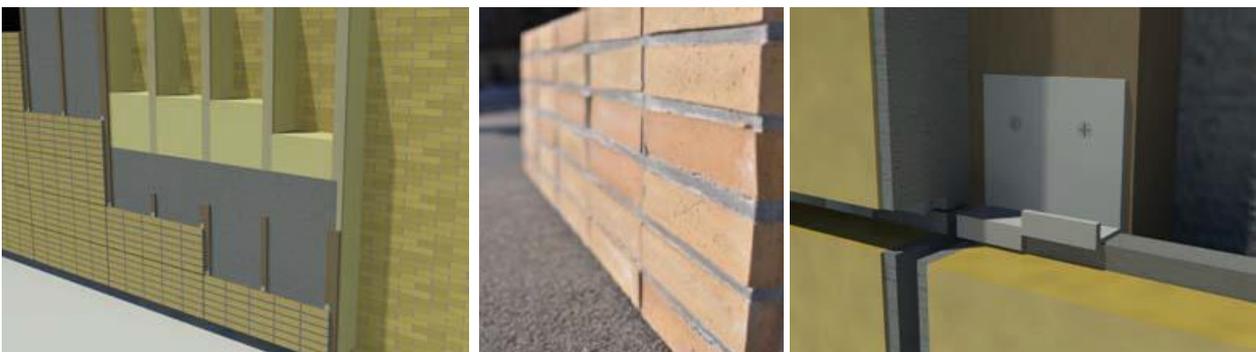
### 2.2.2.3 Development of system solutions

One aspect of this project was to look into the possibility for using system solutions in connection with SFH renovations, because these houses have many similarities. The use of prefabricated renovation solutions could perhaps help reduce the cost of advisers and craftsmen on site.

For the roof, we investigated whether it would be possible to make prefabricated roof elements, and then assemble them on site. The benefit we initially hoped to obtain by this approach was to minimise work on the building site, thereby reducing the time it would take to get a new roof, and perhaps reduce the risk of moisture problems. However, this idea was dismissed by producers of roof elements for other types of building. The elements would require too many adaptations for a project the size of a single-family house to be feasible. It would not achieve any major improvements compared to covering the house and building the roof on site.

New solutions have been developed for use when the house is to receive external insulation. These are further described in Johannesen (2013) and Tommerup et al., (2015). The purpose of these solutions was: A) to use external insulation to ensure lower energy consumption due to reduced heat loss through wall and thermal bridges; B) to provide a low price compared to similar brick-tile façade products; and C) to ensure the product would require very little maintenance compared with the original brick wall. In total, three solutions were developed, two requiring the production of special parts, and one that is off-the-shelf.

The first solution consisted of tile bricks cast in thin plates of high performance concrete, see Figure 8. By using thin tile bricks, the appearance of the wall will be very close to that of the original brick wall, which could make this an attractive solution for people who would like to add external insulation, but prefer not to change the appearance of the house too much.



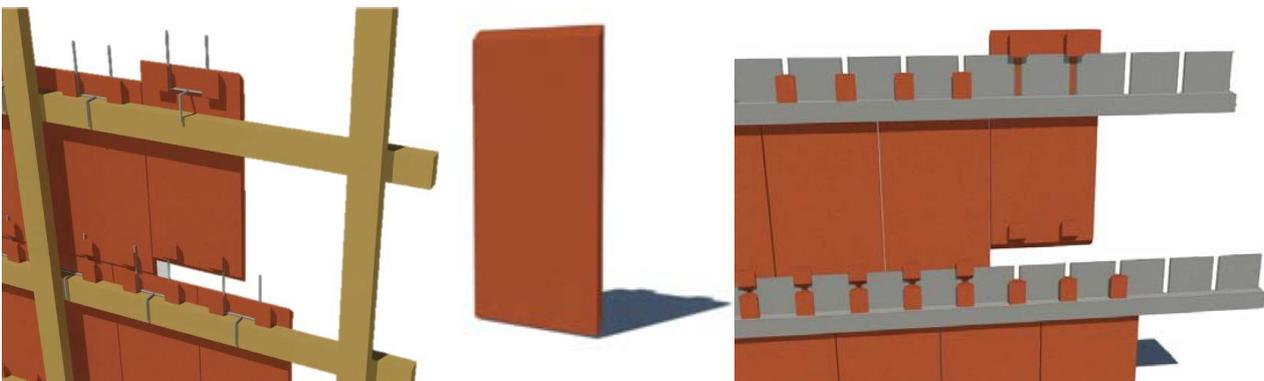
*Figure 8 – Façade solution with brick tiles cast in high performance concrete. Renderings of the solution and a prototype. Source Johannesen (2013).*

The second solution was covering the wall with flat roof tiles, see Figure 9. The benefits of this solution are that it uses off-the-shelf products, and is much cheaper than other existing façade solutions, while requiring very low maintenance. This solution is described in detail in Dam-Krogh and Erikshøj (2013).



*Figure 9 – Façade solution with existing flat roof tiles. Rendering of solution and two examples of use. Source Johannesen (2013).*

The third solution was an adaption of the roof tile solution, but allowing the finished wall to have a flat surface. The tile needs to be rectangular, with slanted edges and four knobs on the back, making it easy to mount on a wall surface. The mounting can be done using either a special bracket on wood lists or a steel section with cut-ins for quick fitting of the tiles, see Figure 10.



*Figure 10 – Façade solution with adapted flat roof tiles. Rendering of solution with both brackets and sections. Source Johannesen (2013).*

In recent years, companies in Denmark have worked on developing tile solutions with many of the same qualities regarding maintenance and cost. Examples of these are “Unity” from Strøjer Tegl (Strøjer Tegl, 2017) and “Teglspån” from Komproment (Komproment, 2017). The existence of these new systems suggests that there is a market for this type of solution.

### 2.2.3 Known barriers towards energy renovation of SFH

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Despite the potential for achieving energy savings, the upgrading of SFH is only progressing slowly. This is due to a number of barriers and a lack of motivation among house owners.

Various models have been used to describe the barriers. A report by SBI and Jensen (2004) describes two different models: a techno-economic “Barrier-model” based on Guy and Shove (2000), and an inertia-model, also known as a lifestyle-model.

The techno-economic ‘Barrier-model’ focuses on the human barriers that block the flow from research & development, and demonstration and dissemination to actual implementation. According to the model, the human barriers can be divided into:

- 1) Lack of interest (people are unaware that the possibility exists or just do not care)
- 2) Lack of knowledge (people are not sure what their specific options are or what they might gain)
- 3) Lack of solutions (e.g. specific technical solutions, trained craftsmen, or finances)
- 4) Lack of movement (a combination of laziness, conservatism, scepticism, and the competition of other priorities).

The way barriers are put into categories varies a lot, but the content is much the same in the following contributions on identifying barriers. In a review on modelling decisions on energy-efficient renovations, Friege and Chappin (2014) identify economic barriers (lack of resources, unwillingness to increase borrowing, doubts about economic benefits), and non-economic barriers (thinking no further renovation is necessary, lack of time, wanting to do as little as possible, or worries about the mess and stress of a renovation). A communication from the EU-commission on strategy for heating and cooling (EU Commission, 2016) highlights the barriers to cost-efficient renovations of owner-occupied houses as being lack of awareness and lack of advice on technical solutions.

Often policy mostly focuses on lack of interest, lack of knowledge, and lack of solutions, because these are the most measurable and easiest to handle. However, the fourth group of barriers, the lack of movement, must also be tackled, because it is not sufficient to find solutions to the first three. When people are unaware of the potential for savings in their house, they will decide on maintenance and improvements based on their immediate needs or choose the cheapest solutions in the short term. Most people will not consider all the relevant information, but rather be influenced by their initial starting point. In most cases, the default option is preferred (Wilson and Dowlatabadi, 2007). Galiotto et al. (2016) identify three types of barrier: politico-economic, to be addressed by policy makers and market developers; technical, to be addressed by the building

industry; and behavioural, described as including lack of interest and knowledge, lack of support and lack of social and emotional understanding. They claim that, over the last decade, attempts to overcome these behavioural barriers have mostly been based on benchmarking buildings, as is the case with the European Energy Performance of Buildings Directive (EPBD), which leads to legislation that affects their market value. However, Galiotto et al. think this limited scope is a problem, because building owners are also influenced by unmeasurable parameters, which are difficult to quantify and assess because they are individual.

Another way of looking at the barriers is to use an Inertia-model, also known as a lifestyle-model (SBI and Jensen, 2004). Here consumption is seen as a form of cultural currency. This means that people will react differently towards the same energy-saving measure, depending on what signals it will send to their social surroundings. An energy efficiency measure can be economically unfeasible, and still be attractive, if it sends a strong signal that raises their social status. On the other hand, a measure that is economically feasible might not have any signal value. This model indicates one of the problems when it comes to energy improvements, because they are often invisible. The idea that choosing energy efficiency is not necessarily an economically rational choice is supported by Gram-Hanssen (2014). Apart from concluding that the renovation of kitchens and bathrooms often has a higher priority than energy efficiency, the author states that economic benefit seldom works as an incentive for renovation. A lack of finance can set the limits of a possible renovation, but this does not imply that house owners are calculating payback periods. Often the renovation will be part of a certain lifestyle of improving the house or a DIY project. Gram-Hanssen emphasises the importance of including social factors when promoting energy efficiency.

Kastner and Stern (2015) take a different view. They set out to identify the most important factors influencing the decision-making about large energy investments in owner-occupied semi-detached or single-family houses. They note that it is difficult to draw strong statistical conclusions because research in this field follows many different methods and covers a large area. However, one problem they notice in particular is the focus on habitual behaviour (frequent actions, e.g. daily), which can be described with the common behavioural models. This is, however, not the case for large investments, because these are rarer and follow patterns more influenced by consequences than personal norms and habits.

A survey among people who received a subsidy for renovating their house, investigated what effect this had on their perception of comfort in the house and why they chose to renovate (Niras A/S, 2015). While the survey showed that a majority had experienced better comfort in their house after renovation, only 39% claimed this as one of their two main motivations for renovating. This is probably because there is only little focus on the comfort benefits that can be achieved, but massive attention on savings, which 67% claimed as a reason for renovating.

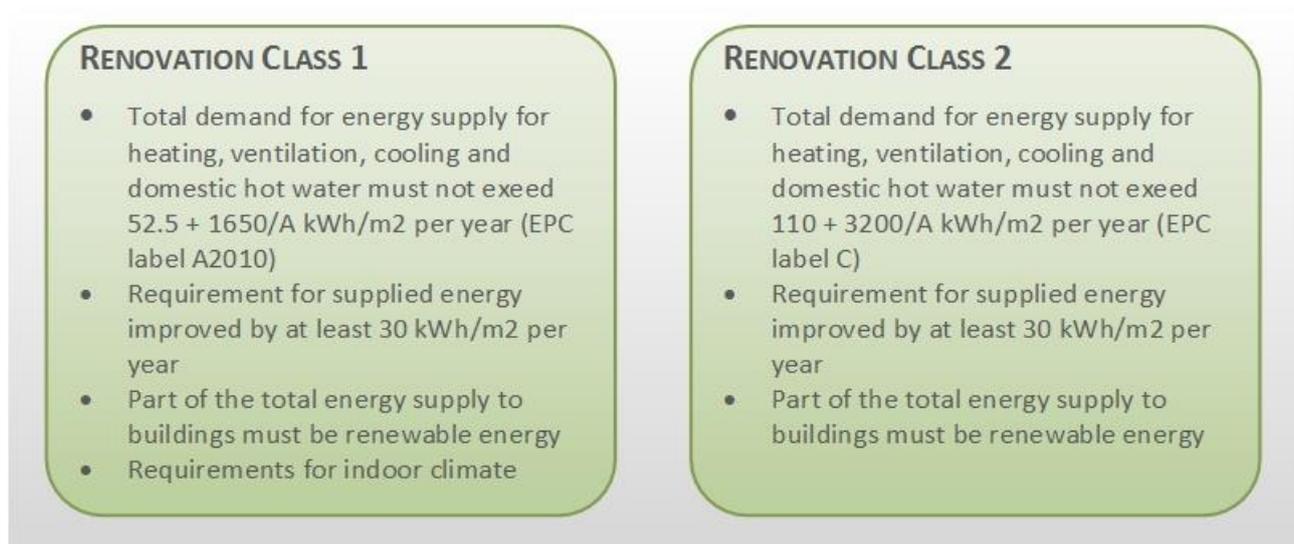
## 2.2.4 Danish schemes and available information regarding renovation

### 2.2.4.1 Building Regulations

The Building Regulations, currently BR15 (Danish Transport and Construction Agency, 2015), regulate all buildings in Denmark, and must be taken into account when building new or renovating.

*Table 2 – Selected relevant requirements for insulation of the building envelope for conversions, maintenance and replacement, according to the Danish Building Regulations from 2010 (BR10) when the case studies in this thesis took place and from 2015 (BR15) which are the current building regulations (Danish Ministry of Economic and Business Affairs, 2010; Danish Transport and Construction Agency, 2015).*

REQUIREMENTS FOR INSULATING THE BUILDING ENVELOPE				
		BR10	BR15	
External walls	W/m <sup>2</sup> K	0.20	0.18	
Roof structures	W/m <sup>2</sup> K	0.15	0.12	
External doors	W/m <sup>2</sup> K	1.65	1.8	



*Figure 11 – Requirements for achieving renovation class 1 or 2 according to the Building Regulations.*

The regulations on energy consumption in buildings have been continuously tightened since the 1970s, and it is planned to further tighten the rules for new buildings in 2020, setting the limit<sup>11</sup> at 20 kWh/m<sup>2</sup> a year for heating, ventilation, cooling and domestic hot water in residential buildings.

But while the ruleset for new buildings has received a lot of attention, there is less regulation when it comes to renovation. In the latest version of the building regulations, two new voluntary renovation classes have been added, see Figure 11, but in other respects the rules have concerned the specifications for specific improvements. The regulations state that cost-effective energy savings must be implemented when alterations are made to external walls, floors, roof structures, windows or installations, see Table 2, but there are currently no rules for how much energy an existing building can consume.

#### 2.2.4.2 Energy Performance Certificate (EPC)

The EPC is a system for benchmarking buildings based on their energy consumption. The EPC is part of the Energy Performance of Buildings Directive (EPBD) initiated by the EU member states and Norway about a decade ago. Only the framework for the EPC is decided at a central level; it is up to the countries to decide how to introduce it.



Figure 12 – Danish energy level scale for the EPC. The unit is kWh/m<sup>2</sup> a year, and A refers to the heated floor area in m<sup>2</sup> (DEA, 2016c). Graphic adapted from [www.spareenergi.dk](http://www.spareenergi.dk).

In Denmark, the EPC includes a rating of buildings on a scale from high energy consumption, G, to low energy consumption, A<sub>2020</sub>, see Figure 12. The calculated energy consumption is based on standard values for consumption, enabling easy comparison of different buildings at the expense of an accurate reflection of the actual consumption in a particular house. The consumption for

<sup>11</sup> in the heated area

## 2 Background

domestic buildings includes heating, ventilation and domestic hot water; it does not include lighting or electricity used for other purposes.

It is mandatory to obtain an EPC report when a house is put up for sale. Apart from containing a rating of the building, the EPC report also makes a few suggestions for feasible improvements that could be implemented to reduce energy consumption and improve the rating. The idea is to inspire the new house owner to implement these improvements, but studies have shown this usually does not happen. A survey carried out among house owners who had received an EPC showed that they did not find it useful, even though they considered it reliable and easy to understand (Christensen et al., 2014). To keep the cost of making an EPC report down, the energy consultant is not required to visit the house before making it. This means that the suggested improvements are often too general and might not even be suitable for that specific house (Bolius, 2014).

However, many studies in Denmark and abroad have shown that the energy label does have a direct effect on house prices (Bio Intelligence Service et al., 2013; Brounen et al., 2009; DEA, 2015b; de Ayala et al., 2016; Fuerst et al., 2016). It affected the distribution of house prices when displaying the EPC rating in sales material became mandatory in 2010 (Jensen et al., 2016), so the EPC has increased awareness about energy renovation, even if it has not directly caused people to renovate.

### **2.2.4.3 House Condition Report**

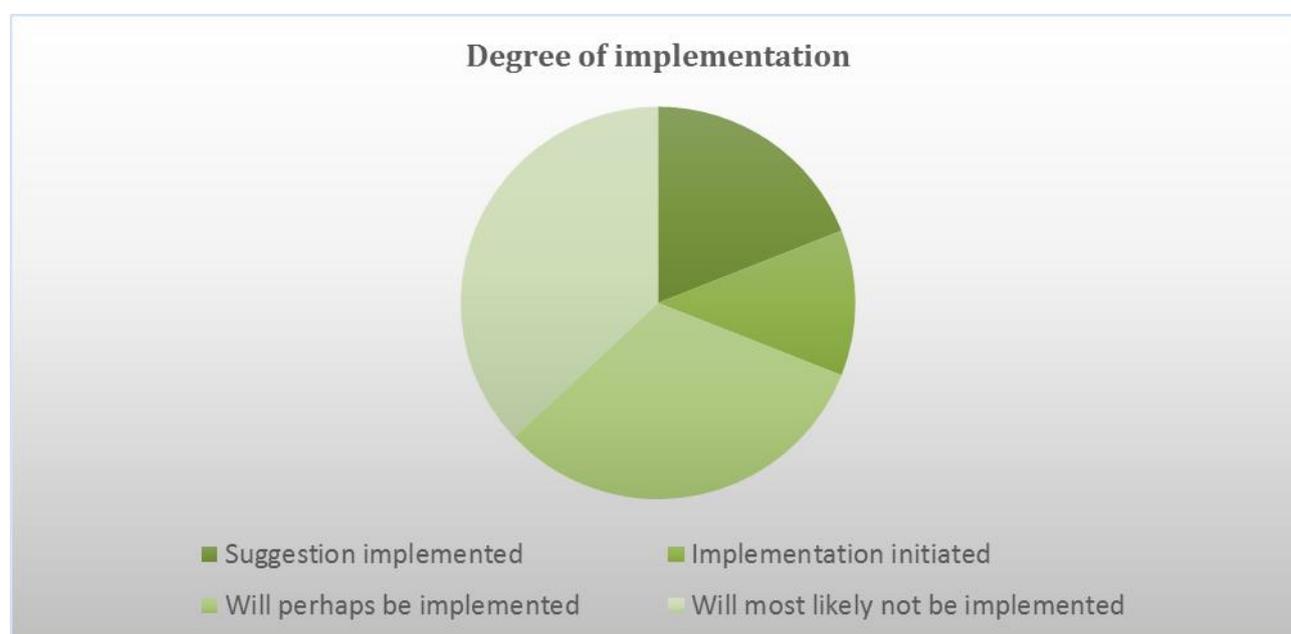
A house condition report (in Danish: Tilstandsrapport) describes the condition of a house (including repairs needed) compared to similar houses, and is often made in connection with the sale of the house. It is drawn up following an on-site assessment made by a building professional appointed by the Danish Business Authority. In its current form, it does not provide information about renovation (except for the expected remaining lifetime of the roof), but it does give the new house owners important information about their house. It provides a systematic overview of repairs needed in the house, and their severity. The house condition report represents an opportunity, where the inclusion of possible energy improvements might supply all new house owners with valuable information on what they could do to improve their house in a sensible way.

### **2.2.4.4 BedreBolig (A Better Home)**

To make energy renovation more approachable, the DEA launched the “BedreBolig” (BB) scheme, as a test in nine municipalities in 2013, and nationwide in the autumn of 2014. It is a voluntary market-based scheme. The idea is to guide the house owner through the process, from first idea, through planning and execution, and ending with follow-up on the project. In this scheme, craftsmen, advisors and other building professionals are trained to provide holistic counselling, so that house owners should receive better advice on how to make energy improvements on their

house. House owners who contact a BB advisor receive an assessment of their house and a BB-plan, containing the renovation suggestions they have decided on with the advisor. They can then use the plan to get quotations from contractors and get a loan in the bank. There are currently no figures on how many BB-plans have been issued, or how many renovations the scheme has generated, but 134 companies are represented as BB-advisors on the official website.

Very few evaluations have been carried out since the initiation of the scheme in 2013. The introduction of the scheme in the test municipalities was evaluated by Geelmuyden Kiese (2014), who found it difficult to draw any strong conclusions after such a short time, because the building professionals had to receive training before reaching out to customers. One conclusion that was drawn was that many house owners might consider the cost of getting a BB-plan a big obstacle, because it cost about DKK 2–3000 or EUR 270–400.



*Figure 13 – The degree of implementation of improvements suggested in the BB-plans according to the survey (Energitjenesten et al., 2016a, 2016b, 2016c).*

In 2016, another evaluation was made by EnergiTjenesten<sup>iii</sup> (the Energy Service) on behalf of three municipalities (Energitjenesten et al., 2016a, 2016b, 2016c and Interview with the author). They made a survey among the house owners in the three municipalities that had received a BB-plan from the Energy Service three months to a year before the survey (59 in total, 48 answers). At the time of the survey, about 1/3 of the suggestions had been implemented or were about to be, 1/3

<sup>iii</sup> The Energy Service is an independent energy consultancy service run by citizen-based organisations that also offers BB counselling itself.

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would perhaps be implemented, and 1/3 would probably not be implemented, see Figure 13. Of the house owners, 75% chose to implement one or more of the suggestions from the plan. When asked, 66% of the respondents said they would not have asked for a BB-plan if they had not received the special subsidy provided by the three municipalities.

### 2.2.4.5 Subsidies

There are currently two different schemes for people who want to renovate their house: the “Energiselskabernes Energispareindsats” (EE) and the “BoligJobOrdning” (BJO).

The EE scheme is based on the commitment of the Danish energy grid and distribution companies to achieve annual energy savings (DEA, 2012). One way for the companies to meet these goals is to buy the right to report the energy saving that a house owner achieves through renovation. A house owner can only sell this right once for each renovation, and the agreement has to be made before the work starts. The house owner receives the full benefit of the renovation (DEA, 2016d). However, there are some problems connected with this scheme. Each company has their own system for calculating the size of the subsidy, so the house owner often has to contact more than one company to get a good deal, making it time-consuming and inconvenient. Moreover, the actual size of the subsidy is unknown before the scale of the renovation has been determined. So, although the EE scheme is intended to motivate more renovations, the system makes it doubtful whether this is the case. A survey among house owners in the process of a renovation showed that only 4% were motivated by an energy company subsidy (Bolius, 2016). Finally, the subsidy is a very small amount compared to the expenses of an extensive energy renovation. For an extensive renovation which was carried out in connection with this project, and which is described in sections 3.1 and 3.2, the subsidy was less than DKK 5000 (about EUR 670) and covered less than 0.6% of the total cost.

The second subsidy scheme, the BJO, is actually a tax reduction scheme, where expenses for the salaries of craftsmen or advisors up to DKK 12,000 (about EUR 1,600) can be deducted. The main purpose of this scheme is to create more jobs, but it has been modified many times since 2011 and now promotes more green solutions, such as energy renovation. Since the scheme, despite being extended every year, is always temporary, it does not promote long-term planning. Moreover, the maximum size of the subsidy only promotes smaller improvements. On the positive side, it might encourage people to have a BB-plan made, because it can cover the cost.

### 2.2.4.6 Sparenergi.dk – the building guide

The DEA has a website dedicated to promoting energy savings, SparEnergi.dk, see Figure 14. This website includes a new building guide, featuring the 15 most common types of single-family houses in Denmark. For each type of house, the website provides easily accessible information for owners

and building professionals about materials, design, common energy levels and possible improvements. Here it is possible for the owner to get information early in the process and it can be used as a tool for the building professional to explain their ideas to the customer.

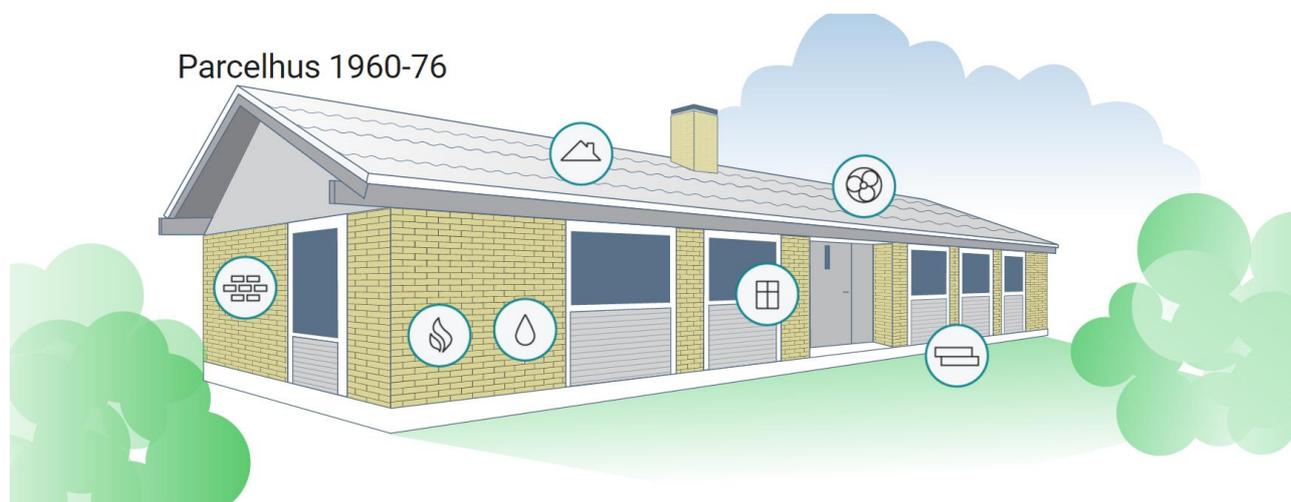


Figure 14 – Example from the website SparEnergi.dk showing an SFH with interactive buttons providing information on different building components.  
Source SparEnergi.dk

## 2.2.5 Foreign schemes to promote energy renovation

### 2.2.5.1 The UK – Green Deal

When initiated in 2013, the ‘pay-as-you-save’ scheme called Green Deal was the flagship of the UK Government in the field of energy renovation of homes (UK Government, 2015). The house owner could get a Green Deal energy assessment made for their house, which would recommend energy improvements such as insulation, heating, windows or local energy production. Moreover, the report would include an EPC, an occupancy assessment that measured how much energy the household consumes, and an estimation of the possible economic savings on energy bills. If the house owner chose to renovate based on this assessment, they could pay for the improvements themselves or use a Green Deal finance plan, under which the loan was repaid through the expected savings on the energy bill. The idea was that the repayments should not exceed the estimated savings on the energy bill. This was called the Golden Rule. It was to ensure the house owner did not get into financial difficulties due to the energy improvements. The Green Deal was linked to the house, so if the house was sold, the repayment of the loan would pass to the new owners, because they would now benefit from the improvements.

## 2 Background

In 2015, funding for the project was stopped by the new Conservative Government, because only about 15,000 loans had been taken out. This is very few compared to a building stock of about 14 million houses in need of renovation and the initial ambitions of the scheme.

According to an online energy-saving advice community (TheGreenAge, 2015), the main flaw of the scheme was 'the Golden Rule'. It was meant to save the house owners from large repayments, but in reality it created an upper limit to the amount house owners could borrow, because it all had to be paid by the energy savings alone and within a limited number of years. This drastically limited the possibility for extensive renovations.

Pettifor et al. (2015) investigated how the Green Deal affected house owners by questioning them four months prior and seven months after the launch. They found that house owners do not distinguish energy efficiency from other kinds of renovation of their houses, so the Green Deal should not have been limited to energy improvements. The focus solely on energy savings meant that a lot of house owners lost interest, because their focus was on necessary maintenance.

Another problem was the upfront cost to get a Green Deal assessment, which had to be ordered before the house owner knew whether anything could be done within the limits of the scheme. This left many dissatisfied, because they paid for assessments that turned out not to reveal any opportunities within Green Deal. Even more people lost interest before they got started due to the cost of the assessment. Furthermore, only a limited number of improvements were eligible within the scheme. All this limited the number of Green Deal renovations that were actually carried out.

Lastly, some people were worried that a Green Deal might affect the saleability of their house. The Green Deal was attached to the house and not the owner, so it would be taken over by the new house owner, which might put some people off buying.

### 2.2.5.2 USA – PACE

One place where a renovation scheme has affected the saleability of houses is the USA. The PACE programme for residential houses was introduced in 2009 (Headen et al., 2011). It allows the house owner to receive 100% funding for eligible energy improvement, and repay the loan through their real estate tax bill. This way, the house owner has no upfront investment, which can often be an obstacle to energy renovation. The loan stays with the property, thereby making sure that the investment is paid for by those who benefit from the improvements. Moreover, the length of the loan must not exceed the useful service life of the improvement, and the increase in property tax should not exceed the expected savings on the energy bill.

This programme ran into problems because the two largest American mortgage loan companies, Fannie Mae (Federal National Mortgage Association, FNMA) and Freddie Mac (Federal Home Loan

Mortgage Corporation, FHLMC) announced that they would no longer buy mortgages on houses in the PACE programme. This was because PACE had first-lien status, meaning the PACE loan would have to be paid before the mortgage in the case of foreclosure (Federal Housing Finance Agency, 2014). For a new buyer to obtain a mortgage for the house in connection with a sale, the past owner would probably have to pay off the PACE loan before selling (Wise, 2016). This example shows that even standard economic procedures can work as a hindrance. However, the programme has so far contributed \$2237 million to upgrade 104,000 homes, where 59% of the improvements were energy efficiency upgrades, while the rest were either renewable energy or water saving (PACENations, 2016).

### 2.2.5.3 Germany – KfW

The KfW is a large, state-owned development bank that supports sustainable development in a number of ways. They assist house renovation through cheap loans and they also supply grants for ambitious renovations that do more than the average renovation. The more energy the renovation saves, the larger the grant available. They also support individual improvements, but a combination of improvements resulting in a larger renovation will generally make it possible to get a larger part of the budget covered by a grant – up to 30% for the most extensive renovations (Galvin and Sunikka-Blank, 2013; KfW programmes for private customers).

Schröder et al. (2011) evaluated these KfW initiatives from a British perspective. They described how the KfW programmes managed to promote the energy-efficient renovation of about 9 million houses between the 1990s and 2010. They report that, in general, the KfW has been a success story due to a number of factors:

- A combination of regulation, information and support to create a framework for energy renovation
- Favourable terms for loaning money and subsidies that promote ambitious solutions
- Providing qualified expert advice and installation, thereby ensuring a positive result
- Subsidies for renewable energy paid only after investments in energy efficiency have been made
- Focus on a ‘whole building approach’ to energy saving, also where improvements are implemented over time
- Support for the innovative and experimental, spreading awareness of new successful solutions
- Using public buildings as good examples
- Consistently shaping public opinion and behaviour in favour of the benefits of energy efficiency

Galvin and Sunikka-Blank (2013) also compare the German experience with that of the UK. Their aim was to look into the German goal of reducing carbon emissions by 80% between 1990 and 2050, and how it is connected to the economic viability of the mandatory savings in the Energy Saving Regulations. They claim that while there may be many benefits from energy renovation, it will not be possible to achieve the energy-saving goal through this measure, because the savings obtained are often less than those calculated, and it would take a massive amount of super-efficient renovation to achieve the goal. They also suggest that the Government should stop promoting thermal renovation by claiming ‘it pays for itself’ and instead focus on some of its other good qualities. In another paper, Galvin (2012) criticises the German policy focus on extensive renovations with a very low energy consumption. While subsidies support renovation to a higher level than new houses, the same regulations stop people implementing small improvements. While the intention may have been to promote major renovation, the result is often that people do not renovate at all because all the available solutions are simply too expensive and large-scale.

### 2.3 Methods

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#### 2.3.1 Economic evaluation methods

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##### 2.3.1.1 Simple payback time

The benefits of a renovation can be evaluated using different economic methods. The way to determine the feasibility of an improvement in connection with energy renovation according to the Danish Building Regulations is to calculate the simple payback time (Danish Transport and Construction Agency, 2015):

*7.4.1(4) – Structural measures may be deemed to be cost-effective if the annual saving multiplied by the lifetime divided by the investment is greater than 1.33. This corresponds to the measure concerned paying for itself within 75% of its expected lifetime. For example, if work performed has a lifetime of 40 years, the investment must be recouped in 30 years.*

Written as a formula, the simple payback time can be calculated as

$$\text{Simple payback period [years]} = \frac{\text{investment [DKK]}}{\text{annual savings [DKK/year]}} \quad (1)$$

This is a simple and quick way of estimating the economic benefit of a measure, but it does not include interest on the investment or any change in energy prices. It can be a problem to use this approach, especially for measures with a long expected lifetime of 30 years or more (Tommerup

and Laustsen, 2008). Although the building regulations do not forbid implementing non-feasible energy measures, but rather demand that feasible measures must be implemented, the framework that a measure is 'unfeasible' if the payback time is more than 75% of the expected lifetime causes a lot of extensive improvements to be rejected solely due to this rule.

### 2.3.1.2 Cost of Conserved Energy (CCE)

Another method, often used in the economic optimisation of building design or renovation with regard to energy consumption is the Cost of Conserved Energy (CCE). The CCE can be calculated as

$$CCE = \frac{t \cdot a(n, d) \cdot I_{measure} + \Delta M_{year}}{p_1 \cdot \Delta E_{year} - p_2 \cdot \Delta E_{operation, year}} \quad (2)$$

where  $a(n, d) = \frac{d}{1 - (1+d)^{-n}}$  and  $t = \frac{n}{n_t}$

CCE	Cost of Conserved energy, [DKK/kWh]
n	Economic lifetime of the component, often set at 30 [years]
$n_t$	Technical lifetime [years]
$a(n, d)$	Capital recovery rate [-]
d	is the real interest rate, often set at 2,5 [%]
$I_{measure}$	is the investment for an energy conserving component [DKK]
$\Delta M_{year}$	Annual maintenance cost [DKK]
$p_1$	primary energy factor for the conserved energy
$\Delta E_{year}$	annual energy conserved by the component [kWh/year]
$p_2$	primary energy factor for the energy used by the component
$\Delta E_{operation, year}$	Annual energy consumption of the component

The CCE can be used to compare different improvement solutions, by showing how much it will cost to save 1 kWh for each component. It can also give an idea of feasibility, because the CCE can be compared to the current energy price or scenarios for future energy prices.

### 2.3.2 Renovate or Replace

The technical and political developments in recent years have enabled low-energy buildings on a large-scale, and the existing building stock is becoming outdated in comparison. This increases the relative need for renovation and lowers the threshold for replacing an old house (DACC and GI, 2011). When a house is in need of a major renovation due to lack of maintenance, its age or being simply outdated, it is worth considering whether the best solution would be to renovate or simply to tear the building down and build a new, energy-efficient building.

## 2 Background

A note from the DEA (DEA, 2016e) sums up two Danish investigations on the subject of renovation or replacement made by the Danish Building Research Institute (SBI Danish Building Research Institute et al., 2013), and the Danish Construction Association (Rambøll, 2013).

*Table 3 – Economic comparison of the average renovation of a 120 m<sup>2</sup> single-family house, as made by the DEA (DEA, 2016e)*

<b>RENOVATION COMPARED TO REPLACEMENT</b>				
	Energy performance	Investment	Energy expenses <sup>A</sup>	Payback period <sup>B</sup>
	-	DKK	DKK/year	years
Unchanged house	G	0	24,387 – 32,241	
Renovated house	C	325,000	9,999 – 2,288	17–23
New house, compared to unchanged house	A2015			53–72
New house, compared to renovated house	A2015	1,600,000	2,288	117–165

Source: Data from Wittchen and Kragh (2013) processed by the DEA (2016e).

<sup>A</sup> Low energy price corresponding to district heating, high energy price corresponding to oil-boiler. The energy in the new house provided by heat pump.

<sup>B</sup> Low numbers corresponding to high energy price, high numbers corresponding to low energy price.

The first report (SBI et al., 2013) makes an estimate of the approximate cost of renovating a single-family house with a very high energy consumption (280–330 kWh/m<sup>2</sup> a year, corresponding to an EPC rating of F or G, see Figure 12, and suggests it can be done for DKK 250 000–500 000. However, it should be noted that this suggestion does not include some of the most expensive tasks, such as replacing the roof or insulating the foundation, although it does include the external insulation of the façade. Based on information about 10 700 houses with a high energy consumption that were sold in 2010–2012, they estimate the average energy renovation for these houses (for 120 m<sup>2</sup>) would cost DKK 325 000. This figure is used by the DEA (DEA, 2016e) to make a simple calculation of the payback period for renovation versus replacement. They assume that tearing down the old house would cost DKK 100 000 and a new house of the same size would cost 1.5 million. The result of the comparison is shown in Table 3.

There is a rather large difference between the investment for renovation and replacement, so the renovation seems a clear winner in this calculation example. The pay back times for replacing the

house become very long, if they are supposed to be paid by the reduced energy consumption alone. However, this might not be a fair way to evaluate the difference between renovation and replacement.

A more nuanced way to evaluate the difference can be found in the second report (Rambøll, 2013). They compare the cost of renovating or replacing 14 examples of public buildings (including both office buildings and social housing), which were new buildings, renovations or extensions in real life. In this economic evaluation they include not just the investment, but also the operation, maintenance, cleaning, etc. Although public buildings have a different financial basis from owner-occupied single-family houses, the results are still interesting. In the analyses, only 3 out of the 14 calculations made favoured renovation, and here it was mainly due to a very large difference between the cost for renovation and the cost for a new building (e.g. DKK 5 million compared to DKK 125 million for a new building). Moreover, they conclude that building new with a lower energy consumption (A2015 instead of A2010) improved the overall economics of the building. For the cases that favoured building new, the breakeven year where the savings caught up with the additional expenses of building new was after 5 to 31 years.

Morelli et al. (2014) present a two-fold economic evaluation method to determine whether to renovate or demolish and build new, and they use it on a multi-storey building as an example. The method is based on the calculation of CCE, i.e. determining the cost of achieving the economically optimal renovation. The benefit from either renovation or replacement must be the market value, less the investment (for renovation or demolition and building new), operation and maintenance. For the case in the paper, they found that renovation was the best option.

However, it may be relevant to consider more than just the economic benefits when deciding whether to renovate. Goldstein et al. (2013) point out in a review that Building Environmental Assessment (BEA) tools and life cycle assessments (LCAs) are seldom used when decisions are made whether to renovate a building or replace it. This is a problem because the LCA includes not only energy consumption for the operation of the building, but also the energy embedded in the construction materials throughout their lifetime. And the BEA (depending on type) can also consider water use, material toxicity, life cycle costs, safety and security. Power (2008) studied the balance between renovation and demolition, including social, economic and environmental benefits in the long term, and came to the conclusion that renovation is probably the best solution, especially compared to large-scale accelerated demolition making room for new low-energy buildings.

### **2.3.3 Development of methods for planning renovation**

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To make the maintenance and renovation of a house more accessible to its owners, a long-term renovation plan and methods for identifying the economically optimal solution can be developed.

## 2 Background

This possibility has been investigated through a number of sub-projects (Andersen, 2015; Jansen and Arabaci, 2013; Marxen and Knorborg, 2011). The main focus of the early projects was to develop the existing EPC into a long-term plan, mapping the beneficial changes that should be made in the house during the next 10 to 40 years, see Figure 15. This was backed up by calculations in which the feasibility was evaluated using the CCE-method rather than the simple payback time.

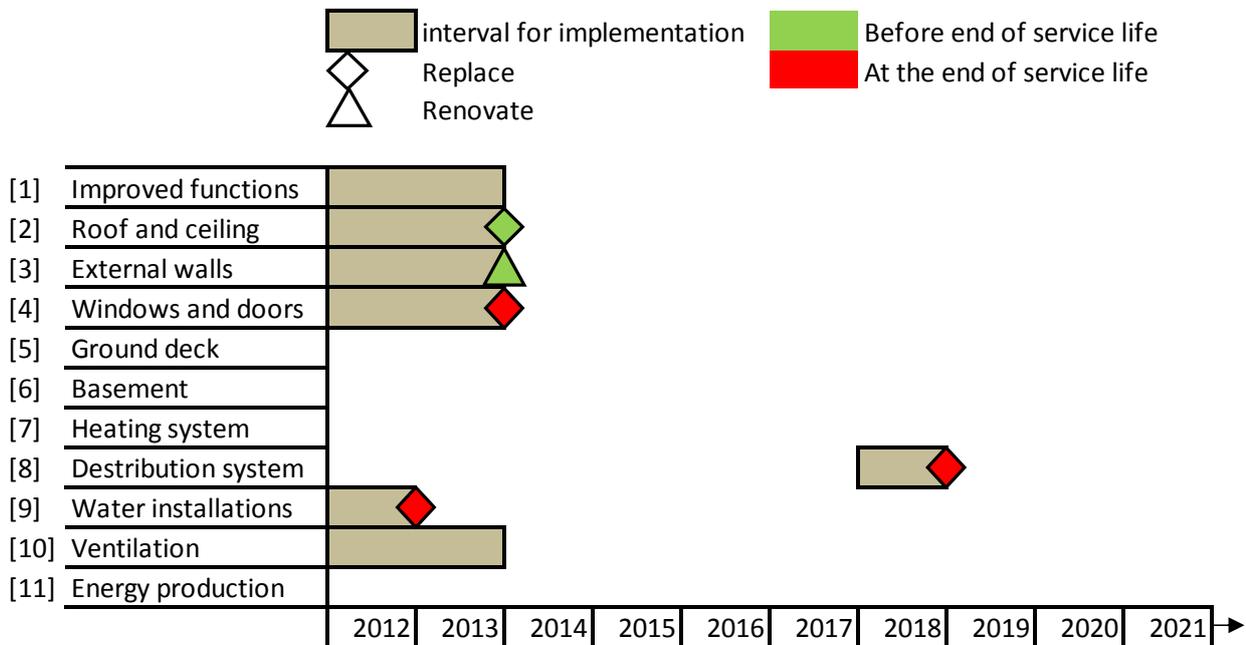


Figure 15 – Example of a 10-year renovation plan. Redrawn and translated from (Marxen and Knorborg, 2011)

The plan was further developed using an excel-based calculation program, CCE-Calc2 (Jansen and Arabaci, 2013). The program was orientated towards renovation, unlike the original CCE-Calc, which had the purpose of economic optimisation of new buildings with regard to energy (Grøn (Bjørneboe) and Roed, 2011). In addition to the CCE-Calc2, which helped identify the most cost-efficient solutions, calculation sheets were also made regarding the increase in value based on the EPC label and whether to renovate or replace based on economic benefits alone. The studies showed that, while it may be difficult to use standard solutions due to the many individual differences in single-family houses, it is indeed possible to use standardised methods (Andersen, 2015). However, these methods will need further development to include more aspects and be more easily accessible before they can be really useful in the planning of renovations.

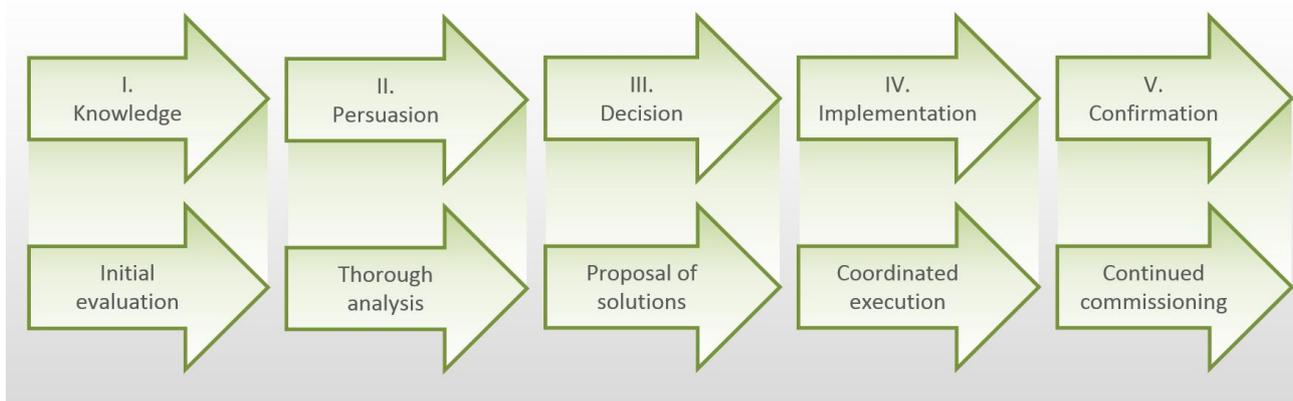
## 2.3.4 One-Stop-Shop (OSS)

### 2.3.4.1 OSS as decision and process support

It has been argued (Haavik et al., 2010) that the decision-making process of house owners facing renovation can be described as a learning process, because they may not know what can or should be done. The decision process can be divided into five phases, as described by Rogers (1995). The five phases can easily be applied to the renovation process:

- I) Knowledge – the owners get to know about the possibility for improvements
- II) Persuasion – the owners form an opinion on the matter, whether this is a good idea
- III) Decision – the owners decide whether to go on with the renovation and what to implement
- IV) Implementation – the renovation is carried out
- V) Confirmation – was the renovation a success?

Vanhoutteghem et al. (2011) use a very similar structure when they describe a full-service renovation concept known as a One-Stop-Shop (OSS). This also has five phases: initial evaluation; thorough analysis; proposal of package solutions; coordinated execution of the renovation; and finally quality assurance and continued commissioning of the house. A comparison of Rogers' decision model and Vanhoutteghem's renovation concept is shown in Figure 16.



*Figure 16 – A simplified version of the innovation decision process, originally by Rogers (1995, 1962) compared with the five phases of the OSS concept as defined by Vanhoutteghem et al. (2011)*

Assuming that the decision process of a house owner in connection with renovation can be described by this model, an OSS is a very useful tool to support this process, because it guides the house owner through all the phases of a renovation. Step I, the initial knowledge about the possibility for renovation can be gained through public information campaigns, but it can also come

directly from an OSS, advertising for customers. Step II, the persuasion, comes from the direct contact between the OSS and the customer, where the specific house is analysed and the options clarified. This helps the customer to Step III, the decision, where specific solutions for the house are picked out. In Step IV, the chosen solutions are implemented through a coordinated effort, in which the OSS is the link between the various building professionals. In Step V, confirmation, the OSS stays in contact with the customer and checks that the solutions implemented have been installed correctly and are being operated correctly, thereby ensuring a result satisfactory to the customer.

### 2.3.4.2 Research projects on OSS

A One-Stop-Shop (OSS) is a full-service concept where house owners are guided through the whole renovation process of their house, with a single contact person or company helping them. Several research projects have been aimed at developing and disseminating OSS solutions on the market of single-family renovation.

In the hope of speeding up the rate of sustainable renovations of single-family houses, the purpose of the project SuccessFamilies (VTT et al., 2009–2012) was to change the business environment by creating full-service concepts (OSS) that included both technical solutions and financial services (Tommerup et al., 2010b). The project made analyses of the building stock and existing technical and sustainable renovation concepts in Denmark, Sweden, Norway and Finland (Tommerup et al., 2010a; Vanhoutteghem et al., 2010, 2009). To a large degree, the objective was to achieve very extensive energy renovations through standard solutions, updating the houses to the standard of new houses at the time<sup>iv</sup>.

Based on these experiences, the ERA-NET Eracobuild project, One Stop Shop<sup>v</sup> (PHP et al., 2010–2012) was aimed at facilitating market volume. The project had participants from Belgium, Norway, Denmark and Finland. During the project, demonstration projects with case studies were carried out and the clusters of small and medium-sizes enterprises (SMEs) were assembled through workshops. Each cluster was to function as an OSS – providing a range of services to their customers and reducing the fragmentation of a renovation process (Haavik et al., 2012).

In the COHERENO project (2013–2016), the aim was to develop a volume market for near-zero energy building renovations. They aimed at creating stronger collaboration in the building sector through innovative business schemes similar to the OSS concept. In this project, the participating countries were Austria, Belgium, Germany, Norway and the Netherlands (Straub, 2016).

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<sup>iv</sup> this would correspond to about 64–85 kWh/m<sup>2</sup> a year for a 150 m<sup>2</sup> house, or a B or A2010 on the current Danish energy performance scale, shown in Figure 12 page 16.

<sup>v</sup> This project has supplied some of the funding for this PhD-project.

# 3 INVESTIGATIONS

## 3.1 Part I – Decision-making and the renovation process

The research in this section has been published in Paper I: *Case study: Using a One-Stop-Shop concept to guide decisions when single-family houses are renovated*. This study was aimed at testing the 1<sup>st</sup> sub-hypothesis.

One way to stimulate renovations is to provide better support for house owners in their decision-making process. The aim of the research was to determine the effect of using a One-Stop-Shop (OSS) concept to support the process of extensive energy renovation in single-family houses. The purpose of using this concept on specific cases was twofold: to identify any disadvantages and benefits of using the OSS-concept and to identify any potential the use of the concept might have for increasing the amount of renovation carried out. The case study was to include up to three houses.

### 3.1.1 Method

To be able to carry out the case study and investigate the effect and use of the OSS-concept in connection with renovation, suitable houses and an OSS company had to be found. The OSS-company was to function as the connection between the house owner and other building professionals, and help the house owner through all phases of the renovation, Figure 17.

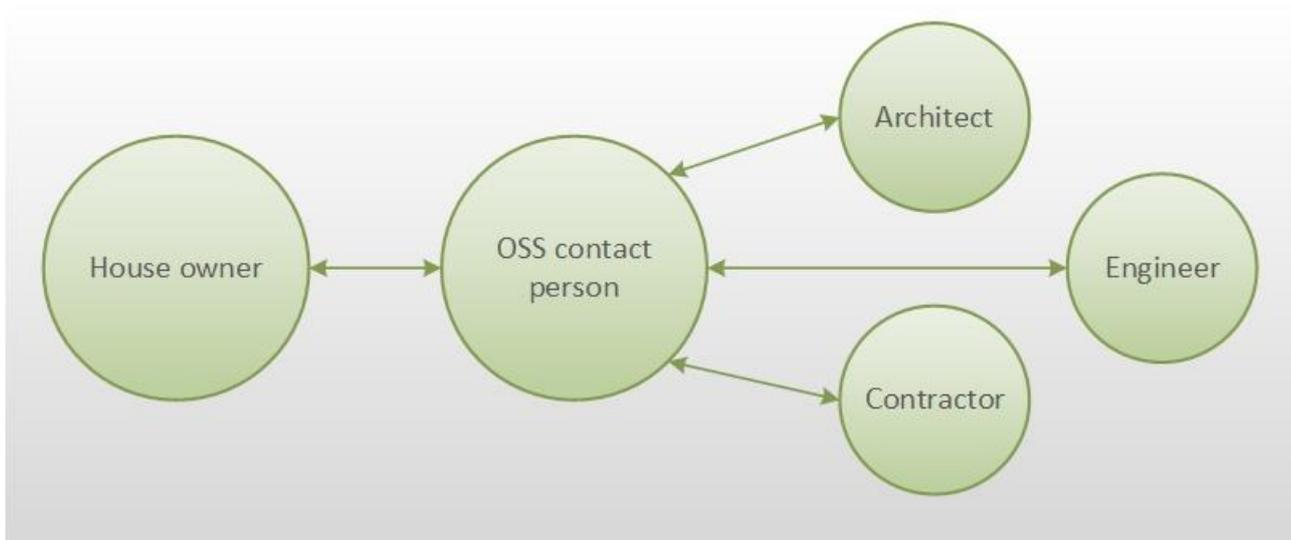


Figure 17 – Diagram showing the communication channels during the renovation.

There were a number of requirements for the houses, if they were to be useful within the framework of this project. The house had to be representative for the many single-family houses built in Denmark during the period of about 1960–1980 (SFH). Furthermore, the house should not have received major renovation and the house owners should be prepared to let their house undergo an extensive renovation and be able to provide the funds necessary to implement it. The commitment of the house owners was crucial for the success of the renovation, because they were the ones who would decide the extent of the renovation.

The process of renovation would go through five steps: evaluation, analysis, proposal, execution and commissioning, which were the five steps of the OSS concept as defined by Vanhoutteghem et al. (2011), see Figure 16 page 34.

The scope of the renovation was determined in the initial assessment, Step 1, by evaluating the house and talking to the house owner. To ensure the renovation would include all relevant measures, the house was evaluated taking into account the three main areas of a renovation: the need for renovation as a result of the poor **durability** of current building elements (maintenance); the wish for renovation in order to improve the **function** of the house; and the relevant **energy** improvements during this renovation, see Figure 6 page 13.

Once the scope of the renovation was determined, a thorough analysis of the possible solutions was carried out as Step 2. This makes it possible to estimate the price of renovating and energy consumption. Where the house owner was unsure which solution to choose, actual prices were collected for the different options to enable a more precise determination of the costs. Once the analysis was carried out, the house owner could make an informed choice, Step 3, and the date for the renovation could be set. The OSS was to keep the house owner informed throughout the execution of the renovation, Step 4. Afterwards, the results were to be verified through measurements, and if there are any faults, they were to be rectified, Step 5. This was to ensure that the house owner would get the best possible outcome from the renovation.

Measurements of energy consumption and indoor climate were to be made on the houses over a 12-month period both before and after the renovation. The before measurements are very important because they set a baseline, enabling better analysis of the measurements obtained after the renovation. These results can then be compared to simulations of the house, predicting the energy saving that could be obtained.

To determine whether the OSS approach has been successful, a number of statements were to be evaluated based on interviews with the house owner, analysis of the measurements, and the experience gained by the researchers and building professionals during the project. Paper I (Bjørneboe et al., 2017) says:

“For the use of the OSS-concept to be a success, the following propositions should be true:

- The owner should have been informed about the best possible solution for the house
- The house owner should have been assisted through the decision-making process
- The house owner should have had only one contact person throughout the process
- The house owner should have had less administration due to the One Stop Shop
- The house should have received a relevant renovation, successfully upgrading the house
- The house should have a lower energy consumption than before the renovation.”

### 3.1.2 Results

#### 3.1.2.1 Finding suitable participants

Finding suitable participants turned out to be a longer process than anticipated. While many showed an interest in participating, this type of project has turned out to have a very large dropout rate, see Table 4. From the beginning of the project, a total of 7 houses were actively involved, but only one house completed the renovation. The houses left the project for different reasons: dissatisfaction with the scope or timeframe of the project; moving to a bigger house or another country; refusal of a bank loan or not being able to implement all the desired improvements within the budget.

It was possible to use 1–2 houses to evaluate the OSS-concept, because one completed the whole process and the other participated in the project until Step 4.

*Table 4 – Time schedule showing the houses participating in the project. The houses were included in the project in the green periods and left in the red periods.*

HOUSES INCLUDED IN THE PROJECT												
Year	2011				2012					2013	2014	
Month	05	10	11	12	01	04	05	06	09		03	09
1 House I	Green	Red										
2 House II	Green	Red										
3 House III	Green	Red										
4 House IV			Green	Green	Red							
5 House A						Green						
6 House V						Green	Green	Red				
7 House B						Green	Green	Green	Green	Green	Green	Red

### 3.1.2.2 Step 1 – Initial evaluation

The evaluation covered durability, functionality and energy improvements.

The durability of the various building parts was assessed for both houses to estimate their remaining service lifetime. In House A, the windows needed replacement and the roof only had a few years left so the house owners wanted to replace it. In House B, some of the windows needed replacement, and the roof was approaching the end of its service life.

Possible improvements in the functionality of each house based on the wishes of the house owners were identified through dialogue with the house owners. The main goal in identifying all the changes the house owners could wish for was not necessarily to implement them all during the renovation, but just to make sure the renovation prepared the house for these improvements rather than blocking them. In House A, the owner wanted to renovate the bathrooms and utility room, install solar panels, and increase comfort through energy improvements such as extra insulation in the building envelope. In House B, the main motivation for renovating was a wish for more space, so the owner wanted an extension, changes in room layout, and to raise the ceiling to the roof and add roof lights in dark parts.

Using the durability estimates and the desired functional improvements as a starting point, beneficial energy improvements were identified. In House A, it was extra insulation of the roof and façade, new windows and doors, and new mechanical ventilation with a heat exchanger. In House B, the suggested energy improvements included extra roof insulation, changing some windows, façade insulation if economically feasible, and mechanical ventilation with a heat exchanger.

### 3.1.2.3 Step 2 – Analysis

The scope of the renovation in House A was to replace roof, windows and doors, add/replace façade-insulation, and install ventilation. The ventilation was very important because renovation of the building envelope can reduce infiltration, with a negative effect on the indoor climate if not addressed. Three different solutions were evaluated for the façade: external insulation, either with boards or plastering, or replacement of the existing cavity insulation. While external insulation would provide by far the largest energy saving (44–48 kWh/m<sup>2</sup> heated floor area per year, compared to only 16 kWh/m<sup>2</sup>), the cost of these solutions was also much higher, resulting in a cost of conserved energy (CCE) of 0.63 or 0.92 DKK/kWh compared to only 0.09 for the cavity solution. All three solutions were economically feasible compared to the energy price of 1.11 DKK/kWh<sup>vi</sup>, but

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<sup>vi</sup> Based on the weighted energy price for gas and electricity for this house in 2012/13. Before the renovation 74.5% of the heating was based on gas (8.9 DKK/m<sup>3</sup>=0.81 DKK/kWh), 22.4% of heating was based on electricity (2.1 DKK/kWh). The remaining 3% came from the wood-burning stove, which has not been included in the price calculation.

the large-scale work involved in implementing external façade insulation combined with the economic incentive persuaded the house owners to choose cavity insulation.

An important aspect to take into account in the renovation of House B was how to extend the house and change the room layout to get an extra bathroom and an extra children's bedroom. These changes were not necessarily to be executed at the same time as the renovation, but it was important to ensure that the renovation prepared the house for this extension instead of blocking it. A suggestion created as part of the analysis is shown in Figure 18.



*Figure 18 – Layout of House B before and after the suggested changes.*  
(Bjørneboe et al., 2017)

The energy cost analysis showed that, because the house already had some effective cavity insulation, additional insulation of the wall would not be economically feasible. The CCE for adding external wall insulation was 1.5–2.2 DKK/kWh, and the energy price for heating this house using gas was only 0.8 DKK/kWh. The plan was, however, that the renovation would include replacement of the roof, including extra insulation and a new vapour barrier because the old one was in poor condition, replacement of the old windows, and the installation of a mechanical ventilation system with a heat exchanger.

#### 3.1.2.4 Step 3 – Decision

Around the time when the house owners of House A had to make a decision, it was found that the original OSS contact would not be able to complete the project as intended. The research team therefore took over the OSS in this project, and three quotations were sought for the execution. The companies were chosen based on their experience within the field of renovation, and the house owners were free to choose the company they preferred based on price, personal impression, and the content of the offer.

Late in the process, the owners of House B chose not to go through with the renovation, and instead put their house up for sale and looked for a larger house in the same area.

### 3.1.2.5 Step 4 – Renovation

During the renovation, the house owners had an independent site engineer to help them through the process, check the progress of the contractor, and ensure that any faults found were corrected immediately. During the renovation, the house owners, advisors and craftsmen held meetings on site every week.

### 3.1.2.6 Step 5 – Validation

The energy level of the house was determined using the official program, Be10 (SBI, 2006), before and after the renovation. According to these simulations, the house would achieve a saving in energy for heating of about 42%, going from E to C on the EPC-scale saving in the total energy consumption that was measured in the house was about 42 kWh/m<sup>2</sup>, which corresponds to a saving of about 24% of the total energy consumption before renovation.

### 3.1.3 Partial conclusion

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The original scope of the study was to complete up to three renovations, but this proved difficult due to a high dropout rate. However, although only one renovation was completed, which prevented comparison between cases, the study still has the merit of being a representative case (Yin, 2003).

This study was carried out to test the 1<sup>st</sup> sub-hypothesis by answering the first research question:

*Will the use of the One-stop-shop concept improve the process of renovating and result in better renovations with a lower energy consumption because the house owners are guided through the process?*

The answer to the 1<sup>st</sup> research question is a cautious Yes.

This study found no evidence that the OSS concept would motivate more people to renovate, but on the positive side, the use of this approach probably helped to extend and improve the renovation that was carried out. The use of an independent advisor was found to be very beneficial. The initial evaluation was also positive, because it helped the house owners identify options they were unaware of before.

Since this study was made, a new scheme called BedreBolig (see section 2.2.4.4 page 23) has been introduced with many of the qualities of an OSS. If expanded and used properly, this may help to inform and guide house owners through the process of renovation.

## 3.2 Part II – Result of a renovation, measurements and simulations

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The research in this section is in Paper II: *Evaluation of the renovation of a Danish single-family house based on measurements*, which has been accepted for publication. This study was aimed at testing the 2<sup>nd</sup> sub-hypothesis.

When a house needs renovation for necessary maintenance, this is a great opportunity to implement energy improvements and update the functions of the house at the same time with the least inconvenience and at the lowest cost. However, too many renovations are carried out with only one purpose in mind: maintenance, lower energy consumption, or functional improvements.

This study is an example of a holistic approach, in which all three aspects are integrated in a renovation case. The energy-saving and comfort increase achieved through the renovation of this SFH has been documented through measurements before and after the renovation, and compared with dynamic simulations. Moreover, an economic evaluation of the renovation has been carried out, including investment cost, savings achieved, and changes in the value of the house.

### 3.2.1 Method

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A number of measurements were made in the house both before and after the renovation, see Table 5. The energy consumption was weighted using the degree days method to make it possible to compare the energy consumption during the year before with the year after the renovation. The analysis included distinguishing the energy consumption for heating from the energy consumption for everything else.

The resulting value was compared to the saving estimated using the dynamic simulation program BSim (SBi, 2015), in which a model of the house was built and simulated before and after renovation using actual weather data from the area and period.

In addition, the energy level of the house was determined before and after the renovation using the program Be10 (SBi, 2006), which makes it possible to benchmark the house compared to other houses.

Changes in user behaviour and the increase in comfort were estimated from the measurements made in the house and interviews with the house owners.

Table 5 – Measurements made in the house

MEASUREMENTS	
Single measurements and readings made before and after renovation	Thermographic pictures Blower-door pressurization The total electricity consumption over a 12-month period The total gas consumption over a 12-month period The house owners' opinions on the renovation were determined through interviews
Continuous measurements made for a year before and after the renovation	Logging of temperature every 10–15 min in all rooms
Readings made by the house owners in the year after the renovation	Date and time of the reading The total electricity consumption shown by the electricity meter (for heating and appliances) The total consumption shown by the gas meter (for heating and hot water) Electricity consumption of the heat pump measured by an energy-cost meter (SparOmeter) Electricity consumption of the electric convection heater measured by an energy-cost meter Notes specifying when the house was empty, when the wood-burning stove was in use, etc.

### 3.2.2 Results

#### 3.2.2.1 The house and the renovation

The renovated house is a 160 m<sup>2</sup> SFH from 1965 (extended in 1975). The plan of the house is shown in Figure 19. The estimated thermal transmission of the various building parts is shown in Table 6. The house received new 3-layer windows, new external doors, a new roof with a raised roof construction to allow for extra insulation and make room for ventilation pipes, a new mechanical ventilation system with heat recovery, replacement of existing skylights with energy-efficient solutions, and replacement of the cavity insulation in the façades.

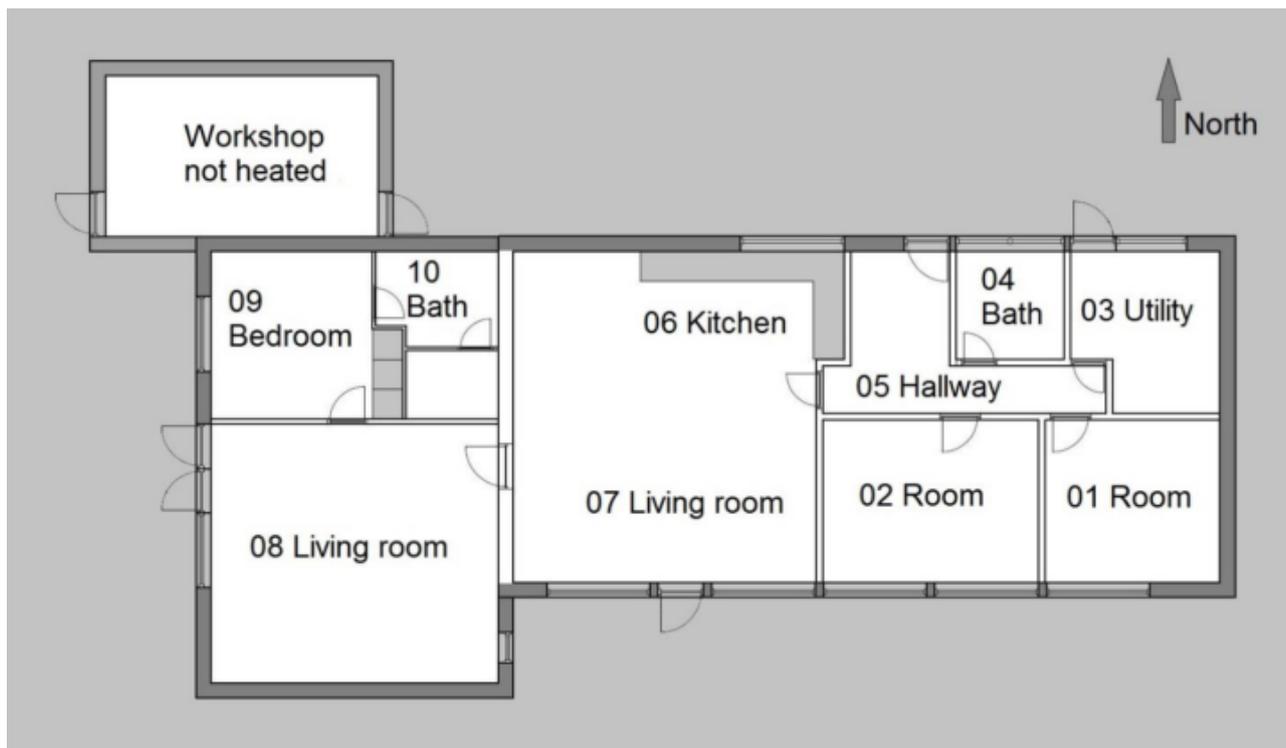


Figure 19 – Plan of the house.

Table 6 – The assumed thermal transmission of the affected building elements before and after the renovation.

THERMAL TRANSMISSION OF BUILDING PARTS		
	Before renovation W/m <sup>2</sup> K	After renovation W/m <sup>2</sup> K
Windows	1.07–4.80 (2.74)	0.63–0.87 (0.71)
Doors	2.00–3.54 (2.71)	0.70–1.39 (0.91)
Roof	0.49	0.10
Skylights	3.52–4.93 (4.23)	1.3
Façade	0.67	0.37

Note: The before-values are estimates based on the house, the construction, and traditional building practices. The after-values include product information on the new materials and building parts. For windows, doors and skylights, where the value covers more than one type, the table shows [min-max (average)] thermal transmission.

### 3.2.2.2 Measurement results

Measurement with an infrared camera before renovation showed that the existing insulation in the cavity walls was in a bad condition. The after-pictures showed that this problem had been solved, and the general heat loss through walls and windows had been reduced. A pressurisation test documented that the infiltration in the house had decreased from 0.19 l/s m<sup>2</sup> before to 0.09 l/s m<sup>2</sup>, making it as tight as new houses built at that time.

Analysis of the measurements of the energy consumption showed a reduction in the energy consumption for heating of 53%, corresponding to 9889 kWh in a standard year. This was in good agreement with the energy saving of about 58% that was found through simulations, although the simulations in general estimated higher energy consumption both before and after renovation.

The renovation moved the house from an EPC level of E to C according to the Be10 calculation, see Figure 12 page 22 for reference. The renovation enables the house to achieve Renovation Class 2 according to the building regulations, see Figure 11 page 21.

The temperature measurements carried out in the house both before and after the renovation showed that the often occupied rooms (rooms 06, 07 and 08) received a slightly more even temperature after the renovation, while often unoccupied rooms (01, 02, 03 and 05) received a temperature increase, reducing cold draughts within the house. On average, the temperature had increased by 1.01 °C in the house. This shows that while the energy renovation has created energy savings for heating in some rooms, part of the saving has been spent on comfort by increasing the temperature in other rooms.

To show that a higher outside temperature during the year after renovation was not the cause of the inside temperature increase, an evaluation was made for a shorter period of 3 days at the end of a 5 day period with similar weather conditions in the years before and after. The analysis showed a temperature increase of 1.3°C on average.

### 3.2.2.3 Economic aspects

Before the renovation, the house was valued by their mortgage bank at about DKK 4.5 million (about EUR 0.6 million). The renovation and including the bathroom and utility room cost a total of about DKK 1.3 million.

After the renovation, the house was evaluated again by the mortgage bank, and by a real estate agent. They both found the house now had a value of DKK 5.7 million, an increase of DKK 1.2 million, of which DKK 200,000 can be attributed to an increase in housing prices (Statistics Denmark, 2016).

The remaining increase in value corresponds to 77% of the investment. Moreover, the cost of heating the house has decreased by about DKK 8,400 a year.

### 3.2.3 Partial conclusion

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This study was carried out to test the 2<sup>st</sup> sub-hypothesis by answering the second research question:

*When a renovation is based on necessary maintenance and includes energy improvements and functional upgrades, is it possible to improve the house and reduce the energy consumption for heating by 50% within a feasible budget?*

The answer to the 2<sup>nd</sup> research question is Yes.

Through measurements and analysis, this study has documented a holistic renovation of a SFH. The renovation was based on necessary maintenance of the house, but it also included renovation in accordance with the house owners' wishes and better-than-minimum energy improvements, resulting in a 53% drop in heating energy consumption. In combination, the increase in house value covered 77% of the investment. The house owners were very pleased with the renovation, as it increased comfort in the house, both summer and winter.

### 3.3 Part III – Policy to support renovation of houses

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The research in this section is in Paper III: *Initiatives for the energy renovation of single-family houses in Denmark evaluated based on barriers and motivators*, which has been submitted for peer review. This study was aimed at testing the 3<sup>rd</sup> sub-hypothesis.

A lot of different barriers keep owners of SFH from engaging in advanced energy upgrades of their houses. It is a political goal in Denmark and the European Union to reduce energy consumption, and the owner-occupied housing sector has been identified as having great potential for achieving energy savings, so it is important to make relevant and effective policies to encourage progress in this field.

This study had a threefold purpose. The first was to create an overview of current Danish policies and information sources in the field. The second was to collect all the known barriers to the dissemination of energy renovation of SFH and put them in a framework to identify the areas where current policy is effective and where further effort is necessary. The third was to use the result to make suggestions on how the policy in this area can be improved to achieve more renovations.

#### 3.3.1 Method

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The current Danish initiatives were mapped by using information from the literature and official websites.

The acknowledged existing barriers and motivators for the energy renovation of single-family houses were identified in a study of the literature and collected in a framework consisting of three fields: information, finance, and decision-making, each with three sub-areas, see Figure 20.

The framework of barriers and motivations was then used to evaluate the current Danish schemes to identify the areas that need further attention. Based on this and experience from other countries suggestions are made for the improvement of current Danish policy.

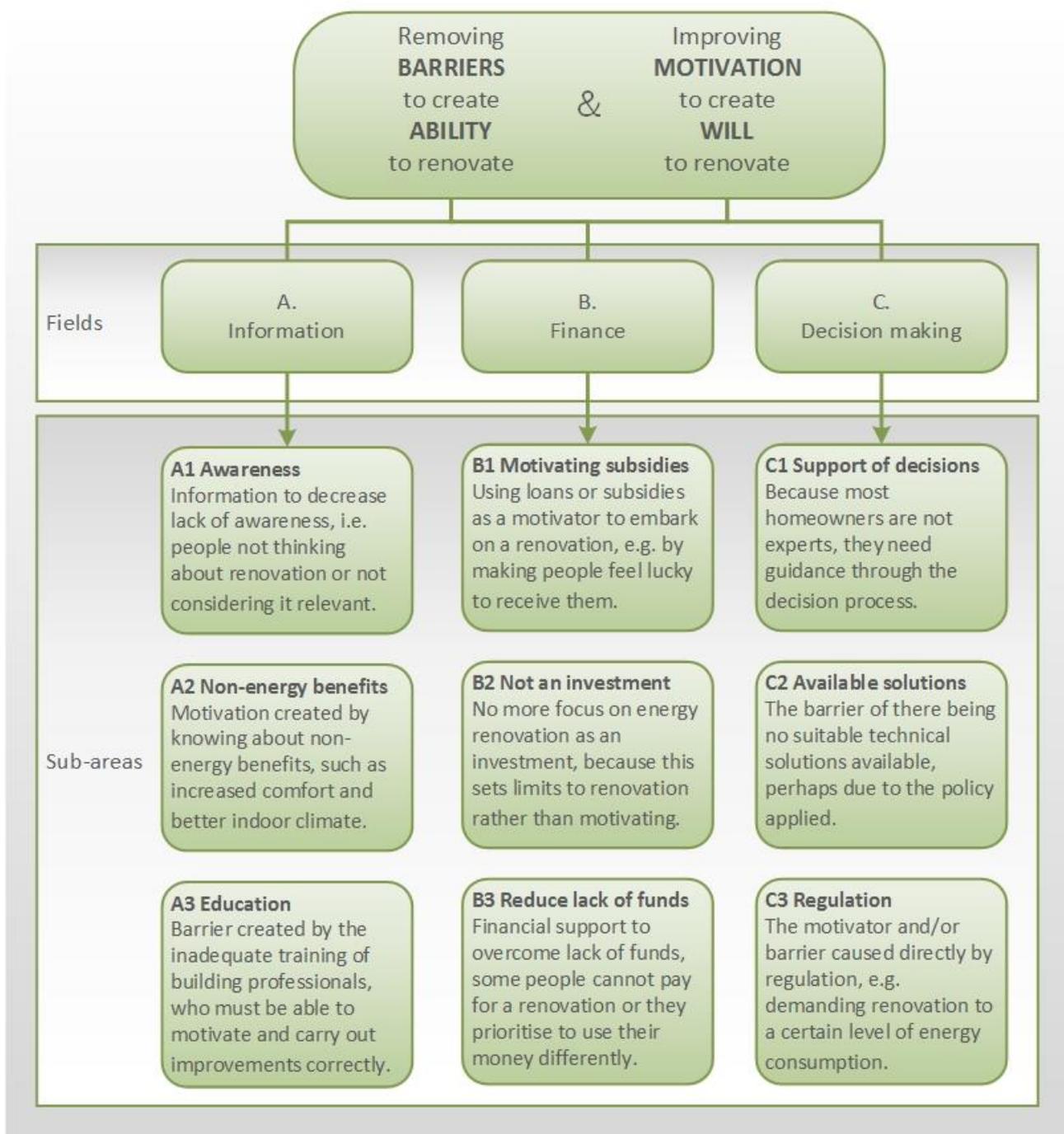


Figure 20 – The three main fields of elements acting as barriers and motivators for energy renovation. In each field, three areas are identified.

### 3.3.2 Results and partial conclusion

Table 7 shows current Danish schemes in a framework of barriers and motivators. In the field Information, it was found that schemes are already in effect to raise awareness and provide training for building professionals, but there is very little focus on promoting non-energy benefits. More problems were found in the field of Finance, because the subsidies available are insufficient, and there is too much focus on energy improvements as a financial investment while the barrier created by having a lack of funds is not addressed at all. When it comes to the field of Decision-making, the main problems are that help is only given to those who actively seek it, that current policy only promotes small improvements, and that the area of renovation is not adequately regulated and the regulations that do exist are not enforced.

*Table 7 - Current Danish schemes and the areas of barriers and motivators they influence. A1 - Raising awareness, A2 - Promoting non-energy benefits, A3 - Educating professionals; B1 - Subsidy motivator, B2 - Investment, B3 - Lack of funds; C1 - Support decisions, C2 - Available solutions, C3 - Regulation. (Grøn Bjørneboe et al., 2017)*

CURRENT DANISH SCHEMES BASED ON BARRIERS AND MOTIVATORS									
	Information			Finance			Decision making		
	A1	A2	A3	B1	B2	B3	C1	C2	C3
The Building Regulations									X
EPC-scheme	X	(x)	(x)		X		(x)	(x)	
BedreBolig	X	(x)	X		X		X	X	
Subsidies				X		(x)			
House condition report	(x)						(x)		

This study was carried out to test the 3<sup>rd</sup> sub-hypothesis by answering the second research question:

*Can documenting the known barriers and motivators for energy renovation be used to identify shortcomings in current schemes, leading to concrete suggestions for improvements?*

As answer to the 3<sup>rd</sup> research question is Yes.

The analysis resulted in a suggestion of four topics on which improvements could be made to the current policy: focus, financial support, a renovation plan and regulation.

The focus when promoting energy renovation today is concentrated on the economic savings that can be achieved when energy consumption is reduced. But while it is a positive thing that this improvement can save money, it treats renovation as an investment requiring economic feasibility to be considered. In most cases, it would be better to promote energy renovation by focusing on the comfort improvements that it can provide. In this way, the money saved would be a benefit, instead of setting limitations.

With regard to financial support for renovation, the current financial subsidy system does not deal with the barrier of lack of funds. The subsidies available help promote small renovations but are close to symbolic for large renovations. If politicians are serious about wanting to generate major energy savings in this sector, the subsidy system must be extended with a lot more funds and targeted towards the levels of renovation desired.

There are still a lot of people who do not seek information about energy renovation of their house, yet today, the initiative is with the house owners alone. This problem could be approached by creating a specific renovation plan for houses when they are put up for sale. This could be based on the existing EPC, the status report, and the BedreBolig plan, and be followed up within a year of the new owners taking possession of their house.

If serious energy reductions are to be achieved in the SFH sector, it will be necessary to use regulation as well as motivation. However, it is very important not to just strengthen the requirements that have to be met when renovating, because this might simply keep people from renovating at all. Instead, long-term policy could be used to gradually reduce the maximum level of energy a house is allowed to consume. This would require great attention to the risk of social imbalance to avoid problems as the housing stock is upgraded.

## 4 DISCUSSION

The previous section described the investigations conducted to evaluate the main hypothesis:

**H:** *The number and level of energy renovations of Danish single-family houses may increase if the process of renovation is improved to motivate house owners to act and policies are adopted to remove barriers.*

This was done by testing and improving the method for conducting renovation of SFH and by looking into how policy schemes can be improved to increase the number and quality of renovations.

### 4.1 Part I

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The demonstration method used to test the OSS approach to renovation includes a very large degree of uncertainty, because it is difficult to set a clear baseline for comparison. A lot depends on the specific house, the house owners, and the varying quality of advice they might have received from outside the project. The baseline in this project was set as an estimation, based on common practice and interviews with the house owners.

In the case of House A, the house owners were planning to get a new roof, which according to the Danish building regulations at the time (Danish Ministry of Economic and Business Affairs, 2010) would have to include extra insulation that would reduce the thermal transmission from 0.41 W/m<sup>2</sup>K before to 0.15 W/m<sup>2</sup>K. In the renovation guided by the OSS, the thermal transmission was reduced to 0.08 W/m<sup>2</sup>K, and the renovation included cavity walls, 3-layer windows, doors and a new ventilation system. It is unlikely that all these building elements would have been included in the renovation without the OSS approach. However, although suggestions for more advanced energy solutions were chosen in some cases, such as the roof or windows, this was not always the case. For the façade, the house owners were reluctant to choose the extensive solution of external insulation, even though calculations found it to be feasible in terms of the cost of conserved energy (CCE). The simple solution of replacing the cavity insulation could only achieve about 1/3 of the energy saving, but it required less work and a smaller investment, resulting in a much lower CCE. This natural hesitation about implementing extensive solutions solely for the sake of saving energy, creates a limit for the size of the energy savings that can be expected in this segment.

Due to the change in the OSS provider during the project, the services (architect, engineer, and contractor) were detached and not integrated in the OSS. The house owners continued to have only one contact person, but the changes resulted in a more flexible process, in which services could

freely be chosen and integrated in the project. In this way, the OSS worked more as an independent advisor. The success of this approach indicates that the process of renovation might benefit more from the increased use of advisors, than from promoting the complete OSS concept.

The house owners found it very informative to have the remaining lifetime of the various building parts presented to them. It helped them realise that the renovation would not only reduce energy consumption in the future, but would also catch up with the maintenance backlog. In general, the process of renovations would benefit from better presentation and visualisation to make it more comprehensible for house owners.

## 4.2 Part II

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The renovation successfully upgraded the house with regard to the durability of building elements, selected functional rooms, and energy consumption. Evaluations by the mortgage bank and a real estate agent showed that the house had increased in value by an amount corresponding to 77% of the investment. The renovation resulted in increased comfort for the house owners, who can now maintain a pleasant temperature and avoid cold draughts all year round. The increase in comfort can be measured to some degree, e.g. as an average increase of about 1 °C in the house. This temperature increase is a benefit for the house owners, but from a national perspective it could be perceived as a problem. This rebound effect, where energy-saving measures result in additional energy consumption, e.g. for heating, makes it difficult to estimate the actual saving that can be achieved, both for an individual house and on a national scale, and it hollows out the effect of energy-saving measures for the sake of saving energy.

The house achieved a measured saving of more than 50% of the energy consumption for heating. This corresponds to about 23% of the total energy consumption in the house, and confirms that there is a significant energy saving to be achieved in this sector, even with the rebound effect. In theory, if all single-family houses in Denmark were able to achieve a similar saving of 23%, it would reduce Denmark's total energy consumption by 5% and save more than 30 PJ or 8.611e+9 kWh per year<sup>vii</sup>.

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<sup>vii</sup> This is a theoretical example, because it has not been investigated whether the 23% saving is at all representative of the saving that can be achieved across the stock of single-family houses in Denmark. This is a simple scaling based on the investigated house, to show that a saving of this size could make an impact on a large scale. The values are calculated based on figures from the DEA (2015a).

### 4.3 Part III

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The research on how to improve Danish policy schemes to overcome barriers and motivate more house owners to renovate resulted in four main points that can be addressed: focus, financing, a renovation plan, and regulation.

There is a massive focus today on energy renovation as an investment that will pay for itself. The fact that energy-saving measures reduce expenses for heating has led to a natural interest in how much money could be saved, and whether it could balance out the investment. However, this has led to the assumption that there is no reason to implement energy-saving measures unless they are economically feasible, and can pay for themselves within just a few years. In this way, the economic saving that can be achieved through energy renovation has gone from being an incentive to setting active limits for energy renovation. This is a problem, because the economic benefits will often not outweigh the inconvenience of having your house renovated, and extensive renovations will often require a very long timeframe to be feasible. If the goal is extensive renovations, it would be desirable to move the focus to the other benefits and the need for renovation, and reduce any economic gain into an added benefit.

At the present time, Danish policy does not deal with the problem that many house owners lack available funds to make extensive energy renovations. The various subsidy systems only supply very small amounts, which cannot make a difference in larger projects. If the aim is to maintain the current pace and support large numbers of small, easy improvements, this may be a good approach. However, it does not increase the number of extensive renovations, and it is not very effective when it comes to making Denmark independent of fossil fuels. When all the small cheap improvements have been implemented, the remaining options become less attractive, because the saving compared to investment becomes less and less.

In some foreign schemes, attempts have been made to solve the funding problem by introducing pay-as-you-save schemes. However, this approach leads back to the first point, where the economic feasibility of energy-saving solutions sets limits on the level of renovation and reduces the total energy saving that can be achieved.

The third point where improvements to policy could be made is in developing long-term renovation plans. The investigations in Part I showed that house owners may not be aware of the maintenance their house requires. This is backed up by a survey from 2012 (COWI, 2012), which found that more than half of the house owners whose homes had building parts in need of maintenance were seemingly unaware of it. This lack of knowledge among house owners has resulted in a maintenance

backlog in this sector<sup>viii</sup>. The EPC has turned out to be a useful tool for increasing awareness about energy consumption, but it has not been found useful for house owners who want to renovate. To make it useful, it needs to be more specific for the house, and it could include a maintenance plan for the house owners to follow at their own pace. In this way, the house owners would have a clear idea of what maintenance their house requires and when it requires it, and they could receive information about mandatory energy improvements in this context, as well as inspiration for achieving further savings. This type of renovation plan could be created by combining and developing existing documents, the EPC, the house status report and the BB-plan.

If massive savings are to be achieved across the stock of SFH, it will be necessary to look into regulation as well as motivation. Today the building regulations only apply to those who have already chosen to renovate. They do not address those who live in houses with a large energy consumption, but are not considering renovating. If the whole building stock is to be upgraded to low-consumption buildings, it would make sense to target the buildings with the highest consumption first, by putting a ceiling on the maximum allowed energy consumption per m<sup>2</sup>. This would ensure that the building stock would be updated fast if, for example, this target had to be met within a year or two of the house changing owner. This would, however, require considerable funding, as well as care to avoid increasing social imbalance.

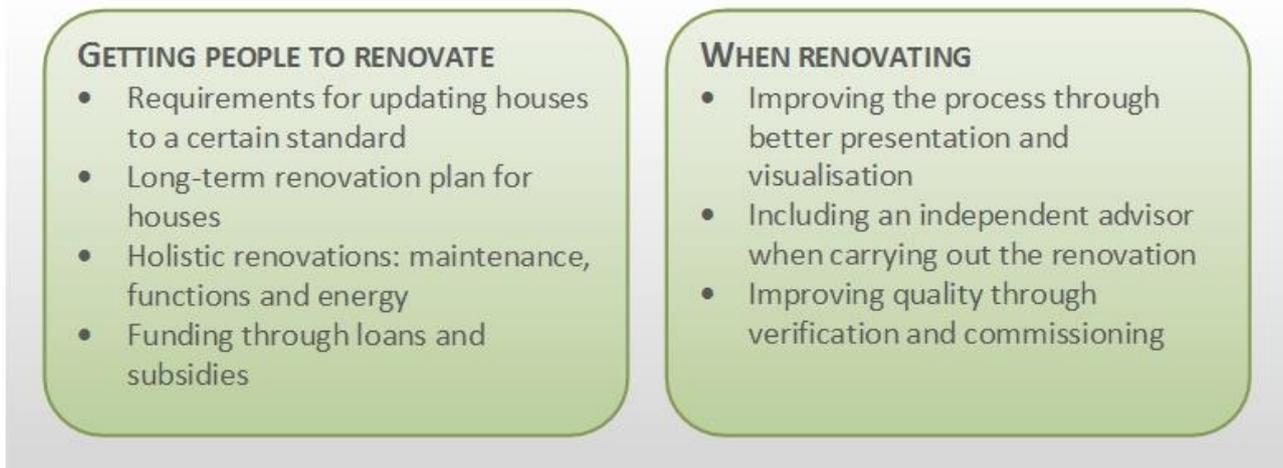
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<sup>viii</sup> In 1998, the maintenance backlog in SFH was found to be DKK 8000 million. The same figure was still found to be an acceptable approximation in 2011 (DACC and GI, 2011)

## 4.4 General discussion

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In general, to increase the number and level of renovations in SFH, the investigations have shown that it will be necessary to change policy and improve the process in several places, see Figure 21.



*Figure 21 – Suggested improvements to get people to renovate and to improve the process.*

### 4.4.1 Getting people to renovate

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If all houses are to be renovated to a certain level, regulation will be needed as well as motivation. Motivation can work effectively for people in average houses who want to improve them, by offering funding options and information on the benefits. Regulation, such as setting a maximum allowed energy consumption per square metre, would be more effective in getting the houses with the highest energy consumption renovated or replaced.

To tackle the lack of knowledge among house owners about the actual maintenance needs of their homes, they should receive a relevant renovation plan. Instead of giving more or less random suggestions for improvements like the EPC does, the plan should be based on the specific house and give information about the expected maintenance over the next 10–30 years. This would tell the house owners what to expect over the many years, and they will not refrain from renovating due to lack of knowledge. As suggested in Papers I and II, the plan should also include the house owners' own wishes for functional updates if possible, and not only the energy requirements in connection with such planned renovation, but also inspiration on how to save more energy and achieve other benefits when building parts are renovated or replaced. Some of these aspects are already included in the new BedreBolig-scheme, but since this is market-based, it will only reach those already considering renovation. To achieve large-scale benefits, such a scheme must become mandatory to

some degree, e.g. like the EPC in connection with sale, though if attached to sale, it must include some follow-up, because the important part is to involve the new owners, not the old.

However, planning alone will not create the development. It will be necessary to back this up with funding. The lack of funds for what is a considerable investment remains one of the main barriers to energy renovation, yet today it is not addressed at all in the Danish policy schemes. To increase the number and scale of renovations, large loans and non-symbolic subsidies must be made available. This is especially important, if regulation is used to force the improvement of the building stock as suggested.

#### **4.4.2 Improving renovations**

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The process of renovation can be improved in a number of ways. One way is to make the possibilities and the process more accessible and transparent by better presentation and visualisation. The agreement made between house owner and craftsmen can be very technical and full of exceptions, which can be difficult for a house owner to comprehend. In this area, too, the OSS concept has many benefits, because most of the administration and meetings between different work fields are kept within the company, enabling a smoother process for the house owner. Nevertheless, it might be beneficial to have an independent advisor when it comes to determining the scope of the renovation and the quality of the work, both on the building site and in the following verification. In general, the sector would benefit from an increased use of advisors and commissioning that ensures the result is as expected, so that house owners get the most out of their renovation.

# 5 CONCLUSION

In this section, the three sub-hypotheses and the main hypothesis are evaluated on basis of the findings in the investigations.

## 5.1 1<sup>st</sup> SH – The use of One-Stop-shop

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1<sup>st</sup> SH        *The use of a One-Stop-Shop concept to guide their decision-making will motivate house owners to add energy renovation components to comfort or maintenance renovations, and their house will receive a more energy-efficient and extensive renovation than with an unsupervised renovation.*

The first sub-hypothesis was (with caution) found to be true.

Due to various circumstances, the study was based on very few cases (1–2). This is not enough to come to strong conclusions, even though the study has merits as a representative case. To draw a strong conclusion, more cases need to be tested.

However, even if it cannot be said that the use of OSS motivated house owners to start their renovations, it did guide the house owners through the process and ensure a more holistic renovation with more energy saving than would be expected from a non-supervised renovation.

## 5.2 2<sup>nd</sup> SH – The holistic renovation

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2<sup>nd</sup> SH        *Energy consumption for heating can be significantly reduced if energy efficiency work is carried out together with maintenance renovation to update design and functionality in accordance with the house owners' wishes – and it can all be done within a feasible budget.*

The second sub-hypothesis was found to be true.

In a renovation based on necessary maintenance, the energy consumption for heating in the house was brought down by more than 50%. The renovation also included updating a bathroom and a utility room. In addition to reducing the energy bill, the renovation also increased the value of the house by an amount corresponding to 77% of the investment (excluding the effect of the general rise in house prices at the time).

### 5.3 3<sup>rd</sup> SH – Barriers and motivation

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3<sup>rd</sup> SH: *The documentation of barriers and motivators for house owners to initiate energy efficiency improvements on their house can identify deficiencies in current Danish policy, so that relevant recommendations for improvements can be made.*

The third sub-hypothesis was found to be true.

The various barriers and incentives for the energy renovation of single-family houses are described in the literature, which made it possible to document them in a clear framework. This could be used to evaluate current Danish policies in the field and to identify four points that need special attention: the focus, financing, renovation plans, and regulation.

### 5.4 Main Hypothesis

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H: *The number and level of energy renovations of Danish single-family houses may increase if the process of renovation is improved to motivate house owners to act and policies are adopted to remove barriers.*

The hypothesis was found to be true.

Improvements in the process and the planning can motivate people to choose better and more extensive renovations (rather than minimum maintenance). Here it is important to plan holistic renovations based on necessary maintenance or wishes for functional improvements, rather than simply promoting energy renovation alone. The house owners should receive adequate advice, and be guided through the process.

The identified barriers to energy renovation of SFH can be removed or reduced if policies are changed and extended to target the problem areas. The main points are: to stop seeing energy renovation as an investment because this creates more limits than motivation; to supply better means of financing, e.g. through loans and subsidies; to make long-term holistic renovation plans based on maintenance and inspiring energy improvements; and, finally, to push the development along using regulation that targets the houses with the highest consumption.

## 6 PERSPECTIVES AND RECOMMENDATIONS

The original scope of this study was to carry out three renovations so that it would be possible to come to stronger conclusions and make comparisons. But, despite having a total of seven houses actively participating in the project over time, only one actually completed the intended renovation. Researchers performing similar studies need to be aware of this very high drop-out rate, because it will be necessary to continue the work with relevant case studies so that we can increase our knowledge and draw strong conclusions about the renovation process in SFH.

The initial planning of a renovation is a good way to raise awareness and help identify any maintenance backlog in the house that the house owners may not be aware of. But such information should not be limited to those who seek it. To drive the development forward, assistance with such planning should also be offered and made available for those who are not currently thinking about renovation.

Most houses would benefit from having a long-term renovation plan based on the necessary/advantageous maintenance over the next 10-30 years. While this is being produced, the house owners could include their wishes for updating the functions of their house, and receive information about minimum requirements for energy improvements and inspiration to go further.

The One-Stop-Shop (OSS) was found to be a good concept in terms of guiding the house owners through the process, and ensuring the quality of the renovation, in terms of both careful planning and validation after the renovation. It was also a great benefit to have an independent advisor. This gave the house owners a larger degree of freedom to act.

It is important to have validation to ensure that the renovation has provided the expected outcome, but it should not be expected that 100% of the possible energy saving will be achieved. The so-called rebound effect means that a varying portion will probably be used on comfort improvement.

It has done energy renovation a serious disservice to focus as much on the economic saving that can be achieved as has been the case in recent years. This has meant that people have come to expect that an energy renovation should be able to pay for itself within few years, and if it cannot do so, see no reason to implement it at all. When energy improvements are seen as an investment, the money saved sets a limit for the level of renovation, rather than being an added incentive. It would

be beneficial to no longer look at energy renovation as an isolated event, but as an integrated part of a general renovation and update of the house.

If Denmark's long-term political goals are to be met, it will be necessary for society to invest in energy renovation. Today there is no support that can overcome the barrier consisting of a lack of funds. An extensive renovation of a house can be a very large investment for a house owner, and many people will not have the money for it, unless they have been living in their house for a long time and have equity to draw on. Targeted loans and subsidies would enable more people to carry out extensive renovations, thereby contributing to reaching the long-term goals for a society independent of fossil fuels.

Finally, it will probably be necessary to use regulation to reach those who cannot be motivated by incentives alone. To achieve the greatest effect, the regulation should target those with the highest energy consumption, e.g. by putting a ceiling on the maximum allowed energy consumption per m<sup>2</sup> in a house. This ceiling could take effect when houses are sold, with an injunction to reach an acceptable energy level within a year or two of buying the house. To avoid a regulation like this creating social imbalance, it would be necessary to back it up with a funding system, because people living in old, unrenovated houses often do not have funds available for renovation.

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## **Case study: Using a One-Stop-Shop concept to guide decisions when single-family houses are renovated**

*Matilde Grøn Bjørneboe; Svend Svendsen; Alfred Heller*

*Journal of Architectural Engineering; 2017*

[http://ascelibrary.org/doi/abs/10.1061/\(ASCE\)AE.1943-5568.0000238](http://ascelibrary.org/doi/abs/10.1061/(ASCE)AE.1943-5568.0000238)

- Case study on the process of an extensive renovation of a Danish single-family house
- Using a One-Stop-Shop (OSS) concept to guide the house owners' decision-making
- Using an OSS is, in itself, not enough to motivate people to renovate
- However an OSS can most likely help expand and improve a renovation

## **Evaluation of the renovation of a Danish single-family house based on measurements**

*Matilde Grøn Bjørneboe; Svend Svendsen; Alfred Heller*

*In Press, Energy and Buildings; 2017*

- A Danish single-family house renovated: durability, functions and energy
- Simulation of the house before and after renovation
- Measurements of energy and indoor climate during a year before and after
- A saving of 53% in the heating consumption with better indoor climate
- Increase in house value corresponds to 77% of the investment, according to mortgage bank

## **Initiatives for the energy renovation of single-family houses in Denmark evaluated based on barriers and motivators**

*Matilde Grøn Bjørneboe; Svend Svendsen; Alfred Heller*

*Under review, Energy and Buildings; 2017*

- Creating a framework of barriers and motivators for energy renovation in homes
- Identification of four possible areas for improvement in current Danish policy
- Need for improved support through relevant renovation plans and financial support
- Focus on non-energy benefits and on stating maximum allowed energy consumption

# APPENDIX I – PAPER I

## **Case study: Using a One-Stop-Shop concept to guide decisions when single-family houses are renovated**

*Matilde Grøn Bjørneboe; Svend Svendsen; Alfred Heller*

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## **Case study: Using a One-Stop-Shop concept to guide decisions when single-family houses are renovated**

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### **Abstract**

One way of reducing the use of fossil fuels in Denmark is to look into possible energy savings in the building stock, especially the large number of single-family houses from 1960-80. Energy renovation in this housing segment is progressing slowly.

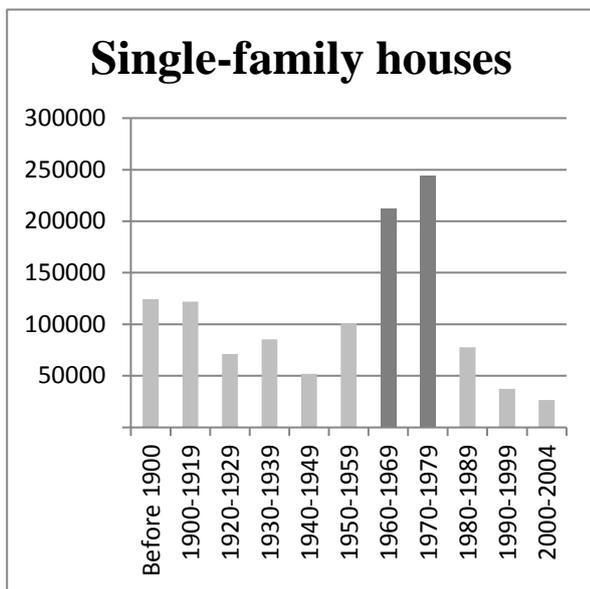
The aim of this project was to find out how a One-Stop-Shop (OSS) or full-service concept could be used to guide the extensive energy renovation of single-family houses. The purpose was partly to identify the benefits and disadvantages of using the concept, and partly to evaluate its potential for increasing the degree of renovation. The scope of the project was to carry out renovations on up to three houses.

The project showed that the concept on its own was not enough to motivate the house owners to engage in extensive renovation. However, interviews with the house owners indicated that the renovation that took place had probably been expanded and improved due to the use of the concept, and that the renovation in general benefitted from an independent advisor.

## Introduction

In Denmark, it is a political goal to reduce the use of fossil fuels to zero by the year 2050 (The Danish Government 2011). To achieve this, all electricity and heat supplied to buildings is to be based on renewable energy sources by 2035. The best solution for this is to find a balance between a sustainable energy supply and a reduced overall consumption.

One of the areas with the largest energy-saving potential in Denmark is single-family housing. In 2014, the total energy consumption, corrected with regard to climate, was 608 PJ, of which single-family houses accounted for 136 PJ, corresponding to 22% (The Danish Energy Agency 2015). This is the largest single contributor apart from road transport.



**Fig. 1.** Single-family houses in Denmark in 2014, shown by year of construction. Data from (Statistics Denmark 2014)

More than 450,000 single-family houses were built in Denmark in the period from 1960 to 1979, see Fig. 1. It is very relevant to look at this segment of housing in connection with energy renovation because there are a lot of them, they are very similar in construction, many of them have high energy consumption, and many of them need renovation soon due to their age. The potential for achieving savings in this segment of the building stock is confirmed by the Danish Building Research Institute (SBI). In a report from 2004 (Wittchen and SBI 2004), they estimated the potential for reducing heat consumption in the Danish building stock on the basis of values from the Danish Building and Housing Register (BBR) and a database, which contains all Danish buildings that have received an energy label as part of the EPBD programme (Energy Performance of Buildings Directive). The study

showed that the largest savings could be achieved in houses built before 1930 or in the standard houses of the 60s due to their large number.

The renovation of single-family housing is proceeding very slowly. The market for single-family house renovation is dominated by do-it-yourself work and a craftsman-based approach (Tommerup et al. 2010). A survey of Danish house owners (Bolius 2016), showed that about 50% seek the advice of craftsmen in connection with the maintenance of their houses, while only about 15% use professional advisors. A study of how Norwegian house owners think about energy renovation (Risholt and Berker 2013) showed the importance of craftsmen as advisors, and how good project management can help smooth the process, while a lack of knowledge is a barrier to reducing energy consumption.

This project is based on a One-Stop-Shop (OSS) concept, where the house owner is guided through the whole renovation process of their house, with a single contact person helping them. A number of projects has worked with the development and dissemination of OSS solutions. The project *SuccessFamilies* (2009-2012) aimed to change the business environment with the hope of speeding up the rate of sustainable renovations of single family houses, by creating full service concepts including e.g. technical solutions and financing services (Tommerup et al. 2010). An ERA-NET Eracobuild project *One Stop Shop* (2010-2012) tried to facilitate marked volume for extensive renovations of single family houses through a clustering of small and medium-sized enterprises (SMEs) thereby reducing the fragmentation of the renovation process (Haavik et al. 2012). The *COHERENO* project (2013-2016) aimed at developing a volume marked for renovation of single family houses to nearly zero energy buildings (nZEB), by strengthening the collaboration of enterprises e.g. in OSS partnerships in 5 countries (Straub 2016). Where the focus of these three projects were mostly on the business/professionals, this current case study investigates the OSS concept when applied to an actual renovation thereby enhancing the importance of the house owner/customer.

A group of researchers involved in the development of new business models for OSS solutions argue that when it comes to renovation, the decision-making process is a learning process for house owners, because they might not know what should or could be done (Haavik et al. 2010). When people are unaware of the potential for savings in their house, they will decide on maintenance and improvements based on their immediate needs or choose the cheapest solutions in the short term. Most people will not consider all relevant information, but rather be biased towards their initial starting point. In most cases the default option is preferred (Wilson and Dowlatabadi 2007). An analysis of the driving factors and obstacles for energy-efficient renovation of single-family houses in Switzerland (Jakob 2007), showed that only 7% of house owners intended to make comprehensive

renovations and modernisations, while 72% were following a strategy of step-by-step renewal or continuous upgrading and 18% were carrying out no more than minimum maintenance. In Denmark, a survey of people who own single-family houses built in 1960-80 showed that, while many have started implementing small improvements (like new windows), very few have carried out larger renovations, such as insulation of the façade (Mortensen et al. 2015).

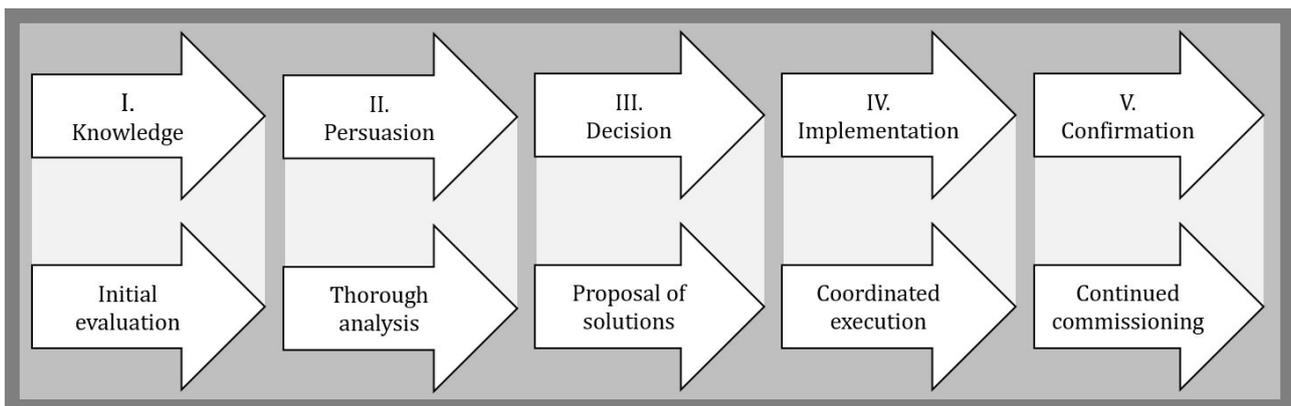
One way of removing these obstacles and encouraging renovation of the building stock would be to support the house owners in the decision-making process by making this process more structured and holistic (Galiotto et al. 2016). The idea is to focus on assisting the house owner in the process by looking at many different aspects of renovation not only energy, so as to encourage the house owner to choose the optimal renovation for their particular house. This current project also stresses the importance of assisting the house owner in the decision-making process. This assistance can ensure that the house owner's knowledge about the possibilities increases and that the renovation is relevant for the house and will save money in the long run. When uninformed customers do not demand energy conserving solutions, the initiative to inform must come from the building sector.

The most important factors influencing the decision making when it comes to large energy relevant investments was reviewed by (Kastner and Stern 2015). The focus was on owner-occupied semidetached or single family houses. They claim that this area is not yet sufficiently investigated, as the available research follows many different methods and cover a large area, which makes it difficult to draw strong statistical conclusions. One problem in particular is the focus on curtailment behavior (frequent actions, e.g. daily) where common behavioral models can apply. However even though energy relevant investments are linked to the daily life in the house, large investments are rare and follow another pattern more influenced by consequences than personal norms and habits. Even though lack of data prevented strong conclusions, one of the tentative conclusions they emphasize is the importance of receiving energy consulting from a reliable source, preferably face to face. Here the OSS-model has its strength, as the house owner receives relevant advice from the same source all through the project. The contact person will be able to emphasize the area's most important to the house owners, and thereby support the decision process.

An analysis of selected Belgian demonstration projects with respect to innovation and the experience of owner-occupants (Mlecnik et al. 2011) concludes that the development of an OSS solution might help to overcome some of the socio-technical obstacles that energy renovation of single-family houses faces today. Others have made the same point (Mahapatra et al. 2011, 2013) and argued that measures should be chosen based on their performance in holistic terms and with a long-term perspective. This project has the overall aim of making advice about extensive energy renovation

more accessible by using an OSS solution. House owners who are fully informed about the ideal renovation of their house are more likely to choose an extensive renovation.

Vanhoutteghem describes a full-service renovation concept which includes all aspects of the renovation process, divided into 5 phases: initial evaluation, thorough analysis, proposal of package solutions, coordinated execution of the renovation, and finally quality assurance and continued commissioning of the house (Vanhoutteghem et al. 2011). These phases are somewhat similar to the 5 step innovation-decision process defined by (Rogers 1962, 1995) and adapted and applied to the building sector by (Mlecnik 2013) for analysing network activities with closed learning cycles. The 5 steps describe the whole decision process beginning with the person gaining *knowledge* about the possibilities, then a *persuasion* that this is a good idea followed by a *decision* to go on with the *implementation* of the concept ending with a *confirmation* whether it was good. An OSS concept as suggested by Vanhoutteghem et al. can follow the house owner through all five phases of the decision process. A comparison between Rogers model and the 5 phases defined by Vanhoutteghem is shown in Fig. 2. Firstly, the house owner must gain *knowledge* about the possibilities, which can be done by the OSS seeking out customers or alternatively by making an *initial evaluation* of houses available through policy. The *persuasion* can be gained through a *thorough analysis* of the house, followed by a *decision* regarding *package solutions*. The *implementation* is the *coordinated execution* of the renovation, and the *confirmation* is provided by *quality assurance and continued commissioning*. The link between the two models indicate that this type of OSS concept should be able to support the house owners through the whole decision-process, assuming that Rogers model applies for this type of decisions. The OSS concept suggested by Vanhoutteghem was used as the starting point for this project, in which it has been further developed and tested in real life.



**Fig. 2.** A simplified version of the innovation decision process, originally by Rogers (Rogers 1995) compared to the 5 phases of the OSS concept as defined by Vanhoutteghem. Sources (Rogers 1995; Vanhoutteghem et al. 2011)

According to a Danish survey (Bolius 2016), about 13% of Danish house owners would see the offer of a One-Stop-Shop approach as a good reason for undertaking an energy renovation to their house, and in the younger segment (aged between 25 and 39), almost one in five would feel motivated by such an offer. Research on developing and identifying collaboration opportunities in renovation taking place in Denmark, Norway, Finland and Belgium (Mlecnik et al. 2012) used interviews and questionnaires to identify the needs of the supply side and to develop methods for creating a business model for OSS collaboration. This project focuses more on the receiving side and tests the concept in actual cases to cast further light on the relevance of the OSS concept.

A study on how to motivate private house owners to carry out renovations on their homes and how this is affected by policy (Gram-Hanssen 2014) concludes that most efforts to encourage energy renovation are based on this being a rational economic choice. However, the study points out that this is rarely the driving force when people decide to renovate. The economics only become significant when it comes to deciding the extent of the renovation. The OSS concept used in this project accommodates this observation by including the functional wishes of the house owner in the initial analysis of the house. The idea behind the holistic renovation concept is to make energy efficiency an integrated part of a total renovation, improving the house at many levels, not just in terms of energy use.

An empirical survey of homeowners in Germany (Stieß and Dunkelberg 2013) put particular emphasis on the link between homeowners and expert knowledge and concluded that a majority of homeowners are positive about using professional advisors who can help promote more ambitious and better energy improvements. However, there is a problem in that only those who are already aware of these benefits to some extent actually seek the advice of professional advisors. This project tries to meet this challenge too, because the OSS concept should appeal to people in general and make not just energy renovation but all kinds of home improvement more accessible.

## **Method**

The study question of this work is how a One-stop-shop (OSS) concept influences the renovation of a typical Danish single family house, and whether the use can result in better and more extensive renovations.

The two most important prerequisites for this project were to find adequate, typical houses and the use of a One-Stop Shop (OSS).

For a house to be useful to this project, the owners had to be prepared to carry out an extensive renovation, they had to have the money to carry it out, and the house had to need renovation. The

houses for the project were found using articles and advertisements in local newspapers. The houses were selected based on the following criteria:

- The type of house (single-family, not terraced houses or multi-storey buildings) which had not received major renovation since it was built
- The amount of money the house owner was prepared to spend on the renovation – it had to be enough for an extensive renovation
- The age and layout of the house (only one floor, no basement or additional levels) – to best represent a large number of single-family houses in Denmark
- No slag used in the foundation of the house – slag can create problems for the stability of the house and may mean that renovation is not relevant.
- The estimated commitment of the house owner – among other things, the project would require the house owner to allow a number of measurements to be taken both before and after the renovation, and the active collaboration of the house owner would be crucial for the success of the project.

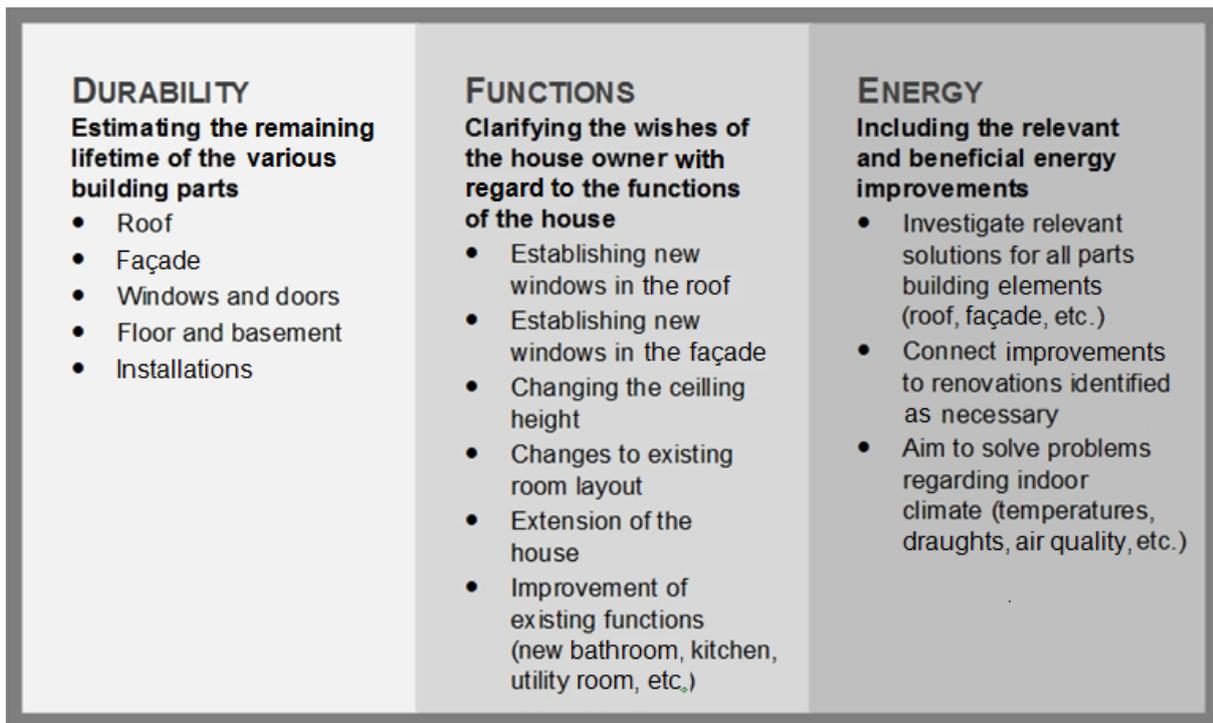
The timeframe was for the houses to undergo renovation within a year and a half, with the possibility of conducting measurements on the house for one year before and one year after the renovation.

The OSS had to have experience in the field of energy improvement, and be able to provide all the services necessary to the house owner, including counselling, calculations, planning, execution, and commissioning. The original OSS connected to the project was an independent company, allowing for the researcher to be an independent observer. However, due to changes in the circumstances during the project, the researchers had to participate in a more direct way, filling out the role of contact person for the house owner.

The planning and renovation process follows the 5 steps of a full-service renovation concept as was described by (Vanhoutteghem et al. 2011).

Step 1, the initial assessment was used to determine the scope and content of the renovation. Based on the wishes of the house owners, a proposal was drawn up by the OSS for their approval. To ensure that all relevant measures were considered, the planning included the following three areas, see Fig. 3:

- Determination of the need for renovation based on the **durability** of the current building elements
- Determination of the desire for renovation based on the wishes of the house owners primarily for improved **functions**
- Determination of the possibility for **energy** improvements based on the current building elements and considering other possibilities.



**Fig. 3.** Diagram showing the process for planning the renovation

Step 2 was the thorough analysis. The house owner receives estimations of the energy balance of relevant solutions and economy based on estimated priced. Where there is doubt about which solution to choose, actual prices are collected for different options (in this case for thermal insulation), and the actual economy of the different suggestions are calculated, for the house owner to make an informed choice, which is Step 3.

Throughout the renovation, step 4, the house owner is to be kept informed about progress. When the renovation is complete, the result has to be verified in Step 5 and any errors rectified, to ensure the optimal effect of the improvements.

Once the renovation is complete, the use of the OSS needs to be evaluated. This is done using pattern matching logic where an empirically based pattern (the outcome of the case study) are compared to a predicted one (Yin 2003). For the use of the OSS-concept to be a success, the following propositions should be true:

- The owner should have been informed about the best possible solution for their house
- The house owner should have been assisted through the decision-making process
- The house owner should have had only one contact person throughout the process
- The house owner should have had less administration due to the One Stop Shop
- The house should have received a relevant renovation, successfully upgrading the house
- The house should have a lower energy consumption than before the renovation

The evaluation of these propositions are mostly based on interview with the house owner, supported by measurements of energy consumption and experiences of the researchers and the building professionals.

## **Limitations**

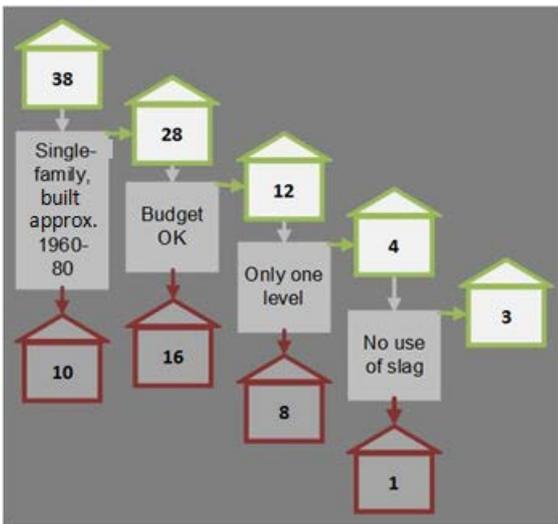
The scope of this article is limited to the use of OSS in the renovation process and the estimated effect OSS has had on the renovation. Detailed evaluation of the energy saving achieved is not within the scope. Due to the limited timeframe of the study, the focus was on houses where the house owner was already prepared to initiate an extensive renovation within a year and a half. Although a renovation plan spanning for many years also have some merits, it is not within the scope of this study.

There can be a number of issues connected with using a large sum on the renovation of a house, e.g. if the location of the house prevents it from getting a corresponding increase in value as a result. These issues are not within the scope of this study, and to avoid them only houses from areas with a reasonable demand was included. This was achieved by advertising for houses in local newspapers from the suburbs of Copenhagen.

## Results

### Locating participants

After a process of advertising in local newspapers, about 40 house owners expressed an interest in being part of the project. The most relevant houses were selected using the criteria described above, see also Fig. 4, and three houses were selected. However, the owners of one house later turned out not to be able to afford the renovation after all, and had to leave the project.



**Fig. 4.** The house selection process. Houses were discarded from the project if: they were terraced houses or multi-storey buildings; they were built long before or after the relevant period or had received significant improvements or renovation; the budget was less than 300,000 DKK (about 44,500 USD); they had a basement or first floor; or slag had been used under the floor. Of the 3 houses selected, one left due to bad economy.

<p><b>HOUSE A</b></p> <p><b>Area</b> 160 m<sup>2</sup></p> <p><b>Built</b> 1965</p> <p><b>Energy consumption</b> 205 kWh/m<sup>2</sup> a year</p> <p><b>Former work on the house</b></p> <ul style="list-style-type: none"> <li>- 55 m<sup>2</sup> extension in 1975</li> <li>- Partly interior renovation in 1985</li> </ul>	<p><b>HOUSE B</b></p> <p><b>Area</b> 122 m<sup>2</sup></p> <p><b>Built</b> 1981</p> <p><b>Energy consumption</b> 91 kWh/m<sup>2</sup> a year</p> <p><b>Former work on the house</b></p> <ul style="list-style-type: none"> <li>- 10 m<sup>2</sup> extension in 2004</li> </ul>
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**Fig. 5.** Basic facts about the two houses chosen as demonstration cases

The remaining two representative single-family houses were therefore the test cases for testing the OSS concept for renovation. Fig. 5 shows the basic facts about the two houses.

At the time the project was initiated, there were no actual OSSs able to take on the task, because the concept was not common in the Danish building sector. However, it was possible to find a professional advisor who could be responsible for both the planning and execution of the renovation. In this way, he could provide a full-service solution for the house owner and act as an OSS contact.

### **Initial analysis of houses**

The extent of the suggested renovation was determined taking into account both the durability of the existing building elements, the house owner's wishes for improved functionality, and the opportunities for implementing energy improvements.

The first step was to estimate the renovation requirements of the two houses based on the durability of the buildings. This was done by assessing the state of each house, and estimating the remaining service life of the various building elements.

In House A, the roof was close to the end of its service lifetime, and although it was still functional, it would need to be replaced within a few years. The windows and doors were still the originals and in need of replacement. The outer walls were masonry and in acceptable condition, with no need for replacement due to their durability. The original motivation for the house owner to start renovation was the need for a new roof.

House B was built more recently than House A, leaving a few years before its roof needed replacement. Most of the windows were the originals, and a few were punctured. Moreover, they were equipped with uninsulated ventilation hatches. The outer walls were masonry in good condition with no need for renovation due to their durability. The original motivation for the house owner to start renovation was the need for more space.

The second step was to implement the wishes of the house owners for improved functionality or other changes to the house, e.g. energy improvement, indoor climate and structural changes. These were specified by interviewing the house owners, ensuring they considered all relevant improvements as mentioned in Fig. 3. The improvements they wanted are shown in Fig. 6. The aim of identifying all their wishes was not necessarily to implement them during the renovation, but to make sure that the renovation prepared the house for these improvements. For example, a bathroom in House A would need to be renovated the near future. One of the existing two windows was to be replaced by wall. The planning of the new bathroom layout ensured that the right window was kept, which would not have been the case otherwise.

<p><b>HOUSE OWNER’S WISHES HOUSE A</b></p> <p><b>Long-term functional improvements</b></p> <ul style="list-style-type: none"> <li>• Renovation of two bathrooms</li> <li>• Renovation of utility room</li> <li>• Installation of solar panels on the roof</li> </ul> <p><b>Improvements to increase comfort and reduce energy consumption</b></p> <ul style="list-style-type: none"> <li>• A new roof, possibly with better insulation</li> <li>• Replacement of roof windows</li> <li>• Extra insulation on façade walls if feasible</li> <li>• Extra insulation under the floor in part of the house if feasible</li> <li>• New windows with reduced heat loss</li> </ul>	<p><b>HOUSE OWNER’S WISHES HOUSE B</b></p> <p><b>Functional improvements</b></p> <ul style="list-style-type: none"> <li>• New roof</li> <li>• Raised ceiling to the roof in part of the house</li> <li>• Extension of the house due to the need for an extra room</li> <li>• Roof lights in dark corridor</li> <li>• Changing part of the room layout</li> </ul>
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**Fig. 6.** List showing the house owners wishes for improvements in the two houses. The focus is on functional improvements, however specific wishes for energy improvements are also included.

Based on the renovation required by the building’s condition and the wishes of the house owner, it was now possible to identify the beneficial energy improvements that should be considered in the two houses, see Fig. 7.

<p><b>ENERGY IMPROVEMENTS HOUSE A</b></p> <ul style="list-style-type: none"> <li>• Extra insulation of the roof</li> <li>• Extra insulation on the façade</li> <li>• New windows and doors with a low U-value</li> <li>• New mechanical ventilation</li> </ul>	<p><b>ENERGY IMPROVEMENTS HOUSE B</b></p> <ul style="list-style-type: none"> <li>• Extra roof insulation</li> <li>• New windows with a low U-value</li> <li>• Possibly external façade insulation</li> <li>• New mechanical ventilation</li> </ul>
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**Fig. 7.** Suggested energy improvements for the two houses.

In House A, it was decided not to install extra insulation under the floor, because this would be very costly and would not achieve energy savings that could justify the cost. If the renovation had included work on the floor for some other reason (new floors, floor heating, etc.), it would have been relevant to consider extra insulation under the floor, but as an energy-saving measure alone it was not found to be worthwhile.

### Extent of the renovation, House A

With guidance from the OSS contact, the house owner decided to renovate the roof, façade, windows, doors and ventilation system.

The replacement of the roof made it possible to install extra insulation and make room for new ventilation pipes above the old ceiling. Since the old roof was being replaced, it was very beneficial to change the translucent part of the ceiling to actual light tunnels to reduce heat loss through these poorly insulated parts of the building envelope.

In connection with the new roof, a plan for the façade was prepared. If the house owner chose external insulation for the façade, the roof would require an extension of the overhang. To enable the house owner to make an informed choice, two solutions for external insulation (I and II) and a solution replacing the cavity wall insulation (III) were calculated and presented. The results are shown in Table 1.

**Table 1.** Solutions for insulation of the façade in House A.

Type of solution	Energy saving	Investment	Payback period	CCE
-	kWh/m <sup>2</sup> a year <sup>a</sup>	DKK	Years	DKK/kWh
I External insulation, boards	44.3	233,000	41	0.63
II External insulation, plastered	47.3	327,000	54	0.92
III Cavity insulation	16	21,000	11	0.09

Note: The energy savings were calculated using the program Be10. The investment was estimated using a pricelist in the program V&S prisdata (Byggecentrum 2014). The payback period was calculated in accordance with the Danish Building Regulations (The Danish Transport and Construction Agency 2015). The CCE is the cost of conserved energy (the cost of saving 1 kWh) and was calculated using the method described in (Hansen and Vanhoutteghem 2012).

<sup>a</sup> The energy saving is kWh/m<sup>2</sup> total floor area every year.

Solutions I and II yielded by far the best energy saving, estimated to about 44-47 kWh/m<sup>2</sup> a year, while the cavity insulation, Solution III, provided a saving of only about 16 kWh/m<sup>2</sup> a year. However, Solutions I and II would have been much more expensive than Solution III, and they had a longer payback period and a higher price per saved kWh (CCE). Despite a CCE that was lower than the cost of buying the energy (1,11 DKK/kWh for this house in 2013, including electricity and gas for heating), the size of the investment combined with the more comprehensive implementation and a significant change to the visual exterior of the house, made the house owner choose Solution III: replacement of the cavity insulation.

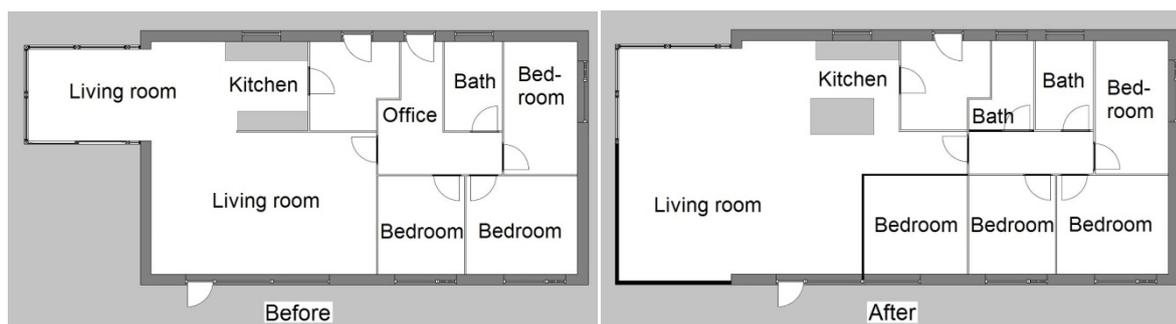
To some extent, implementing the cavity insulation solution was independent of other improvements, but it could more advantageously be achieved after the windows and doors had been replaced, because removing them might cause the insulation to fall out. However, this improvement would replace the old cavity insulation that was inefficient, so it would be beneficial to implement it as soon as possible. Since the windows were approaching the end of their service life and their ability to maintain a good thermal indoor climate was poor, it was decided to include both replacement of the windows and the new cavity insulation in the current renovation.

During the renovation, the house would be given a new roof, new windows, new doors and new cavity insulation. All these would contribute to a reduction of infiltration, which is beneficial for the thermal indoor climate but critical for the atmospheric indoor climate if not addressed. To avoid creating a problem when the air change through the building envelope was reduced, it was decided to install a mechanical ventilation system with heat recovery in the house.

### **Extent of the renovation, House B**

The owners of House B had many wishes for extensions and changes in room layout, because the house was getting too small for a family with 3 children. To get the best result, it was important to determine how the house would be extended before any large renovation was planned. Changing the functions of rooms could have a large influence on the building envelope and might for example require repositioning of windows and doors.

A proposal for the new layout of the house was made in collaboration with the OSS contact, who was an architect, see Fig. 8. If the living room was expanded with an extension of the building, part of the old living room could be made into a new children's room. Replacing a wall in the kitchen with a kitchen island would open up the space. The original entrance hall, which had been used as an office, could be made into a second bathroom.



**Fig. 8.** Layout of House B before and after the suggested changes. The changes were: an extension expanding the living room; removal of the kitchen wall; an extra bedroom; an extra bathroom.

It was decided not to apply extra insulation to the façade, because the energy benefit would be small compared to the cost. The house already had cavity insulation so, as shown in Table 2, the energy saving would only be about 10-12 kWh/m<sup>2</sup> a year, while the large investment would have a payback period of at least 164 years. The cost of conserved energy (CCE) was also very high, and from an economic point of view the cost of saving can in this case not compete with the cost of using the energy (about 0.8 DDK/kWh for this house in 2013, including gas for heating). When the CCE is higher than the energy price it is cheaper to use the energy than to save it.

**Table 2.** Possible energy improvements for House B.

Type of solution	Energy saving	Investment	Payback period	CCE
-	kWh/m <sup>2</sup> a year	DKK	Years	DKK/kWh
A External insulation, boards	10.5	168,500	164	1.53
B External insulation, plastered	11.7	222,000	195	2.17

Note: Solution A was external insulation covered with plates of e.g. metal or stone to protect the insulation from weather. Solution B was hard insulation boards covered with plaster to create a rain shield.

The renovation would, however, include a new roof, because the old one was at the end of its service life. In connection with this, the old vapour barrier would have to be replaced, because it was in poor condition, so extra insulation could be added to the ceiling. Moreover, the old windows would have to be replaced, and a mechanical ventilation system would be required to avoid problems with the indoor air quality when the other improvements had been implemented.

In the end, the house owners chose not to go through with the renovation because the house would still not meet their functional needs. The extension and new room layout could have solved many problems, but they would no longer have an office, and the extension would remove some of the qualities they originally liked about the house. Instead of renovating, they decided to put their house up for sale, and find a new home that better suited their needs.

### Renovation of House A

Before the renovation of House A, the project encountered an obstacle. The company which was supposed to carry out the renovation on behalf of the OSS went out of business due to lack of customers. This meant that the original contact person could not complete the project as intended, but had to be replaced halfway through the project by a new contact person and a new company to execute the renovation.

To carry out the renovation on which the owners of House A had decided, three quotations were requested from companies with experience in energy renovation. The estimated cost was similar for two of the offers but the third was much higher, see Table 3. The prices were requested by researchers from DTU (Technical University of Denmark) acting as the new contact, based on the specifications prepared by the architect. The house owner selected Company B based on their strategy for the renovation, which included complete scaffolding over the house while replacing the roof.

**Table 3.** Collected prices for the renovation of House A.

	Company A	Company B	Company C
	DKK	DKK	DKK
Replacement of cavity insulation	38,500	34,900	28,528
New roof incl. light tunnels	408,700	377,919	457,004
New doors and windows, mechanical ventilation + other expenses	236,000	273,814	484,215
<b>In total</b>	<b>683,200</b>	<b>686,633</b>	<b>969,747</b>

The renovation of the house was carried out in the summer of 2013, with Company B as contractor, see Fig. 9. To guide the house owner through the process, an independent site engineer was appointed to advise the house owner during the renovation. He also checked the work for faults and ensured that they were corrected during the building process. Meetings were held at the building site every week to ensure communication between the house owner, the advisers and the craftsmen.



**Fig. 9.** House A before and after the renovation. Visible changes are the new windows and roof.

**Table 4.** The energy use of House A before and after the renovation.

	Measured on house Total energy use <sup>a</sup>	Model in Be10 Energy used for heating
Energy consumption before renovation (kWh/m <sup>2</sup> a year)	173.3 <sup>b</sup>	216.5
Energy consumption after the renovation (kWh/m <sup>2</sup> a year)	131.2 <sup>c</sup>	125.0
Energy saving due to renovation (kWh/m <sup>2</sup> a year)	42.1	91.5
Energy saving due to renovation (%)	24.28	42.3

Note: The measured and simulated energy consumption in kWh/m<sup>2</sup> a year should not be compared directly because they cover different things; the relevant comparison is between before and after.

<sup>a</sup> Total electricity use plus total gas consumption. This includes the use of hot water and electrical appliances, but since these factors would not change to any extent due to the renovation, the difference can still indicate the energy saving.

<sup>b</sup> Total gas consumption for a year (May 1<sup>st</sup> 2010 – April 30<sup>th</sup> 2011) with a conversion value of 11 kWh/m<sup>3</sup> added to the total electrical consumption for the year divided by the heated area of 160 m<sup>2</sup>. The number is weighted according to climate using degree days.

<sup>c</sup> Total gas consumption for a year (January 2<sup>nd</sup> 2014 – January 2<sup>nd</sup> 2015, half days included) with a conversion value of 11 kWh/m<sup>3</sup> added to the total electrical consumption for the year divided by the heated area of 160 m<sup>2</sup>. The number is weighted according to climate using degree days.

After the renovation was complete, the energy use of House A was measured and compared to the energy use before the renovation, see Table 4.

Calculations of the energy consumption were made in the program Be10 (SBI Danish Building Research Institute 2006; The Danish Transport and Construction Agency 2015), which is normally used to assess whether a building meets the requirements for energy consumption according to the Danish Building Regulations. The calculations showed that the energy consumption of the house was reduced by 91.5 kWh/m<sup>2</sup> a year, or 42.3%. This moved the house from Energy Label E to Label C on the Danish energy labelling scale (The Danish Energy Agency 2013). The measured saving was less, only about 24%.

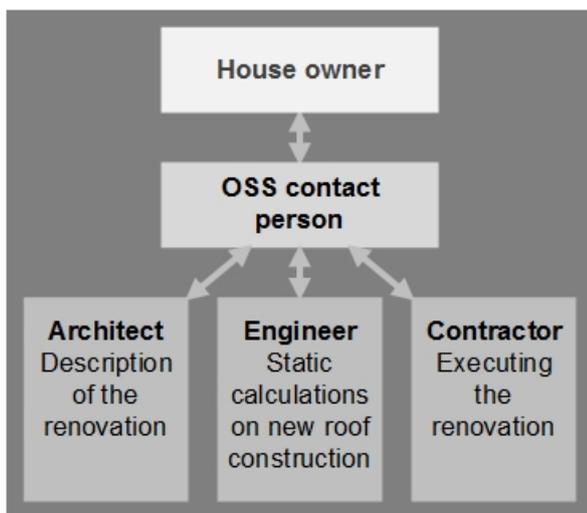
## **Discussion**

The aim of the project was to test the effect of using the OSS concept to guide a real renovation of a single-family house. This sort of demonstration includes a large degree of uncertainty, because the process cannot be compared to a precise baseline. How much guidance the house owner would have received or how much they would have decided to renovate can only be estimated based on their own statements and an estimation of the average house owner. Even two houses that were similar when built would have different owners making it difficult to compare them directly.

Originally, the project should cover 3 renovations, enabling comparison of the results, even if the cases could be seen as individual case studies. However, only one renovation was completed making this a single-case study. Although it would have been beneficial with 3 or even 2 completed renovations, the study still has its merits as it is a representative case (Yin 2003).

The OSS concept is not yet common in the sector of renovation of single-family houses. This posed a challenge when it came to finding a company to guide the house owners through the process following the concept. The initial solution, where an adviser was chosen as contact person through his contact with relevant companies, did not work out in the end. The contact person was replaced by a researcher working as contact halfway through the process. The negative consequence of this was partly that the researchers were no longer only observing, and partly that the project then had an extra layer of coordination, because all services (architect, engineer, contractor) were detached from the OSS contact, and not integrated as originally planned. But since most of the contact to all these actors went through the new contact person, the effect of having an OSS was still maintained for the house owner, see Fig. 10. One benefit from this change in administration was that it gave the house owner an independent and impartial adviser. The house owner could now choose from multiple offers on the execution of the renovation, and the advisor was able to check the progress of the renovation on

behalf of the house owner. The successful process of the renovation suggests that perhaps the answer is not to change the building industry towards OSS, but rather to enhance the role of the independent building advisor. Alternatively, the freedom to choose between different contractors should be included in the OSS, even when the contact person is more closely connected to one company. This could be achieved by making the initial planning free if the house owner decides to use the company, but also by making it possible to pay for the initial planning as an independent service as suggested in (Vanhoutteghem et al. 2011). Otherwise the initial planning should be removed from the OSS, and instead e.g. be a mandatory part of selling a house, as is currently the case for energy certificates in Denmark. By making it mandatory, all house owners would receive a plan providing *knowledge* about a possible renovation, which is the first step in the decision process according to (Rogers 1995), see also Fig. 2. By an estimation based on similar services, the initial plan for a house would cost the owner of a 150 m<sup>2</sup> house about 12,500 DKK (about 1,900 USD) (Marxen and Knorborg 2011). Current policies in Denmark enables a tax reduction for 12,000 DKK for energy efficient improvements of houses including energy advice. This would help pay for a mandatory initial energy renovation plan.



**Fig. 10.** Diagram showing the communication channels during the planning process of the renovation of House A. The main contact person for the house owner was DTU, who then contacted people with the necessary competence.

Despite the difficulties, a renovation was carried out using a form of the OSS concept. The house owners were successfully informed about the best solutions for their house, taking into account the current durability of existing building elements, their wishes for improved functions, and the possibilities for energy improvements. In the case of the façade, the house owners chose the least ambitious solution by only replacing the cavity insulation. However, this was the best solution economically, because the cavity insulation resulted in a much lower cost of conserved energy. The

fact that people reject extensive measures like external insulation sets a limit to the savings that can be achieved in each house, which increases the number of houses that need to be renovated to reduce the total energy consumption sufficiently. However, ensuring that the house owners were informed about the possibilities means that lack of information is no longer an obstacle and increases the probability of extensive measures being implemented.

The house owner was kept informed on most aspects of the renovation, but this was very time-consuming. The process would benefit from better presentation, making the information easily understandable and more visual. The process could be helped by having a checklist, catalogue or program presenting the options to the house owner in an easily accessible and visual way. The overview of things to consider shown in Fig. 4 is a good beginning, but should be extended with possible solutions or inspiration for the house owner to look at. Moreover, visualisation of the remaining lifetime of different building elements can help the house owner understand that the house requires maintenance to avoid greater expense later.

The owner of the renovated house was very much involved in the renovation in this project. The goal of achieving a significant reduction in the administration for the house owner was not met, at least in the planning process. However, the constant access to impartial advice was a great help, especially during the execution of the renovation. Having a building professional as representative for the house owner, checking the quality of the work during the process increased the satisfaction with the project according to the house owners. The close connection between the house owner and the contact also aided the discovery and rectification of errors in and after the building process, such as a new front door that was not tight and had to be replaced and a ventilation system that needed to be balanced more than once to achieve the optimal operation.

The renovation resulted in a better insulated house with a higher level of comfort. In general, the house owners were very pleased with both process and result, and they report that they can feel the effect of the renovation in terms of better air quality, less draught, and smaller temperature fluctuations. These observations were in compliance with measurements made in the house. In general, and if the OSS concept were to go large scale, it might be necessary with some form of independent party to make measurements to ensure the quality of the renovation.

As mentioned above, it can be difficult to determine the exact effect of the use of OSS on this project. Originally, the owners of House A did not have a large renovation in mind. They knew something had to be done about their roof, and because of its low slope it was not possible to just clean it. They knew that there might be a benefit in adding extra insulation when replacing the old roof. There is also a requirement in the Danish building regulations of the time (The Danish Ministry of Economic and Business Affairs 2010) for a maximum thermal transmittance of  $0.15 \text{ W/m}^2\text{K}$  when

a roof has been renovated. Before the renovation, the thermal transmittance of the roof was about 0.41 W/m<sup>2</sup>K, which was reduced to about 0.08 W/m<sup>2</sup>K, considerably better than required by the building regulations at the time of the renovation. Moreover, the cavity walls received new insulation, the windows and doors were replaced, and a ventilation system with heat recovery was installed. Whether some or all of these improvements would have been implemented without the OSS guidance cannot be determined conclusively. But it seems very unlikely that the owners would have installed ventilation if they had just approached a company asking for a new roof.

The renovation measures were successfully implemented. However, the measured saving of 24% was less than expected in view of the simulation in which savings of 42% were found. The numbers cannot be compared directly because electricity for light and appliances was not included in the simulation, but the difference was also due to other factors:

- Uncertainty about the mutual contribution from the four different heat sources in the house (gas boiler, electric convector, heat pump, and wood burning stove)
- The wood burning stove was not included in the simulation
- Simulation conditions do not reflect actual conditions
- Changes in user behaviour with increased comfort after renovation

Although the saving was less than initially expected, the house has still achieved a significant reduction in the total energy consumption.

One of the aims of this project was to test how the use of an OSS could motivate house owners to undertake better renovations on a larger scale. However, the owners of two of the houses chose to leave the project, so only one out of three houses underwent the planned renovation. This suggests that the use of the OSS concept alone is not enough to motivate people to undertake extensive renovations. The goal of a OSS with some marked volume is to make renovation more accessible to many house owners, including those who do not have great interest in the subject to begin with. The house owners participating in the project must be considered as already having a certain interest in a more energy efficient home to begin with, or they would not have applied for a place in the project. Despite this, the drop out rate was high. The OSS might still work as a motivator, but it is unlikely that the concept on its own will solve the problem of the slow progress of renovating the existing building stock.

## **Conclusion**

The purpose of this project was to determine benefits and disadvantages when using OSS, and to see if the use of OSS could improve specific renovations.

The initial advising of the house owners enabled them to make informed choices about the extent of the renovation. This process brought benefits in terms of less uncertainty and better long term solutions, but was very time-consuming. There is a need to create tools to make the process more effective. The tools or checklists should ensure that house owners are aware of all the options and the urgency of certain improvements – all presented in an easily accessible and visual way.

The involvement of one single contact person did not work out as planned. However, the independent advisor proved to be a benefit for the house owners, who became free to choose their contractors and received an impartial check of the work during the renovation.

It is not possible to determine the level of renovation the house owners would have chosen had they not participated in this project where the OSS concept was used to inform and guide them. However, interviews with the house owners and knowledge of the usual procedure suggest that the house received a more extensive renovation than would otherwise have been the case, even though not all proposals were implemented. The energy consumption of the house was reduced by more than 25%, and the house owners report an increase in comfort and air quality.

Since the house was successfully renovated with a satisfactory result, the use of the OSS concept was a success. However, the fact that in two out of three cases house owners decided to leave the project without renovating puts into question whether the concept would be useful on a larger scale in motivating more people to renovate their houses. It might ensure better renovations for those already interested in the renovation, but may not be able to motivate those still in doubt.

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# APPENDIX II – PAPER II

## **Evaluation of the renovation of a Danish single-family house based on measurements**

*Matilde Grøn Bjørneboe; Svend Svendsen; Alfred Heller*

*In Press, Energy and Buildings; 2017*

- A Danish single-family house renovated: durability, functions and energy
- Simulation of the house before and after renovation
- Measurements of energy and indoor climate during a year before and after
- A saving of 53% in the heating consumption with better indoor climate
- Increase in house value corresponds to 77% of the investment, according to mortgage bank

## **Evaluation of the renovation of a Danish single-family house based on measurements**

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### **Abstract**

Building renovation is too often carried out with only one objective: necessary maintenance, updating design and functions, or reducing energy consumption. But, if a necessary maintenance is exploited as an opportunity for renovation, energy improvements can be implemented, house functions can be updated, and indoor climate improved with minimal nuisance and expense. This paper illustrates this approach by documenting the renovation of a single-family house in Denmark, and monitoring its energy consumption and indoor climate before and after the renovation. Building elements were replaced where necessary, and the total energy consumption was reduced by 23%, giving the house owners a saving of about DKK 8400 per year. The energy consumption for heating was reduced by 53%, close to the 58% found using dynamic simulations. The temperatures reached a more comfortable level, and the house owners were satisfied with the result. The increased value of the house was estimated to cover about 77% of the investment.

### **Keywords**

Measurement and verification, simulation, energy renovation, detached single-family house

### **Highlights**

- A Danish single-family house renovated for durability, functions and energy
- Simulation of the house before and after renovation
- Measurement of energy and indoor climate for a year before and after
- 53% reduction in heating consumption with better indoor climate
- Mortgage bank estimates increase in house value corresponds to 77% of the investment.

## 1 Introduction

The energy renovation of existing building stock is one way to reduce the overall use of fossil fuels and achieve a society based on sustainable energy. The large potential for savings through the renovation of the many single-family houses built in Denmark in the period 1960–1980 has been pointed out by many researchers (Gram-Hanssen 2014; Tommerup and Svendsen 2006; Vanhoutteghem et al. 2009). But while this potential for savings has been supported by simulations and surveys, actual case studies based on measurements are rare. An international literature review by Ma et al. (2012) concludes that while measurement and verification are effective ways of documenting energy savings achieved as a result of renovation, most studies have been based on simulations. There is still a need for more research with practical cases, because the actual savings achieved through energy renovations might not be the same as those found in simulations (EBC 2012). This difference, often called the performance gap, is likely due to deviation between simulations and the real world, including changes in user behaviour known as the rebound effect (Audenaert et al. 2011; Galvin and Sunikka-Blank 2013; Majcen et al. 2013). Harrestrup and Svendsen (2015) describe the renovation of a Danish multi-storey building with heritage value, where they estimated the resulting energy savings using measurements and compared them with simulations made using the program IDA ICE. Here the total measured saving was 47%, while the calculations had shown a theoretical saving of 39–61% depending on room set-point temperature. They also found that the space-heating consumption varied between apartments by a factor of 80, which emphasises the effect of occupant behaviour on the outcome of a renovation.

Thomsen et al. (2016) describe another energy renovation in a multi-storey residential building where the energy consumption and indoor climate was estimated using measurements, calculations made in the program Be10, and questionnaires aimed at evaluating the experience and satisfaction of the tenants. Here they achieved a 31% reduction in the consumption for heating and hot water. However, they stress that it is often the non-energy benefits of a renovation, such as improved indoor climate, that determine whether the occupants find the renovation to be a success, not the actual energy savings. Considering energy saving as an isolated goal is very common in economic evaluations of building renovation and also in the field of energy efficiency promotion. However, most house owners have a broader perspective that influences their decision-making, which is why, when a renovation is evaluated or promoted, it can be beneficial to include other aspects, such as increased comfort, upgrading building elements, and the increased value of the property (Bartiaux et al. 2014; Galvin and Sunikka-Blank 2013; Wilson et al. 2015). Risholt et al. (2013) describe a case study where the sustainability of two different energy renovation strategies with different ambition levels were evaluated. One of their conclusions was that the choice of the optimal renovation depends on the type of house owner, and that qualitative preferences can be as decisive as quantitative measurements.

There have been even fewer full-scale case studies where the renovation of a single-family house has been measured. One example is the renovation of two different two-storey single-family houses in the UK described by Gupta and Gregg (2016). Here the focus was on reducing CO<sub>2</sub> emissions, and while the renovation reduced emissions by 53% and 75%, the target was an 80% reduction. However, a reduction in carbon emissions was not the only benefit, because there was a significant improvement in occupant comfort and satisfaction. Tommerup (2008) describes the renovation of a typical Danish single-family home, where it was shown that the building could be brought up to what was the new-house standard at the time: a consumption of only 12.7 MWh/year. While the study successfully used an actual house to show the potential for improvements in energy consumption and indoor climate, the scope of the study did not include an evaluation of the actual need for renovation of the various building elements or the size of the investment the house owners would face. Without the obstacle of a lack of finance or the need to renovate specific building parts, they were able to perform a more thorough and extensive renovation and force several tasks of maintenance.

The renovation described in this paper is based on more realistic financial conditions faced by building owners. The renovation was mostly paid by the house owners themselves, so the relevance of the renovation and the overall cost were central for its success. Although the effect of the renovation on energy consumption was evaluated based on measurements, the scope of the renovation was not limited to reducing this. The aim was to upgrade building elements for durability and according to the house owners' wishes and to improve the indoor climate. Moreover, the evaluation of the cost of the renovation was not based only on direct energy savings, but also on an estimation of the increase in the value of the house.

## **1.1 Aim**

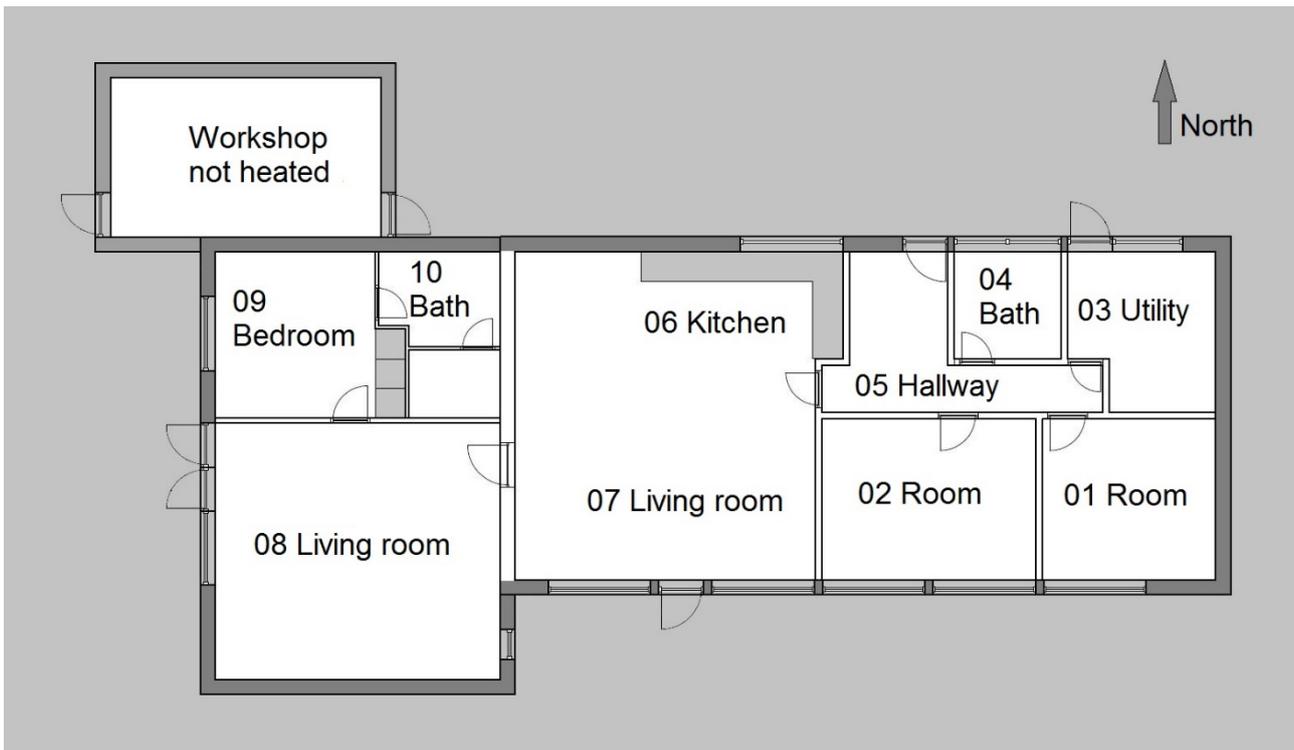
This paper evaluates the renovation of a typical Danish single-family house with a holistic focus, taking into account the durability of building elements, the improved function and value of the house, and the reduction in energy consumption.

The renovation is evaluated through simulations and measurements made in the house before and after the renovation. The aim is to show that it is possible to renovate the house in a relevant way and thereby reduce energy consumption for heating significantly and improve the indoor climate while keeping the scope of the renovation economically feasible from the house owners' perspective.

This paper provides a relevant contribution because it presents an economically realistic renovation of a representative Danish single-family house that updates the house with regard to maintenance, energy consumption, indoor climate and functions. It also documents the results through measurements and simulations, contributing to the knowledge about the results of renovations of single-family houses in general.

## 2 House description

The original house was built in 1965. It was extended by 55 m<sup>2</sup> in 1975, bringing the area up to 160 m<sup>2</sup>. Figure 1 shows the layout of the house, with the rooms numbered for future reference. Apart from this extension, and a new kitchen in 1985 that included some structural changes in rooms 06 and 07, the house has not been renovated or been the subject of significant maintenance. The house is located in a suburb to Copenhagen with relatively high house prices. This is a benefit for the renovation, because a house in an area with very low market value would not increase so much in value due to renovation.



*Figure 1 – Plan of the house. The extension built in 1975 consists of rooms 08–10.*

The house was built with a double wall in masonry insulated with expanded clay clinker (thermal transmittance about 0.085–0.09 W/m<sup>2</sup>K) in the cavity of the original house and 80 mm mineral wool insulation in the extension. The roof is double-sloped at an angle of approximately 14° (see Figure 2), and in most of the house the rooms are open up to the rafters. The roof was insulated with approximately 100 mm mineral wool (thermal transmittance about 0.49 W/m<sup>2</sup>K) and the cladding was corrugated fibre cement. The windows were single layer with a secondary single uncoated pane, and the doors were also the original ones from 1965. The house also had a skylight over the entrance hall, consisting of translucent fibre-reinforced polyester in the same shape as the roof cladding and an original skylight dome in the original bathroom (room 04). The ground slab was insulated with 50 mm mineral wool. All thermal transmissions are shown in Table 1.



*Figure 2 – The house before the renovation as seen from west and southeast.*

The house had a number of different heat sources. The original part of the house was heated by a gas boiler from 2003. The extension was heated using an electric convectional heater from 1975 and a heat pump from 2012, supplemented on cold days with a wood-burning stove also from 2012. The house had no mechanical ventilation.

The house was found through a process of advertisement for houses in need of renovation, and selected based on it being representative and having potential. Beside this, the house owners had to have enough money and the will to perform a renovation, as they would have to pay for everything except the advice from the authors (only concerning energy) and reduced price on some building materials with maximum 30000 DKK. For more details on the process, see Bjørneboe et al. (2016). The house owners are 2 adults, both retired, with one adult child who no longer lives with his parents. They have lived in the house for more than 30 years.

## **2.1 The renovation**

The scope of the renovation was decided by the house owners based on professional advice using a One-stop-shop or full-service concept whereby the house owners are guided through the whole renovation process by one company or contact person. The renovation took into consideration the remaining service life of the building components, the need for functional improvements in the house at the time and in the near future, and the opportunity to implement energy improvements. Simulations and calculations were used to estimate the possible savings each measure could achieve. The renovation concept and process is further described by Bjørneboe et al. (2016).

The renovation was carried out in the summer of 2013 and included the following measures, which were all implemented during this renovation:

- The replacement of all windows with 3-layer energy windows. One of the two windows in room 04 (Bathroom) was removed and replaced with a brick wall with 100 mm insulation
- The replacement of all external doors (in rooms 03, 05, 07 and 08)

- The raising of the roof construction to allow for more insulation (365 mm in total) and make room for ventilation. The replacement of the cladding of corrugated fibre cement
- The replacement of the existing skylights with more energy-efficient light tunnels
- The installation of a mechanical ventilation system with heat recovery
- The replacement of the cavity insulation in the façade

Once the renovation of the building envelope was complete, an internal renovation was also carried out, in which rooms 03 and 04 were replaced and updated. This was carried out in the spring of 2014.

*Table 1 – The assumed thermal transmission of the affected building elements before and after the renovation.*

Thermal transmission of building parts		
	Before renovation W/m <sup>2</sup> K	After renovation W/m <sup>2</sup> K
Windows	1.07–4.80 (2.74)	0.63–0.87 (0.71)
Doors	2.00–3.54 (2.71)	0.70–1.39 (0.91)
Roof	0.49	0.10
Skylights	3.52–4.93 (4.23)	1.3
Façade	0.67	0.37

Note: The before-values are estimates based on the house, the construction and traditional building practices. The after-values include product information on the new materials and building parts. For windows, doors and skylights, where the value covers more than one type, the table shows [min-max (average)] thermal transmission.

### 3 Method

To document the effect of the renovation on energy consumption and indoor climate, a number of measurements were made before and after the renovation, see Table 2.

To put the house and the renovation in a national context, the energy level of the house before and after the renovation was determined by simulation in the program Be10 (SBI Danish Building Research Institute 2006, 2008) in accordance with the Danish Building Regulations (Danish Transport and Construction Agency 2015). This program was chosen because it is the standard program for determining the energy level of buildings in Denmark. The energy level found using this program enables comparison with all other houses calculated in a similar way, and helps to place the house on the scale used in the national scheme for energy performance certificates (EPC) for buildings. However, the program simulates using a single-zone model, which (Vanhouetteghem and

Svendsen 2014) underestimates the need for space heating. Moreover, this program does not include user behaviour, so the energy level found cannot be directly compared to the energy consumption measured. The program calculates the energy consumption for heating and cooling, excluding electricity used for other purposes, such as lighting and appliances.

*Table 2 – Measurements made in the house*

Measurements	
Single measurements and readings made before and after renovation	Thermographic pictures Blower-door pressurisation The total electricity consumption over a 12-month period The total gas consumption over a 12-month period The house owners' opinions on the renovation were determined through interviews
Continuous measurements made for a year before and after the renovation	Logging of temperature every 10–15 min in all rooms
Readings made by the house owner in the year after the renovation	Date and time of the reading The total electricity consumption shown by the electricity meter (for heating and appliances) The total consumption shown by the gas meter (for heating and hot water) Electricity consumption of the heat pump measured by an energy-cost meter (SparOmeter) Electricity consumption of electric convectional heater measured by an energy-cost meter Notes specifying when the house was empty, when the wood-burning stove was in use etc.

Once all relevant values were obtained, they were analysed and compared:

- The energy consumption measured before and after the renovation was weighted according to climate using heating degree days (HDD). 1 degree day means that for 1 day the temperature was 1 degree lower than the indoor temperature. Degree days can be used as a simple measure of the buildings exposure to cold, and thereby the weather influence on the heating demand. See e.g. (Bromley 2008) for further explanation.
- The contribution from the wood-burning stove before and after renovation was estimated and included in the consumption measured

- The energy saving achieved was found by comparing the energy consumption before and after the renovation
- The energy level calculation made in the program BE10 was used to assign the house an energy label in accordance with the Danish Energy Performance Certificate (EPC), which is part of the European Energy Performance of Buildings Directive (EPBD)
- A simulation model of the house before and after renovation was made using the building simulation software BSim (SBI Danish Building Research Institute 2015)
- The increase in comfort and changes in user behaviour were evaluated based on the temperatures measured and interviews with the house owners. The aim was to achieve comfortable temperature levels in the opinion of the current owners in their daily use of the house. To determine general temperature comfort is not within the scope of the study.
- The financial saving was estimated based on the energy savings measured
- The cost of the renovation was evaluated based on the size of the investment and the increased house value estimated by a real estate agent and the house owners' bank
- The overall result was evaluated based on energy, indoor climate, cost and opinions of the house owners

#### 4 Measurements

The measurements on the single-family house were made during a before-period from May 2012 – April 2013 and an after-period from December 2013 – November 2014.

A professional company was hired to take infrared pictures of the house before and after the renovation to identify thermal bridges and sources of large heat losses. Both days had similar weather conditions, with wind about 4m/s from NV (Danish Meteorological Institute DMI 2012, 2013) and temperatures measured at the location of  $-0.4\text{ }^{\circ}\text{C}$  to  $-1.4\text{ }^{\circ}\text{C}$  at the time.

The air tightness of the house was examined before and after renovation using the fan pressurisation method in accordance with DS/EN 13829 (Dansk Standard 2001). This was done using a blower door mounted in the main entrance door in room 05 (see Figure 1) and determining the volume flow at 50 Pa,  $q_{50}$  [ $\text{l/s m}^2$ ]. From this value, the infiltration (also known as air leakage into the building) was calculated (SBI Danish Building Research Institute 2008) as:

$$0.04 + 0.06 \cdot q_{50} \tag{E.1}$$

As the infiltration covers the unintentional air leakage into the building e.g. through cracks, it is important to know the actual size of infiltration when calculating building energy use, as this can have a significant impact.

The total energy consumption of the house before the renovation was taken from the energy bills for electricity and gas provided by the house owners. We decided to look only at the consumption

over one year before the renovation, and no further back, because the house had a heat pump installed just before this period, which would confuse the results. The house owners explained that they had problems heating up the occupied spaces before the heat pump was installed, which means that the indoor climate and energy consumption was greatly affected by this improvement. The energy consumption measured for the period of 12 months after the renovation was determined from readings of the electricity meter and gas meter in the house.

HOBO U10 Temp/RH and HOBO U12 Temp/RH/Light/EXT loggers were set up in every room and used to log the temperature every 10–15 min. The loggers have an accuracy of  $\pm 0.35$  °C from 0 °C to 50 °C. The house was inhabited throughout the project, so the loggers were placed with the objective to achieve minimum inconvenience rather than optimal measurement. They were generally positioned on internal walls about 1.5–2 m from the floor, not close to any heat sources or in direct line of solar radiation. They took measurements in the periods both before and after the renovation.

The owners of the house were very much involved in the project, which made it possible to obtain more detailed data on the energy consumption after the renovation. Energy-cost meters to measure the electricity consumption were installed on the supply for the heat pump and for the electrical heating in room 10, and the house owners noted down the consumption every day. The total electricity and gas consumption was also read from the energy meters on a daily basis. The house owners made these readings almost every day for a year after the renovation, and also made a note of whether the house was empty, whether the wood-burning stove was in use, and anything else that might have a significant effect on the energy consumption that day.

## 5 Evaluation and analysis

The energy consumption before and after the renovation were compared by weighting the values using degree days provided by the Danish Technological Institute (Teknologisk Institut 2015). The standard year was set to 2906 degree days, the before-period had 2852 degree days, and the after-period had 2038 degree days. The energy consumption was split into weather-independent use (WIU) and weather-dependent use (WDU). WIU consists of consumption for hot water and electricity used for other purposes than heating. The WIU for hot water was based on gas consumption during a period in the summer when there was no heating in the house. The WIU of electricity was found by subtracting the measured use for heating from the total consumption. The same consumption was assumed for WIU before and after the renovation, although this calculation of WIU was only possible for the period after the renovation, because the specific electricity use for heating was not measured before. However, since the WIU is not affected by the weather, it should not have changed much due to the renovation. The weather-corrected energy consumption (WCEC) in the given period was calculated as follows:

$$WCEC = WDU \cdot \frac{2906}{\text{degree days in period}} + WIU \quad (\text{E.2})$$

The contribution from the wood-burning stove was based on estimates. The house owners estimated the use to be about 4 kg wood on an average day when the wood-burning stove was in use. The average specific energy of the wood is set to 4.1 kWh/kg (træfælderens.dk 2011), giving an average contribution from the wood-burning stove of:

$$4 \text{ kg/day} \cdot 4.1 \text{ kWh/kg} = 16,4 \text{ kWh/day} \quad (\text{E.3})$$

The number of days the wood-burning stove was in use was only registered after the renovation. Based on this, an estimate of its use before the renovation was made based on degree days, because the wood-burning stove is used in cold weather as a supplement to the other heating sources:

$$\text{use before} = \text{use after} \cdot \frac{\text{degree days before}}{\text{degree days after}} \quad (\text{E.4})$$

This number has a large degree of uncertainty due to the simplicity of the estimation. However, the stove contributes with less than 3% (1.45–2.65%) of the total energy consumption, which means that uncertainty about the exact contribution will not have a significant effect on the total result. The estimated use can be assumed to be conservative, because the need to use the wood-burning stove should decrease independently of the weather, after the house was renovated and the relative heat loss was reduced.

The increase in comfort and changes in user behaviour were evaluated based on the temperatures measured. The average and extreme temperatures were determined for each room, and patterns in the fluctuations were identified. The conditions before and after the renovation were compared to identify changes.

The overall result of the renovation was evaluated based on the energy savings achieved, the improvements in indoor climate according to the measurements and the house owners, and the cost of the renovation.

The house was simulated in the program BSim (SBI 2015), where it is possible to model indoor climate and energy consumption both at room level and in total based on a 3D model. The simulation modelled the building for a year before and after the renovation, with weather data reflecting the actual conditions at the time and place of the measurements taken at the house. This data was provided by the Danish Meteorological Institute (DMI). The model was mostly based on registrations made in the house in terms of geometry, building components, installations and user-defined settings such as set-points for heating, which was based on an average of the temperatures that were measured in each room.

## 6 Results

### 6.1 One-time measurements

The entire house was examined using an infrared camera to create thermographic pictures indicating the sources of heat loss from the house before and after the renovation. Figure 3 shows a representative corner of the house before and after the renovation. On the before-picture, a large triangle with a higher temperature (about 0.5 °C, the coldest part is about -2 °C) indicates that the insulation has partly collapsed and is no longer evenly distributed in the wall. Moreover, the window itself has a higher temperature (about 1.8 °C) indicating significant heat loss. In the after-picture, the temperature of the wall and window is much lower (about -13 °C on the window and -16 °C to -4 °C on the wall), and the shape of the warmer area under the roof indicates that the higher temperature here could be due to this part of the wall being more sheltered from wind and sky radiation.

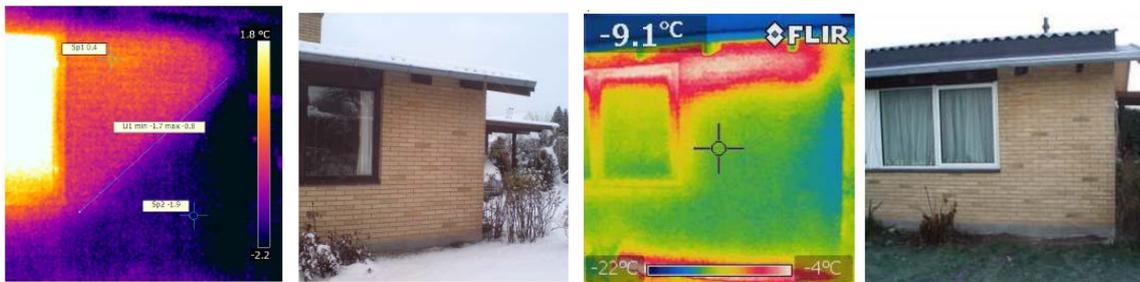


Figure 3 – Examples of infrared pictures of the same corner of the house before and after the renovation. The scale on the before picture is -2.2 to +1.8°C, the after is -22 to -4°C.

Table 3 – Volume flow through leaks in the building envelope at a pressure of 50 Pa, measured according to DS/EN 13829 (Dansk Standard 2001). The volume flow is compared to the requirements for new buildings according to the Danish Building Regulations (Danish Transport and Construction Agency 2015).

Air tightness	Measured		Building Regulations, new buildings		
	Before	After	2010	2015	2020
	l/s·m <sup>2</sup>	l/s·m <sup>2</sup>	l/s·m <sup>2</sup>	l/s·m <sup>2</sup>	l/s·m <sup>2</sup>
Volume flow through leaks in building envelope, $q_{50}$	2.5	0.8	1.5	1.0	0.5
Infiltration	0.19	0.09			

The results of the pressurisation test are shown in Table 3, and compared to the requirements for new buildings according to the Danish building code (there being no current requirements for tightness in the case of renovation). The table also shows the infiltration calculated based on the results. As the average house of this type and age has an infiltration of about 0.45 l/ s·m<sup>2</sup> (Teknologisk Institut 2007), the infiltration in this house was very low before the renovation, and it was further decreased by the renovation.

## 6.2 Energy consumption

The total energy consumption values measured in the house before and after the renovation are shown in Table 4. Once the consumption is weighted using degree days, the total energy consumption before and after renovation can be compared. According to the measurements, the renovation reduced the total energy consumption by 23%.

*Table 4 – The measured energy consumption of the house before and after the renovation.*

Energy consumption					
		Before	After	Difference	Difference [%]
<b>Energy consumption, measurement</b>	<b>kWh</b>	<b>27 390</b>	<b>17 664</b>	<b>9 725</b>	<b>36%</b>
Electricity	kWh	9 966	7 070		
Gas	kWh	17 424	10 594		
Assumed contribution from wood-burning stove	kWh	574	410		
Degree days in the period	-	2 852	2 038		
<b>Weather-independent use</b>	<b>kWh</b>	<b>9 286</b>	<b>9 286</b>		
Electricity	kWh	5 776	5 776		
Gas	kWh	3 510	3 510		
<b>Weather-dependent use (Heating)</b>	<b>kWh</b>	<b>18 677</b>	<b>8 788</b>		
Electricity	kWh	4 190	1 294		
Gas	kWh	13 914	7 084		
<b>Weather-corrected energy consumption</b>	<b>kWh</b>	<b>28 317</b>	<b>21 817</b>	<b>6 500</b>	<b>23%</b>

Prices for electricity and gas vary over time, so to get an idea of the economic saving an estimated standard price was used. The price of gas is estimated to 8.9 DKK/m<sup>3</sup>, based on the average cost in this part of Denmark during the year when the house was renovated. The price of electricity was set to 2.1 DKK/kWh, including all charges, based on the information from the electricity bill for the house in the year 2013/2014. When these prices are applied to the weighted energy consumption before and after, the total saving was found to be about DKK 8400 per year on electricity and gas.

The program BSim was used to simulate the energy consumption for heating the house. A comparison of the energy consumption for heating found through simulations and measurements in the house is shown in Table 4. It is not necessary to weight these values according to temperature to enable comparison, because weather data from the period were used in the simulation model. While there is a noticeable difference between the size of the energy consumption found in the simulation compared to the measurements, the saving of 53% of the heating consumption achieved is close to the 58% calculated in the simulation model.

*Table 5 – Comparison of the measured and simulated energy consumption for heating the house before and after renovation.*

Energy for heating					
Consumption		Before	After	Difference	Difference [%]
Measured energy consumption	kWh	18 677	8 788	9 889	53%
Simulated energy consumption (BSim)	kWh	24 775	10 291	14 484	58%

### 6.3 Energy level

To make it possible to compare the energy level of this house with other houses, the energy level of the house was calculated in the same way as it would be if the house was to receive an energy performance certificate (EPC) in accordance with Danish and European requirements (Retsinformation 2016). The result of the energy level calculation is shown in Table 6.

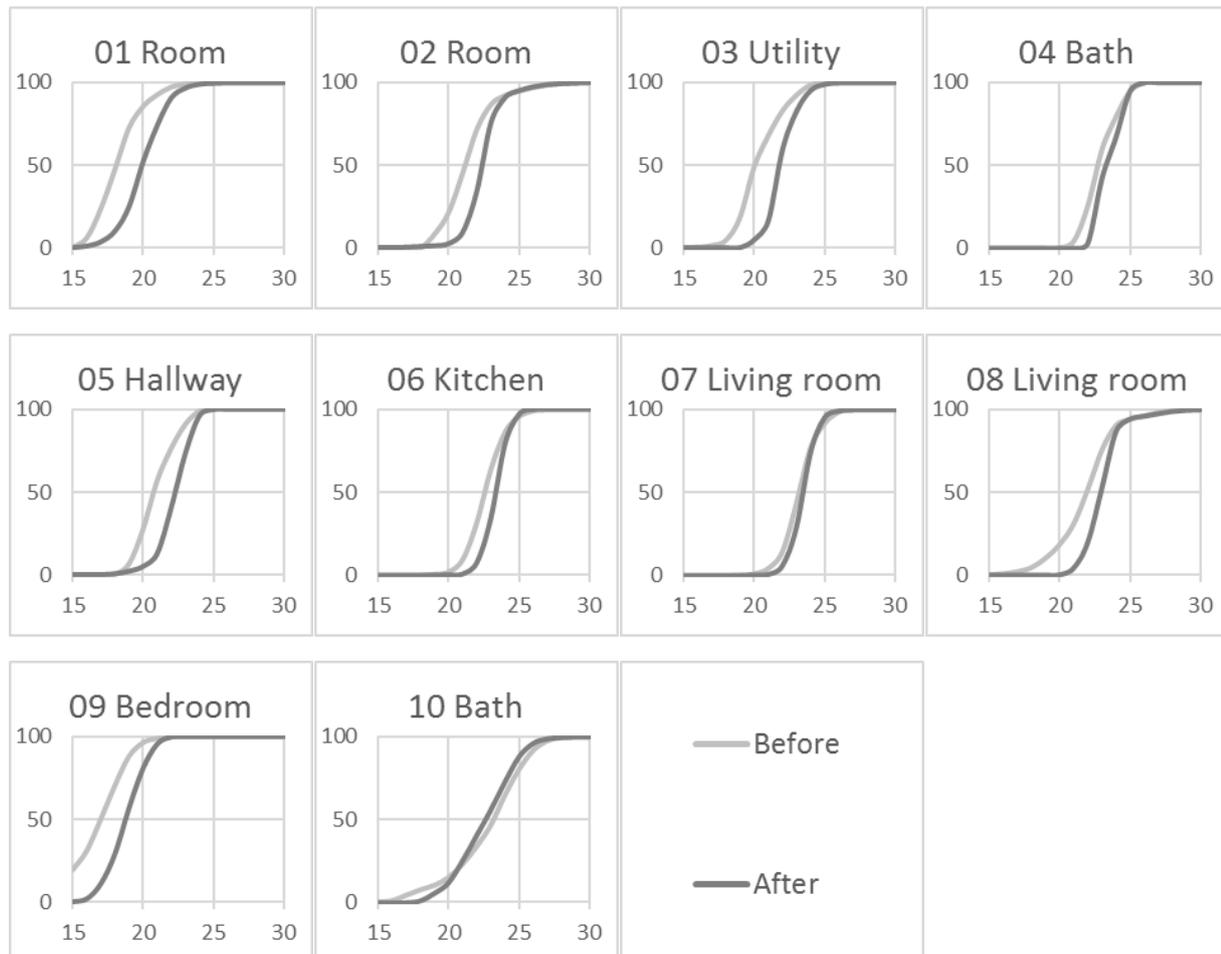
*Table 6 – Energy level of the house calculated in Be10*

Energy level calculation					
		Before	After	Difference	Difference [%]
Energy level	kWh/m <sup>2</sup> /year	192.8	120.8	72	37%
Corresponding energy label	-	E	C		

The energy level includes heating, hot water and ventilation based on standard values, and does not include electricity for other purposes, because this depends very much on the occupant of the

building. The EPC has a scale from G ( $>240+6500/A$  kWh/m<sup>2</sup> year,  $>281$  kWh/m<sup>2</sup> year for a house of this size) to A2020 (20 kWh/m<sup>2</sup> year). Before the renovation, the house had an EPC rating of E, which is very common for a house of this type and age (Energistyrelsen and Danish Energy Agency 2016). After the renovation, the house has an EPC rating of C, corresponding to new houses built in 2008–2010. The renovation also enables the house to receive the rating Renovation class 2 according to the Danish Building Regulations (Danish Transport and Construction Agency 2015).

#### 6.4 Indoor thermal climate

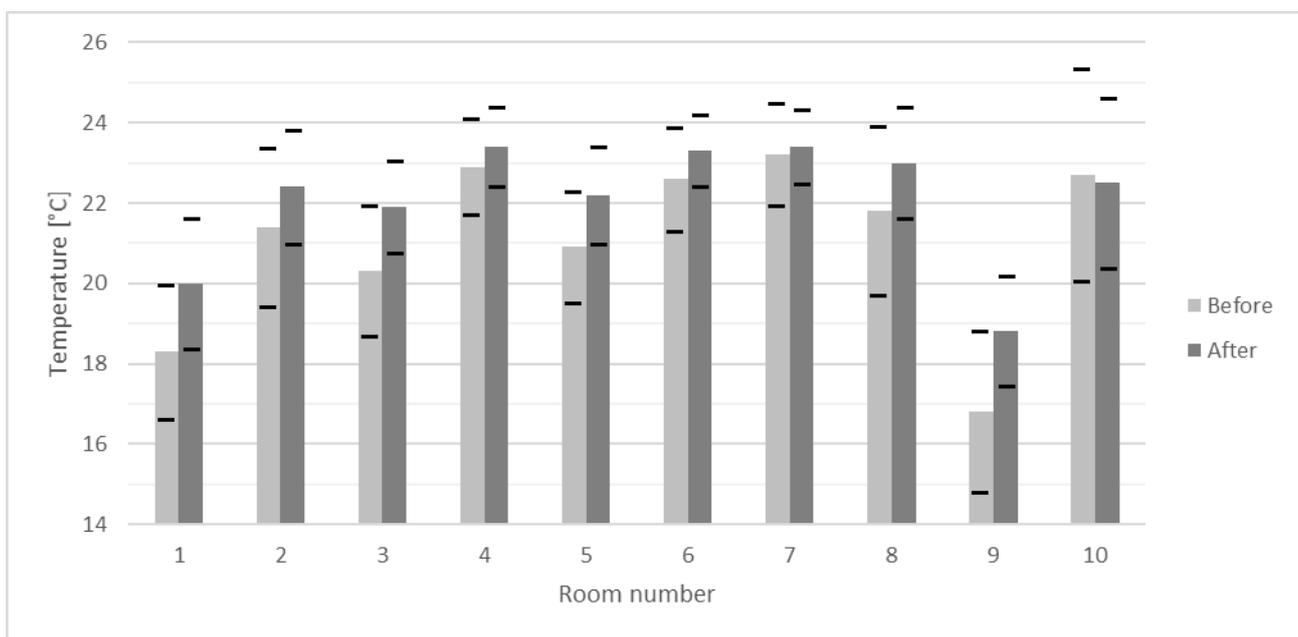


*Figure 4 – Cumulative percentage distribution of measured temperatures during the heating period before and after the renovation.*

The temperature level in all 10 rooms in the house was monitored for a year before and a year after the renovation, and the cumulative percentage distribution of the values measured during the heating season is shown in Figure 4, the average temperatures and their standard deviation before and after are shown in Figure 5 and Table 7.

The room temperature was regulated by the house owner themselves, based on their preferences. In the rooms most often occupied (06, 07 and 08), the temperature is slightly more even (more

vertical curve, lower standard deviation), which indicates that it is now easier for the occupants to maintain a steady temperature of about 23 °C. In room 08, there has been a particular improvement, because the temperature now rarely slips below 20 °C. In the more rarely occupied rooms (01, 02, 03 and 05), the temperatures before were often low, making it more difficult to maintain a comfortable temperature in the occupied rooms and avoid draughts. After the renovation, the temperature in these rooms has increased, making them more usable and reducing draughts in the house. In the bedroom (09), the occupants prefer a lower temperature, but before the renovation the temperature was below 15 °C almost 20% of the time. Such very low temperatures during the heating season can cause problems with condensation and mould, which is why it is much better to keep the rooms heated at all times.



*Figure 5 – The average temperature and standard deviation of temperature in the 10 rooms before and after the renovation.*

In average, the temperature has increased by 1.01 °C in the rooms. A paired t-test on the average of temperature measurements before and after gives a P value of 0.0014, so the difference in temperature can be considered to be very statistically significant. The 95% confidence interval is -1.5 to -0.5. When performing an unpaired t-test for the measurements of each room, all P values are below 0.0001, so the difference can be determined as extremely statistically significant. However this calculation cannot prove that this rise in temperature is a general consequence of this type of renovation, as a number of factors can have contributed to the increase.

Firstly, the temperature inside could be the result of changes in the outside temperature. The average of the temperature measured outside the house was 3.4 °C higher in the winter after the renovation compared to the year before (average 4.6 °C before (-10.5 to 22.0), 8.0 °C after (-5.9 to 23.3)). An evaluation of a shorter period of 3 days was made, in order to assess whether similar

outdoor conditions would eliminate the indoor temperature difference. Data was selected for periods during the before and after year, where the weather conditions were similar, concerning downpour, hours with sunshine, wind speed and direction and temperature development (when comparing each outdoor temperature measurements from the before period with the corresponding temperature in the after period, the difference is never more than 1.4 °C, and only 0.4 °C difference in either direction in average). When looking at the indoor temperatures during these periods, there has been a temperature increase in all rooms, 1.3 °C in average and up to 2.3 °C (in 06 Kitchen). A paired t-test found this difference to be extremely statistically significant with a P value below 0.0001. The analysis of this period suggests that the difference in temperature measured during the year before and after the renovation is not caused by changes in the outside temperature.

*Table 7 – Average measured temperatures in all rooms in the house during the heating season before and after the renovation.*

Average temperatures measured during heating season, and the Standard Deviation											
Room number	#	01	02	03	04	05	06	07	08	09	10
Average temperature before	°C	18.3	21.4	20.3	22.9	20.9	22.6	23.2	21.8	16.8	22.7
Average temperature after	°C	20.0	22.4	21.9	23.4	22.2	23.3	23.4	23.0	18.8	22.5
Difference	°C	1.7	1.0	1.6	0.6	1.3	0.7	0.3	1.2	1.9	-0.2
Standard deviation, before	°C	1.67	1.98	1.62	1.2	1.38	1.29	1.27	2.11	2	2.63
Standard Deviation, after	°C	1.63	1.42	1.14	1	1.21	0.9	0.91	1.38	1.37	2.12
Difference	°C	-0.04	0.56	0.48	-0.2	0.17	0.39	0.36	-0.7	-0.6	-0.5

Secondly, the temperature increase varies a lot from room to room, depending on the before temperature and the use of the room. In some of the rooms (04, 06, 07 and 10), the temperature is at the same level before and after the renovation, see Table 7. In these rooms, the renovation resulted in decreased energy consumption, because it now takes less energy to maintain a comfortable temperature. However, in other rooms (01, 02, 03, 05, 08 and 09), the energy consumption has not decreased very much, because part of the potential energy saving is spent on heating the rooms to a higher temperature. This phenomenon where the potential energy saving is used to increase comfort is called the rebound effect. This is very common in connection with renovations, and is often the result when a house was insufficiently heated before the renovation. Although increasing the temperature reduces the achieved energy saving, this is to some degree

necessary in order to achieve a more uniform temperature throughout the house, thereby reducing internal cold draughts.

### **6.5 The house owners' opinion**

Once the renovation had been carried out, the house owners were asked to evaluate the result. In general, they were satisfied with the way the renovation had been carried out and the overall result.

With regard to the indoor climate, the house owners experienced a significant improvement as a result of the renovation. They feel the temperature has become less fluctuating, even during night when the heating is turned off in part of the house. They describe the house as being warmer during the winter, and they no longer feel a cold draft from the entrance hall (room 05), which they perceived as a problem before. In the summer, they also experience an improvement. The thick insulation layer in the roof keeps the living room much cooler during the summer.

The house owners have kept many of their old habits from before the renovation. For example, the house is vented through the windows on a daily basis, despite the fact that they find the air quality to be good due to the new mechanical ventilation system, which makes venting redundant. This has a negative impact on the energy consumption after the renovation because it increases the heat loss.

### **6.6 Cost of the renovation**

The value of property and cost of renovation are shown in Table 8. Before the renovation in March 2013, the whole property (house and land) was worth about DKK 4.5 million (about EUR 600,000) according to their mortgage bank.

The renovation of the house cost an investment of about DKK 850,000 for the first part in 2013, including the building envelope and the ventilation system, and about DKK 450,000 for the second part in 2014, including rooms 03 and 04. The total investment was about DKK 1.3 million.

After the renovation, a new evaluation of the value of the house was made, by the mortgage bank to increase the mortgage and by a local real estate agent (both in September 2014). Both parties found the house to have a value of about DKK 5.7 million after the renovation, an increase of DKK 1.2 million compared to its value before the renovation.

The increase in housing prices were calculated according to the price index for sales of property, specifically one-family houses in the quarters where the evaluations took place (Statistics Denmark 2016). According to these numbers, the value of the house, disregarding the renovation increased with about 200 000 DKK. However, even taking this into account, the increased value of the house due to renovation is estimated to be about DKK 1,000,000. This increase in price corresponds to

about 77% of the cost of the renovation. In addition to this, there is now a reduced expenditure for electricity and gas of about DKK 8,400 per year<sup>1</sup>.

*Table 8 - Value of property and cost of renovation*

<b>Value of property</b>				
		Before renovation March 2013 (1 <sup>st</sup> quarter)	After renovation September 2014 (3 <sup>rd</sup> quarter)	Difference
Evaluation by mortgage bank	DKK	4 500 000	5 700 000	1 200 000
Evaluation by real estate agent	DKK	-	5 700 000	
Price index <sup>a</sup>	-	86.1	90.9	
Approx. value increase based on price index	DKK			200 000
Resulting value increase due to renovation	DKK			1 000 000
<b>Cost of renovation</b>				
		Part one	Part two	Total
Renovation cost	DKK	850 000	450 000	1 300 000

<sup>a</sup> Price index for sale of property (2006=100) for one-family houses in the specific quarters according to Statistics Denmark (2016).

## 7 Discussion

### 7.1 Accuracy of measurements and simulations

A number of factors influence the accuracy of the measurements. The fact that the house has a wood-burning stove makes the prediction of the savings less clear, because the total use of the wood-burning stove is unknown. Its wood consumption and energy contribution are based on rough estimates, and its use is based on information from the house owners collected after the renovation. However, the contribution from the wood-burning stove only covers about 3% of the total energy consumption of the house, which lessens its effect on the results. A more precise determination of

<sup>1</sup> The average yearly disposable income in Denmark is about 220,000 DKK. For more information on the overall economy of Danish households, see (Statistics Denmark 2015).

the energy contribution from the wood-burning stove would therefore not make a significant difference to the total result.

Another thing that affects the accuracy is the method of weighting energy use by degree days. Although this is a commonly used method for weighting energy needs, it is still a relatively simple method, because it is based solely on temperatures and does not include, for example, the effect of sun and wind. The weighting of the energy use is also very dependent on the division between weather-dependent and weather-independent use. Due to the detailed measurements of the energy consumption for heating carried out after the renovation, the remaining electricity consumption has little uncertainty. However, the figures for the remaining electricity consumption before the renovation are more uncertain, because these are also based on the values from after the renovation. The hot water consumption, which is the weather-independent part of the gas consumption, is based on the values measured during a summer period with no heating. While the value is based on average figures from measurements in the actual house, there is still some uncertainty, because the consumption changes continuously.

The temperature data was collected by putting a HOBO-logger in every room of the house. Since the measurements were made over a long period of more than two years and the house was inhabited all the time, the loggers were located to avoid inconvenience. The temperatures measured therefore are not an accurate documentation of the operative temperature in the house. However, the loggers remained in the same place throughout the period, so their data gives a good account of the size of temperature fluctuations over time and the difference in temperature levels before and after the renovation.

The accuracy of the simulations was also affected by various factors. While the model was built to come as close to the actual conditions as possible, it still required a lot of assumptions, e.g. about material properties and building systems, and the geometry is slightly simplified.

## **7.2 Discussion of results**

Most of the measurements carried out on the house show that the house has been improved through the renovation, because the house became warmer and more air tight. The house owners are satisfied with the result of the renovation, because they can feel an increase in comfort, which are important factors to determine the success of a renovation (Thomsen et al. 2016). The reduction in the total energy consumption was about 23%, and the energy consumption for heating was reduced by about 53%. This is not far short of the 58% savings found through the simulation of the house. Due to measurements made in the house, it was possible to make a simulation model that was fairly close to the actual conditions, which can explain why the achieved saving are close to that found through simulations. A saving of about 50% on the energy consumption for heating confirms that there is a large potential for achieving energy savings in this part of the building stock through renovation. It is also on the same level as the savings achieved by (Tommerup 2008), who measured

on the renovation of a similar single-family house, and found a reduction of 54% on heating consumption.

As the house owners were very much engaged in the renovation, and were made aware of their energy consumption on a daily basis when reading of meters, it is possible that part of the energy saving achieved are due to changes in behaviour and not the renovation itself. In favour of this, is the fact that the house owner started to gradually change old energy consuming light bulbs to more efficient LED. However, other things did not change, such as the house owner continuing their daily venting routine despite the new ventilation system. Although the awareness may have had an effect on the size of the energy saving, it is not deemed to be significant. Especially as the measurements show that part of the energy saving has been consumed by increased comfort. Before the renovation, a large part of the house was allowed to have very low temperatures during the winter, which resulted in cold draughts in the house. After the renovation, the house is easier and cheaper to heat, which creates the option of keeping a more even indoor temperature in the whole house.

All too often, the feasibility of an energy renovation is judged solely by calculating the simple payback time for the improvements. However, this approach is problematic, as it can be beneficial to include other aspects as well, as suggested by (Bartiaux et al. 2014; Wilson et al. 2015). This renovation included purposes other than reducing energy consumption, such as replacement of worn-down building parts, but it could still be considered an energy renovation, because insulation was added to walls, better-than-average windows were chosen, and so on. The measurements and calculations show that the house has achieved an average saving of about DKK 8400 per year. With a total investment for the renovation (disregarding the later investment of upgrading rooms 03 and 04) of DKK 850 000, this would result in a payback time of about 100 years. This figure alone might indicate that this was not a sensible investment, but the increased value of the house, the improved terms for the mortgage, the improved condition of the building parts, and the improved comfort in the house say otherwise. This shows how problematic it can be if there is too much focus on the simple economic and energy savings that can be achieved through renovation.

In this renovation, part of the energy saving was lost due to the rebound effect, where energy is used to achieve a higher comfort level than before the renovation. This is not surprising, as the rebound effect is very common, and well documented in literature, even though the size of it can be difficult to predict, as it depends heavily on user behaviour. Even though the rebound effect makes it more difficult to predict the exact energy saving that can be achieved, it is not necessarily a bad thing to have a rebound effect. In this case, the house owner could save a lot of energy by lowering the temperature a little all over the house. But to have cold rooms, with a temperature below 15 °C, can give problems with drought and moisture, so increasing the temperature in the cold rooms actually help to create a more heathy environment in the house. In this way, the rebound effect is often more a problem for building professionals when making calculations and by reducing the credibility of energy renovation, than it is an actual problem in the house due to behaviour.

However, it is very important to take into consideration if the budget of a renovation depends on the achieved savings, or when making political goals in this field, as the saving potential might be less than expected.

## **8 Conclusion**

This paper has documented the renovation of a typical Danish single-family house and thrown light on the benefits. The house was renovated to improve its durability, decrease energy consumption, and increase indoor climate comfort – all within a feasible budget. Building elements approaching the end of their service life were replaced. The energy consumption of the house was reduced by 23%. The energy consumption needed for heating was reduced by 53%. Measurements in the house show that the temperatures are now less fluctuating and more even throughout the house. The house owners report that the house is now cooler in summer and warmer in winter, and they are no longer bothered by cold draughts. The investment in the renovation totalled DKK 1.3 million, while the increase in the value of the house has been determined to be about DKK 1.2 million (incl. DKK 200 000 due to change in price index). Moreover, the house owners will save about DKK 8,400 per year on gas and electricity. Documenting this renovation has shown that, while many projects are unable to match the expectations created by simulations, it really is possible to achieve a relevant renovation that updates the house and reduces energy consumption, while staying within a feasible budget. The study has shown that from the house owners perspective, a general renovation can be successful and economically balanced, while improving the comfort and general condition of the building increasing its functional lifetime. From a researcher/adviser perspective, the study has highlighted the necessity to include the rebound effect when predicting energy savings. Further it is suggested that this should not only be considered a problem, as it is not only increases comfort for the occupants, it can actually be beneficial for the building itself to avoid very cold rooms. On a national level, however, the study suggests that the energy savings that can be achieved through renovating the building stock, might be less than hoped based on general analysis of the potential. This does not suggest that energy savings in the building stock should not be pursued, however, it may be necessary to lower the expectations as to what can be achieved.

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# APPENDIX III – PAPER III

## **Initiatives for the energy renovation of single-family houses in Denmark evaluated based on barriers and motivators**

*Matilde Grøn Bjørneboe; Svend Svendsen; Alfred Heller*

*Under review, Energy and Buildings; 2017*

- Creating a framework of barriers and motivators for energy renovation in homes
- Identification of four possible areas for improvement in current Danish policy
- Need for improved support through relevant renovation plans and financial support
- Focus on non-energy benefits and on stating maximum allowed energy consumption

# Initiatives for the energy renovation of single-family houses in Denmark evaluated based on barriers and motivators

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## Abstract

The renovation of single-family houses in Denmark is progressing only slowly. Changes in current policy are needed if the political goal of a fossil-free building sector is to be achieved. Known barriers and motivators for energy renovation are identified, and arranged in a framework with three main fields: Information, Finance and Decision-making, each with 3 sub-areas. With this framework, current Danish policy is analysed to identify shortcomings, found to mainly exist in connection with financing and decision support. Using experience from other countries, suggestions are made for improvement in four areas: focus on non-energy benefits rather than investment, enhancement of subsidy system, including relevant renovation plans in the energy performance certificate (EPC), and long-term regulation on the maximum allowed energy consumption of houses.

## Keywords

Government policy; home renovation; energy efficiency; fossil-free society; single family houses; detached houses

## Highlights

- Creating a framework of barriers and motivators for energy renovation in homes
- Identification of four possible areas for improvement in current Danish policy
- Need for improved support through relevant renovation plans and financial support
- Focus on non-energy benefits and on stating maximum allowed energy consumption

## Introduction<sup>1</sup>

The renovation of single-family houses in Denmark is progressing only slowly [1,2], despite the attention this area has received for a long time. This slow pace is an obstacle to reaching the goal of a fossil-free society by 2050. Single-family houses are important in the Danish context, because in 2014 they accounted for about 22% of the total energy consumption, making them the largest single contributor apart from road transport [3,4].

One way to increase the rate of energy renovation of owner-occupied single-family houses is to implement policies that encourage renovation. This can be done at many levels, municipal, regional or national, and even covering several countries, as seen in the European Union. Denmark already has a number of such policies. This paper presents a new overview of the main barriers and motivators aimed at identifying gaps in current Danish policy. Our recommendations for improvements also draw upon experience from other countries and regions.

The effect of various policies on the energy-efficient renovation of housing has been the subject of a number of studies.

Baek and Park [5] wanted to improve energy policy in Korea and looked into how policy measures are used to overcome barriers to energy renovation in four European countries: Denmark, Netherlands, Germany and France. They conclude that, while there is increasing focus on energy efficiency and there are a lot of savings to be found in the existing building stock, it can be difficult to exploit this potential because house owners are reluctant. They think the main barriers are insufficient awareness, finances and information, and the absence of a regulatory system. To solve these issues in Korea, they suggest expanding the energy performance certification system, improving financial support, and strengthening regulations.

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### <sup>1</sup> Abbreviations:

BB	BedreBolig [A Better Home], a Danish Government energy renovation scheme
BJO	BoligJobOrdning [Home-Work-Scheme], a tax reduction scheme
EE	Energiselskabernes Energispareindsats [the Energy companies' Energy-saving initiative]
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate

Bartiaux et al. [6] used a practice-theory approach to examine the effect of energy retrofit policies in four different European areas: Denmark, Latvia, the Coimbra area in Portugal, and Wallonia in Belgium. From this and earlier studies [7,8], they conclude that financial savings and climate protection alone are not effective as motivators for energy-efficient renovations. Nevertheless, these are often the focus of energy renovation policies, notably the EU's Energy Performance of Buildings Directive (EPBD) with its Energy Performance Certificate (EPC). They note that, while the EPC can raise awareness on energy renovation, it will probably not generate renovation practice on its own. Watts et al. [9] evaluated the domestic EPC-scheme in England and Wales based on a survey of homeowners who had received an EPC within the first year of the scheme. The most common barrier to energy renovation was the cost, followed by it not being a priority. They conclude that the suggested improvements are rarely implemented and that many homeowners thought the EPC was a waste of money and not very useful. Moreover, only 45% of the homeowners who had received an EPC were aware of the grants available even though they are described in the EPC, which suggests that people do not really read EPCs. The conclusion that an EPC does not lead to many energy improvements has also been confirmed in the Danish context by Christensen et al. [10].

While many studies focus on the financial barriers and motivators, Wilson et al. [11] point out that this focus could be a problem because many other factors influence the decision process. They focus on the influence of non-energy benefits and promote a view of energy-efficient renovation as a fluent part of everyday life, rather than an extraordinary event. This approach is supported by Gram-Hanssen [12], who, based on a survey among Danish house owners, concludes that the renovation of kitchens and bathrooms often has higher priority than energy efficiency, the author states that economy itself rarely works as a motivator for renovation. While a lack of finances can set limits on a possible renovation, homeowners often renovate to improve their lifestyle or as a DIY project. Gram-Hanssen emphasises the importance of taking social factors into account when promoting energy efficiency.

This current article also includes analysis of a new scheme (BedreBolig introduced nationwide in 2014) and draws on a number of sources to create an overview of the most relevant barriers and motivations. This newly developed framework is then used to identify shortcomings in current Danish policy.

## Germany

Germany has very ambitious goals and policies aimed at reducing energy consumption. Schröder et al. [13] evaluated the German KfW Investment Bank initiatives from a British perspective. They describe how the KfW programmes managed to promote the energy-efficient renovation of about 9 million houses between the 1990s and 2010. They report that this success has been due to a number of factors, including a combination of regulation, information and support to create a framework for energy

renovation; favourable terms for loans and subsidies that promote ambitious solutions; focus on a 'whole building approach' to energy saving, also where improvements are implemented in phases; and consistently shaping public opinion and behaviour in favour of the benefits of energy efficiency. However, Grösche and Vance [14] estimate that about half the households that received the grants would have implemented the improvements anyway in view of their assumed willingness to pay for energy improvements.

Galvin [15] criticises German policy initiatives to promote thermal renovation because they promote very extensive energy renovations through subsidies and loans, while regulations stop people implementing smaller and inexpensive improvements to their houses. Often people do not see their houses as needing major renovation and upgrading to a new-house standard can seem far too comprehensive and expensive, with payback periods that are too long. Galvin thinks that the policies aimed at promoting extensive energy renovation of single-family houses might actually be preventing people from renovating at all.

Weiss et al. [16] focus on the opportunity that arises when a house changes owner. They suggest that requirements should be made for the renovation of the house within a limited time period after the change in ownership. This would mean high energy consumption would reduce house prices, because houses with a high consumption would come with a demand for renovation. They point out two specific challenges in this area. The first is that great care should be taken when setting the appropriate energy efficiency level in the renovated houses, because the scheme can freeze the level of renovation for many years. The second is to avoid creating greater social imbalance, because socially vulnerable groups are more threatened by this type of regulatory law. A number of social support measures would be needed to prevent people ending in a hopeless financial situation. However, this type of regulation could have a large impact and target the houses where the largest energy savings could be achieved.

Galvin and Sunikka-Blank [17] compared the German experience with that of the UK. Their aim was to look into the German goal of reducing carbon emissions by 80% between 1990 and 2050, and how it is connected to the economic viability of the mandatory savings in the Energy Saving Regulations. They claim that, while there may be many benefits from energy renovation, it will not be possible to achieve the energy-saving goal through such savings, because they are often less than calculated and it would take a massive amount of super-efficient renovation to achieve the goal. They also suggest that the Government should stop promoting thermal renovation by claiming 'it pays for itself' and instead focus on some of its other good qualities.

## The UK

When initiated in 2013, the ‘pay-as-you-save’ scheme called Green Deal was the flagship of the UK Government policy on the energy renovation of homes [18]. The house owner could get a Green Deal energy assessment, including recommended improvements, estimates on possible savings, and an EPC. If homeowners decided to renovate based on this assessment, they could pay for the improvements themselves or use a Green Deal finance plan, where the loan was repaid through the expected savings on the energy bill. To protect the house owner from additional expenses, the programme included a ‘Golden Rule’ stating that the repayments should not exceed the estimated savings on the energy bill. The Green Deal was linked to the house, so if the house was sold, the repayment of the loan would pass to the new owners, because they would now benefit from the improvements.

In 2015, funding for the project was stopped because only about 15,000 loans had been taken out. This is very few compared to a building stock of about 14 million houses in need of renovation and the initial ambitions of the scheme. An online energy saving advice community [19] argued that the main flaw of the scheme was ‘the Golden Rule’. It was meant to protect homeowners from large repayments, but in reality it created an upper limit on the amount house owners could borrow, because it all had to be paid from the energy savings alone and within a limited number of years. This drastically limited the possibilities for extensive renovation.

Pettifor et al. [20] investigated how the Green Deal affected house owners by questioning them four months before and seven months after the launch. They found that house owners do not distinguish energy efficiency from other kinds of renovation, so a lot of them lost interest, because their focus was on necessary maintenance, and the Green Deal only covered energy savings. Pettifor et al. also found that the energy renovation decision process is very slow, often taking about a year from detailed planning to actual renovation. Another problem was the upfront cost of getting a Green Deal assessment. Many people found that they paid for assessments that turned out not to reveal any opportunities within the limits of the Green Deal scheme. The cost of assessments and the limited number of improvements that were eligible within the scheme meant the number of renovations carried out was low. And some people were worried that a Green Deal might affect the saleability of their house.

## Aim

This paper is contributing to the body of knowledge in three ways. Firstly, by providing an updated evaluation of current Danish policy schemes in this field. Secondly, by collecting the main known barriers and motivators for energy renovation in single-family housing, and presenting them in a new framework that makes it easy to identify areas that need more attention from policy makers. And

thirdly, by making suggestions on how to overcome the barriers and motivate more and better renovations. Although the work is based on a Danish context, the overview of barriers and motivators can be used to identify gaps in other policy schemes as well.

## **Methodology**

To increase the number of renovations, it will be necessary to remove barriers currently holding the process back and motivate those who can carry out renovation if they want to. Acknowledged barriers can be divided into three different fields, cf. Wilson et al. [11]: Information, finance and decision making. Each field contains three significant sub-areas that should be addressed, see [Figure 1](#).

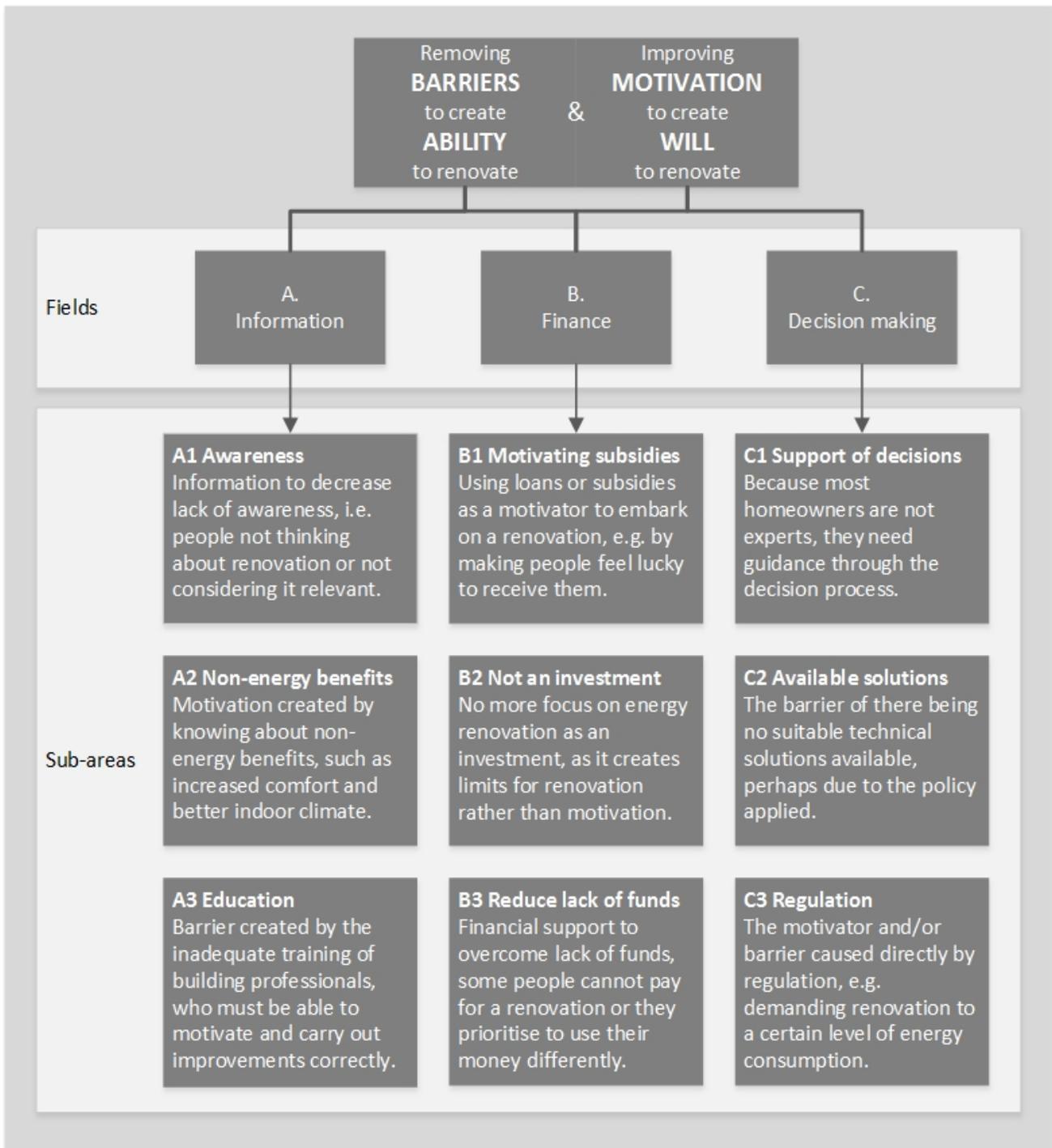


Figure 1 – The three main fields of elements acting as barriers and motivators for energy renovation. In each field, three areas are identified.

Table 1 – Literature references for the existence of the areas of motivation and barriers described.

<b>A. Information</b>	<b>B. Finance</b>	<b>C. Decision-making</b>
<b>A1 Raising awareness</b>	<b>B1 Subsidies as a motivator</b>	<b>C1 Supporting decisions</b>
[5] [9] [16] [20] [21] [22] [23]	[9] [14] [15] [16] [21]	[9] [11] [12] [16] [21] [23] [24] [25]
<b>A2 promoting non-energy benefits</b>	<b>B2 investment, pay for itself</b>	<b>C2 Available solutions</b>
[11] [12] [20] [23] [24] [25]	[16] [20] [21] [22] [24]	[12] [14] [15] [16]
<b>A3 Education of building professionals</b>	<b>B3 Lack of funds</b>	<b>C3 Regulation</b>
[12] [16] [21] [22] [23]	[5] [9] [16] [21] [22] [24]	[5] [9] [15] [16] [22]

Information (A) refers to the homeowner’s knowledge about renovation and the availability of the information needed. This includes rising awareness, promoting non-energy benefits and educating building professionals. Finance (B) includes loans, subsidies, grants, tax reductions and financing. Here the important sub-areas identified are using subsidies as a motivator, stop considering energy renovation as an investment that pays for itself, and overcoming the barrier created by a lack of funds. Decision making (C) covers the choices the house owner makes, the options they have, and how to overcome the strong inclination to stick to the default choice of doing nothing or very little. This includes the need to support the decision process, ensuring that suitable technical solutions are available and ensuring that regulation are used in the right way, to work as a motivator not a barrier. The existence of these barriers and motivators is confirmed in the literature, see [Table 1](#).

The current Danish initiatives are described based on the literature and information from official and/or Government websites. The initiatives are then evaluated using the framework of barriers and motivators, in order to identify gaps in the current schemes. Finally, improvements are suggested based on experiences from other countries.

## Existing renovation policies in Denmark

### The Building Regulations (in Danish: Bygningsreglementet)

The Danish Building Regulations (BR15) set the legal framework for buildings in Denmark. They cover most aspects of a building including its energy consumption [26]. Until the 1970s, the energy consumption of buildings was not really regulated, but since then the Building Regulations have been continuously tightened up to reduce energy consumption in both new and existing buildings.

The building regulations set up rules for the maximum allowed energy consumption of new buildings. The consumption of existing buildings, however, is usually only regulated when the owner plans a renovation of a part of the building. Cost-effective energy savings must be implemented when alterations are made to external walls, floors, roof structures, windows or installations. The latest version of the building regulations introduces voluntary renovation classes, which provide a total energy performance framework for the building when renovated. To achieve one of the two renovation classes, the renovation must

- Improve the energy performance by at least 30 kWh/m<sup>2</sup> a year
- Include sustainable energy supply
- Meet requirements on the indoor climate
- Achieve the energy requirements of class C or class A2010 on the Danish energy performance certification scale, described in section 0.

### Energy Performance of Buildings Directive (EPBD) and Energy Performance Certificate (EPC)

The EU member states and Norway have made a joint effort to reduce the energy consumption in buildings with the Energy Performance of Buildings Directive (EPBD), which has now been in force for about a decade. A key aspect of the EPBD is the Energy Performance Certificate (EPC). The EPC takes a different form in each member state, because only the framework is decided at a central level. Unless otherwise specified, the EPC described in this paper is the Danish version.

The EPC is mandatory for houses when they are to be sold or rented out. The EPC rates the energy performance of a building on a scale from A2020 to G, where A2020 is the lowest energy consumption; see [Table 2](#). The energy performance is calculated using standard values for temperatures and the consumption of hot water, and it does not include lighting or electricity for anything other than heating and ventilation. This makes houses easier to compare, because the influence of the specific occupants is removed from the calculation. But it also means that the energy label might not give a very accurate picture of the actual energy consumption in the house.

**Table 2 – The rating scale of the Danish EPC for homes. The unit is kWh/m<sup>2</sup> a year, and A refers to the heated floor area in m<sup>2</sup> [27].**

A2020	A2015	A2010	B	C	D	E	F	G
20	< 30.0 + 1000/A	< 52.5 + 1650/A	< 70.0 + 2200/A	< 110 + 3200/A	< 150 + 4200/A	< 190 + 5200/A	< 240 + 6500/A	> 240 + 6500/A

Beside the estimated energy consumption, the EPC includes suggestions for feasible energy improvements. The idea behind this is to tell the house owner about a few relatively cheap improvements that might improve their energy label. However, because these suggestions are very general and might not even be suitable for the specific house, they can sometimes do more damage than good [28].

The purpose of the EPC is defined in an evaluation report describing the progress of its implementation [29]. Its purpose is to increase awareness about the energy performance of buildings, and enable the comparison of buildings based on energy performance, thereby influencing their market value. The increased value of a building can work as a motivator for more energy renovation.

A number of studies have shown that the price of houses is affected by the energy performance [30–34]. It may be difficult to isolate the effect of energy performance, but all the above-mentioned studies have found a statistically significant increase in house market value due to energy performance. This suggests that the EPC does increase focus on the energy performance of a building in connection with a sale. Jensen et al. [35] looked into the effect of making the EPC more visible when it was first made mandatory in sales material in 2010. They found that the display of the EPC had a clear effect on the distribution of prices for the buildings labelled.

Whether the EPC has increased the number of energy renovations is more doubtful. Christensen et al. [10] carried out a survey among Danish house owners with an EPC and found that, while most consider the EPC reliable and easy to understand, very few find it useful when it comes to home renovation. Those who were aware of the improvements suggested in the EPC were more likely to implement energy savings, but it is impossible to say whether the EPC increased the chance of improvements or whether the people who made improvements were just more aware of the EPC. Christensen et al. conclude that the EPC in its current form is insufficient, and suggest that house owners are not ‘economically rational’ in their decisions, that aspects other than energy should be included, and that the EPC should not only be relevant in connection with a sale.

An indication of the amount of renovation currently taking place can be found by analysing changes in the energy level of houses being sold, because all houses for sale must have an energy assessment. Data for 50,000 houses sold in the period from July 2010 – November 2016 provided by Boligsiden.dk show a development in the distribution of energy labels. The 50,000 houses in the database correspond to about 22% of all single-family houses sold in Denmark in the period [36]. The number of houses sold and registered gradually increased during the period 2011–2015 from 6306 to 9570. To see the tendency in the distribution between the labels, we calculated the percentage of houses receiving each label, see [Figure 2](#). The figure shows that fewer houses with high energy consumption are being sold,

while more houses with a better energy level are being sold. This tendency becomes even clearer in [Figure 3](#) where the levels are collected into groups (A2010–A2020: “new buildings”; B–C: “good or renovated buildings”; D: “average buildings”; and E–G: “un-renovated buildings”). [Figure 3](#) shows a clear tendency, and combined with the knowledge that houses are typically improved by 2 steps up the scale during an extensive renovation. The figure suggests that many houses are being renovated from D-G to B-D.

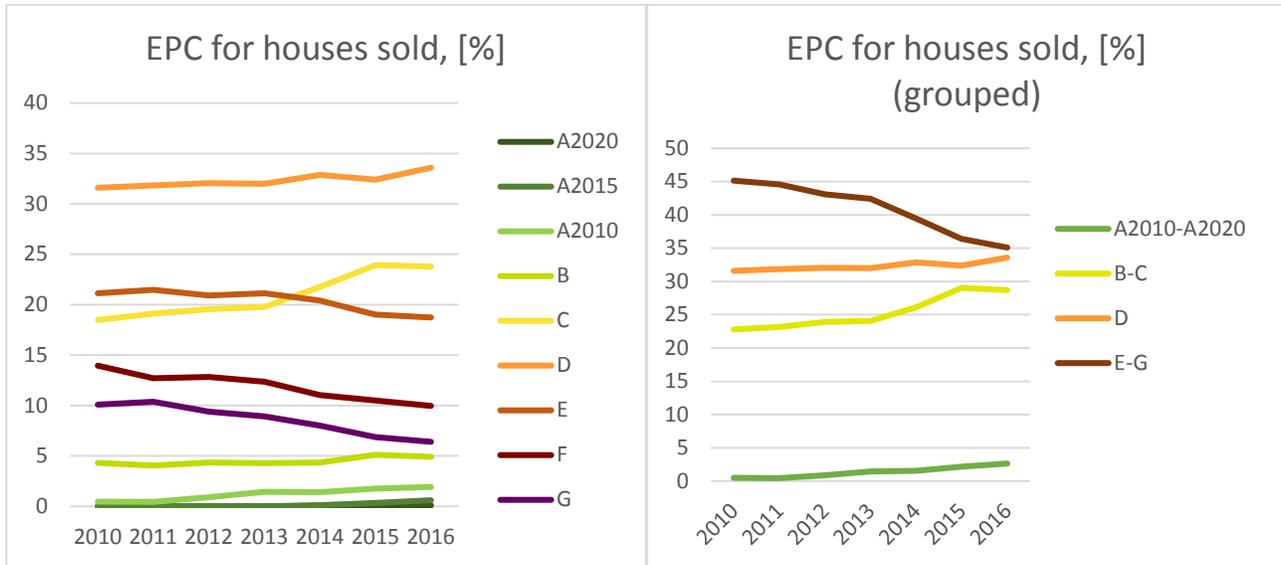


Figure 2 – The percentage distribution of the registered houses for each year. Data: Boligsiden.dk

Figure 3 - The percentage distribution of the registered houses for each year, collected in 4 groups. Data: Boligsiden.dk

## 1.1 BedreBolig [A Better Home]

BedreBolig (BB) is an initiative from the Danish Energy Agency, which is an agency currently under the Danish Ministry of Energy, Utilities and Climate. The idea behind the scheme is to offer better advice to house owners when it comes to energy renovation. This is done by educating advisors, craftsmen and other relevant actors to provide more holistic counselling and to enable them to create a renovation plan for the house. The scheme is based on the One-Stop Shop concept, where the house owner can get all services from the same company, from initial advice and planning to execution and follow-up on their renovation project. Once they have the initial plan for the house, they can, for example, use it as an instrument to get a loan from their bank or collect quotations from craftsmen.

The BB initiative dates from 2013. It started as an experiment in nine municipalities before it was introduced in the whole country in the autumn of 2014. Since it is relatively new, there are very few reports and evaluations of the effects and the success rate of the initiative, though Geelmuyden Kiese

[37] made an evaluation on behalf of the Danish Energy Agency of the experiment in the municipalities. While many of the municipalities were positive about the initiative, they indicated that it was difficult to evaluate the effect that quickly, because of the time it took to get the professionals through the necessary qualifying course before they could start advising citizens. Nevertheless, some expressed the view that many house owners might find the cost of getting the BB-plan made (about DKK 2-3000 or EUR 270-400) a big obstacle.

Three more recent evaluations have been carried out by EnergiTjenesten (the Energy Service) on behalf of Ballerup, Furesø and Lyngby-Taarbæk municipalities. The Energy Service is an independent energy consultancy service run by citizen-based organisations and offers BB counselling itself. The three reports evaluate the initiative, its effect, and how it has been received by customers [38–40]. Only the report for Furesø municipality is currently publicly available, but all three were obtained and reviewed as part of this current study, and supplemented with an interview with the authors of the reports. From the three municipalities, 48 citizens (81% of those who had received a BB plan from the Energy Service and were therefore included in the survey) responded to the questionnaire within a period of three months to one year after receiving the BB plan. The survey shows that 75% of the respondents decided to implement one or more of the improvements suggested. Out of the total number of the suggested improvements, 31% have been or are about to be implemented, 32% might be implemented, and 37% will probably not be implemented. All three municipalities offered a subsidy for having a BB-plan made, and 66% of the respondents said that they would not have requested a plan had it not been for this special subsidy provided by the municipality.

The authors conclude that while some are motivated by maintenance or a wish to update the house, a majority mention economic benefits and the payback period as incentives to implement improvements. This is backed up by a survey made among about 3000 house owners from across Denmark [41], where 58% give the economic benefits as a motivator for starting an energy renovation. However, 50% mention improved comfort and indoor climate as motivators. The BB initiative slogan is ‘Besparselsen Betaler’ (the saving pays), which further increases the focus on the economic benefits of energy renovation.

## **1.2 Subsidies for energy renovation**

When a house is renovated in Denmark, there are two national schemes that provide subsidies: “Energiselskabernes Energispareindsats” (EE) [the Energy companies’ Energy-saving initiative] and the “BoligJobOrdning” (BJO) [Home-Work-Scheme].

In 2012, the Minister for climate, energy and buildings made an agreement with the Danish grid and distribution companies for electricity, natural gas, district heating and oil. The agreement commits the

companies to achieve energy savings among their end users every year in the years up to 2020 [42]. This is the Energy companies' Energy-saving initiative (EE). For the private house owner, it means that they can 'sell' their energy saving to a distribution company and thereby receive a subsidy for their renovation. They can only do this once for each renovation, and they must apply before the work has started [43].

In addition to this subsidy, it is possible to get a tax reduction for the payment of craftsmen through the 'BoligJobOrdning' (BJO). Originally introduced in 2011 as a temporary subsidy scheme, it was meant to increase the demand for services in private homes, such as professional cleaning and repairing, and thereby increase employment in these sectors and perhaps reduce the amount of undeclared work [44]. Since its introduction, the scheme has been renewed and updated a number of times, most recently in 2016, when it was directed towards more energy-saving improvements and included a possible subsidy for professional advice on energy improvements.

### **1.3 House Condition Report (in Danish: Tilstandsrapporten)**

When a house is put up for sale in Denmark, the seller will usually have a house condition report made, which describes the current condition of the house compared to houses of the same type. The condition report is made by an experienced building professional who is appointed by the Danish Business Authority. The condition report is not an actual policy instrument for renovation, but it provides homeowners with general information about their new house, so it is relevant to include in our study on the renovation of single-family houses in Denmark.

The House Condition Report is a damage report, systematically describing visible damage and problem areas that could evolve into damage. The level of damage found is stated using a special scale depending on its severity, i.e. how critical it is for the house. The scale is from K0 (cosmetic), K1 (minor), K2 (serious), K3 (critical), to UN (needs further investigation). The level says nothing about the cost of rectifying the damage.

While this report helps the new owner to get an overview of the house they might buy, the report does not reflect the general level of maintenance required or (with the exception of the roof) the remaining service life of the building parts. The report only mentions actual damage and not things that can be expected for a house of that type and age. For example, the report will not mention moisture in the basement of an older house, unless it is causing damage to the building.

## 2 Results - The Danish schemes within the framework

**Table 3 – Current Danish schemes and the areas of barriers and motivators they influence. A1 - Raising awareness, A2 - Promoting non-energy benefits, A3 - Educating professionals; B1 - Subsidy motivator, B2 - Investment, B3 - Lack of funds; C1 - Support decisions, C2 - Available solutions, C3 – Regulation.**

	Information			Finance			Decision making		
	A1	A2	A3	B1	B2	B3	C1	C2	C3
The Building Regulations									X
EPC-scheme	X	(x)	(x)		X		(x)	(x)	
BedreBolig	X	(x)	X		X		X	X	
Subsidies				X		(x)			
House condition report	(x)						(x)		

The schemes described above are collected in [Table 3](#), which shows their influence on the 9 areas in the framework of barriers and motivators. In the following, the coverage of the current policies and their shortcomings is discussed for each of the three fields.

### 2.1 Information (A1-A3)

Several of the current schemes work within the field of information. The EPC was made mandatory in connection with the sale of houses in Denmark in 2010 and has helped raise general awareness about the energy consumption of buildings. It enables direct comparison of the energy level of different buildings, and this has had an effect on house prices [32]. Combined with the marketing effort following the launch of the BedreBolig-scheme, the area A1 (Raising awareness) is already receiving a lot of attention in current policy. A survey among Danish house owners shows that 63% are interested or very interested in home energy improvements, while only 11% were not interested; see [Figure 4](#) [41].

When we look at area A2 (promoting non-energy benefits), the picture is very different. While the benefits are briefly mentioned in both the EPC and the BedreBolig-scheme, they are not used actively to motivate people. This can be a problem because many house owners may not be motivated into action by a financial gain in the future or by the prospect of reducing their energy consumption.

The same two schemes are responsible for building professionals receiving further training (A3) in the area of energy renovation, because this is a requirement to be certified within the schemes. This motivates companies to have certified personnel, because it offers the opportunity for more work. Whether the current training is satisfactory is not within the scope of this study, but the mere existence of a framework for further training makes it easier to implement improvements if necessary. These government-backed schemes also help increase the trust of the house owners.

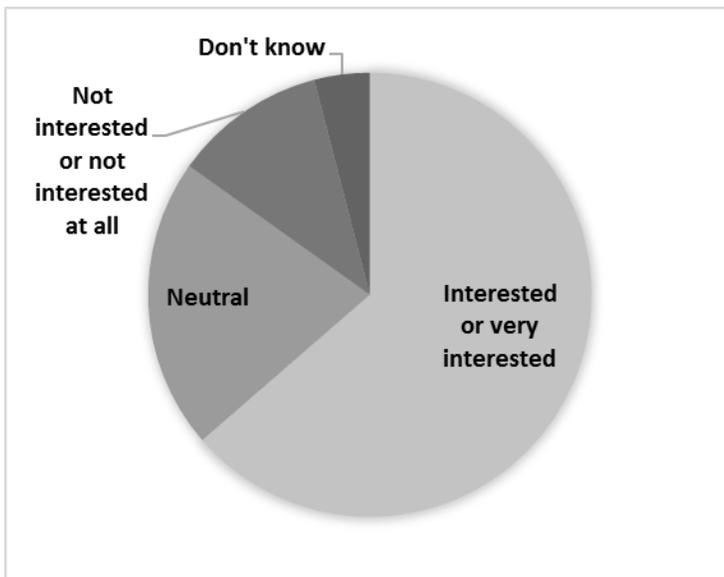


Figure 4 – Level of interest in home energy improvements among house owners according to a survey. Data from Bolius [41].

## 2.2 Finance (B1-B3)

There are currently two subsidy schemes aimed at motivating renovations (B1), but three things make this difficult. Firstly, every energy company has its own version of the scheme, with different amounts of subsidy available. So homeowners have to spend time finding the best deal. Secondly, the size of the subsidy is unknown before the scope of the renovation is decided. This means that most of the important decisions have already been made before the size of the subsidy is known, which limits the ability of the subsidy to motivate renovations. Lastly, the size of the subsidy is not impressive. For example, a house that was to undergo a renovation costing DKK 850,000 received less than DKK 5000 DKK (about EUR 670), corresponding to less than 0.6% of the total expenses<sup>2</sup>. Energy companies are obliged to promote energy savings through the EE scheme, yet a survey among Danish house owners who had recently made renovations or were planning to do so showed that only 4% attributed this decision to the encouragement of an energy company [41]. The other subsidy scheme, the BJO, is also very modest in size, allowing a maximum tax-reduction of DKK 12,000 (EUR 1608). The short-term nature of this scheme, which has been scheduled to end many times, means it cannot promote long-term planning of renovation, and the size of the subsidy makes it less relevant for large renovation projects, though it may encourage people to carry out minor improvements or help pay for BB-plans and building audits.

<sup>2</sup> found in a study by the author described in [3]

The EPC and the BB-scheme both try to sell energy improvement to house owners as a good investment (B2) that will pay for itself in time. It is true that this type of comfort improvement can actually save money, unlike e.g. a new kitchen, but this focus can also be a disadvantage. If energy improvements are seen as investments, the other benefits lose focus, and instead renovation is compared to other financial investments. In this context, an investment in energy efficiency will often have a comparatively long payback time and the size of the saving is uncertain due to the possibility for increased energy consumption, the so-called rebound effect.

The lack of funds (B3) for the size of investment an energy renovation might require is the most significant barrier to energy renovation [41]. This problem, however, is not addressed in the current Danish policy on energy renovation, because the subsidies available are of a very limited size.

### **2.3 Decision-making (C1-C3)**

The support of the decision process (C1) has improved with the introduction of the BB-scheme, because it enables house owners to get an overview of the possibilities in their house and even follow a sort of One-Stop-Shop full-service concept. This, however, only happens for those who actively seek the service. And a BB-counsellor can be anyone from a local carpenter to an engineer or an architect, so it is possible to get a wide variety of support, from practical matters and scope to theoretical background. To reach more people, the initiative should not be left to the house owner. Everyone who buys a house receives an EPC with a few suggestions for energy improvements, but these are too general and might not even be suitable for the house.

The area C2 covers the options made available, both technically and through policy. Technical solutions are not the focus of this study, but it should be mentioned that many good technical solutions are available for optimizing the energy consumption of a house. In terms of policy, it is possible to encourage both small and large renovations, but there is presently no incentive to choose large renovations. On the contrary, the subsidies are very small and the BJO-subsidy is even fixed in size, so they encourage only small improvements.

In general, the regulation (C3) of energy consumption for existing houses only affects houses that are undergoing renovation. And even then, the requirements for feasible improvements are not really enforced. Moreover, there are no maximum limits on how much energy a house is permitted to use.

### **2.4 Shortcomings in the current system**

For Danish policy in this field to address all the areas identified in the framework defined, our conclusions are as follows.

A – Information: schemes are already in effect to raise awareness and train building professionals. The area that needs some work is promoting the non-energy benefits of renovation.

B – Finance: subsidies are small and sometimes non-transparent, there is an overwhelming focus on energy improvement as a financial investment, and current policies do not address the barrier of lack of funds.

C – Decision-making: only those who actively seek it get support, subsidy policy promotes only small improvements, and there is little regulation or enforcement.

### **3 Discussion of possible improvements**

As we have seen, there are many good initiatives aimed at energy renovation in single-family houses in Denmark. In this section, we discuss possible improvements in the light of experience from other countries. To overcome the shortcomings identified in current Danish policy, we make four suggestions: a change of focus, increased financial support, a specific renovation plan, and the long-term regulation of maximum energy consumption.

#### **3.1.1 Focus on maintenance and comfort**

Subsidies can play an important role in overcoming the barrier of a lack of funds, but money in itself is not necessarily a motivator for energy renovation unless the economic gain is vast and the inconvenience minimal. An example of this was the change in the financing of PV solar panels in 2012. During this year, the total number of PV panels in Denmark went from about 4,000 to more than 70,000 due to a combination of favourable rules for the taxation and settlement of electricity production and a drop in prices for the panels which made them affordable for the average house owner [45–47]. Here the opportunity for economic gain was a clear motivator for people. A subsequent change in the rules that removed some of the benefits led to a slower pace with only about 5000 systems implemented per year.

With energy renovation, the economic advantages may not outweigh the inconvenience, and many people do not see energy saving as a goal in itself [20]. To reach these people, the focus should move from energy and economic savings to maintenance and comfort instead. With the right regulations, maintenance aimed at more comfort can include energy improvements, and the economic savings would be a bonus, instead of setting the limits of a feasible renovation. Using the potential economic saving as a motivator is doing the area of energy renovation a disservice, because it divides improvements into feasible and unfeasible, a fate never suffered by other comfort investments, such as a new kitchen or a new car.

### 3.1.2 Subsidies and financing

House owners who are already motivated for energy renovation can be helped to realise the renovation or make it more ambitious by providing the necessary funds through cheap loans or subsidies. Today, the Energy companies' Energy-saving initiative (EE) helps reduce the costs of an energy renovation by giving a grant of about DKK 0.30 per kWh saved energy. Although the size of the grant increases with the amount saved, the initiative will not in itself motivate the large renovations seen in Germany with the KfW scheme. KfW assists advanced energy renovation through cheap loans and they also supply grants for ambitious renovations that do more. The more energy the renovation saves, the larger the available grant [17,48]. However, when a system for supplying grants and loans is designed, the terms must be thought through, because they can also have a negative effect as seen in the British scheme Green Deal. Here a strict framework (the golden rule) meant that people could not get subsidies for more advanced renovations, because they could not be paid back by savings alone in a limited period.

The second possibility for a Danish household to obtain a subsidy today, the BoligJobOrdning (BJO), directly favours small improvements, where the cost of advice and labour does not exceed DKK 12,000. And although it has been extended and renewed several times, it is still a temporary scheme set to end in 2017. If the goal is to achieve more renovation with larger saving potential, support for the initial advice and planning should not be temporary and the size of the grants available should reward the more ambitious schemes. The relatively small size of the subsidies available reduces motivation and misses the opportunity to promote more extensive and ambitious renovation to reduce energy consumption further. In the short term, it may be a good use of subsidy money to achieve a large number small improvements rather than a small number of large ones, because this can save more energy for the same price [49]. However, the result is that the remaining possible improvements become less and less feasible. The government therefore needs to think in the long term and have a clear idea of its goal for total savings across the building stock. The important thing is to find a balance where small improvements are sufficiently supported while larger improvements are still attractive. And if large scale renovations are to be achieved across the building stock, more money must be set aside for subsidies and grants to promote this agenda.

An energy renovation can reduce the energy bill, so it is an enticing idea to use that saving directly to pay for the renovation. This is done in the 'pay-as-you-save' schemes, e.g. Green Deal in the UK and the American PACE-program [50,51]. In theory, this is a good idea because the house receives the improvement with no increased monthly expenses for the house owner. In reality, however, this type of scheme poses three significant problems: house saleability, renovation extent, and size of repayments.

The saleability of the house is affected because the loan to pay for the renovation in both schemes is attached to the house and not the house owner. While the impact of this never became clear in the UK, it became very visible in the USA, where access to mortgages for buying a house with PACE was limited [52,53].

The second problem is that the scope of the renovation might be limited to stay within the 'pay-as-you-save' concept. If the whole renovation has to be paid by the potential saving, a lot of improvements will be excluded because they save too little or cost too much, making the payback time too long. The scheme can then actively prevent people making extensive renovations, thereby working against its own purpose.

The third problem is determining the size of the repayments based on the expected energy saving. Due to the rebound effect and other factors, the saving can be difficult to predict. The rebound effect is when increased energy efficiency actually leads to an increase in consumption. This is a well-known problem in connection with energy renovation [24,54–58], although it is only rarely acknowledged and dealt with. The rebound effect occurs as house owners use the energy improvements to increase the comfort of their homes. For example, before the renovation, they might have kept part of the house less heated and lived with a lower temperature, e.g. 19 °C, because the house was too expensive to heat to a comfortable level. But after the renovation, they find they can keep a nice warm temperature in the whole house, e.g. 22°. However, the saving they were supposed to obtain through the renovation was based on the house having the same temperature, e.g. 21 °C both before and after the renovation. In fact, many houses used less energy before renovation than calculated, and more after renovation, which means that a house owner in a pay-as-you-save scheme might end up with increased monthly expenses after all. Energy consumption is affected to a very large degree by user behaviour, and it is therefore difficult to make precise estimations through simulations, especially when the house owner may or may not change behaviour due to the renovation.

### **3.1.3 Turning the EPC into a renovation plan**

When a house is put up for sale in Denmark, it is mandatory to have an EPC (energy performance certificate) and most people also choose to have a house condition report made. While the EPC is a great tool for increasing general awareness about energy consumption in houses, it would require some changes to make it useful for house owners who want to renovate. The theoretical energy framework the EPC uses to describe the energy consumption of a house is designed for comparing houses and does not give an accurate picture of the actual energy use in that specific house. This confuses many house owners, and the confusion is further enhanced by the standard suggestions for energy improvements, which are not necessarily usable in the specific house.

The ideal assessment report should be both relevant for the house owner and a source of inspiration for more extensive renovation. Instead of the questionable standard suggestions, a specific renovation plan could be added to the EPC. This could be a further development of the house condition report, which most house owners buy anyway. Combining the report on damage to the house with a BB-plan by adding the expected maintenance and possible improvements would give the potential house buyer a much better overview of the house. Many owners do not know 'what can be expected in that type of house' and therefore could do with more information in the report. Such a plan could work as a motivator for renovation, giving the house owner more comprehensive knowledge about their house and what they should expect to have to do in terms of maintenance and renovation in the future. It could also make suggestions for more advanced renovation, bringing the house close to new house standards, with lower energy consumption and a higher comfort level. In Denmark, these standards could be the renovation classes from the building regulations, see section 0.

To increase the usability of the plan, it needs to be followed up and should not be in focus only when the house changes owner. The process of deciding to renovate is often a long and slow one [20] and renovation is in no way limited to the time after a sale [10]. It would also be beneficial if the building professionals who make the renovation plan are put in contact with the new owners.

#### **3.1.4 Introducing a maximum allowed energy consumption**

When people are already planning to renovate, the best way to ensure that they implement the best energy solutions is through regulation. In Denmark, the recent introduction of renovation classes is a move in the right direction because they enable an examination of the whole house, and thereby motivate larger and more holistic renovation as well as individual improvements.

While using policy instruments to motivate can help increase the number and quality of renovations, the question remains whether this will be enough to meet the political goal of a fuel-free society. Kragh et al. [59] analysed the potential energy saving in the whole Danish building stock. They made calculations for three scenarios, the least ambitious of which predicted a 52% reduction in energy consumption by 2050 if the whole building stock was renovated to a level corresponding to the demands for new buildings in 2010 (EPC level A2010, 63.5 kWh/m<sup>2</sup> for a 150 m<sup>2</sup> house). This would require a significant increase in the number and scale of renovations currently being carried out.

To achieve such a dramatic increase in the amount of renovation, it would be necessary to increase regulation in the field, as suggested by Weiss et al. [16]. Their focus was on the opportunity that arises when a house changes owner. Here they suggest that requirements should be made for the renovation of the house within a limited time period after the change in ownership. This would increase the effect energy consumption has on house prices, because houses with high consumption would come with a

requirement for renovation. Weiss et al. point out two specific challenges in this area. The first is that great care needs to be taken when setting the appropriate energy efficiency level in the renovated houses, because the scheme can freeze the level of renovation for many years. The second is the need to avoid creating greater social imbalance, because socially vulnerable groups are more threatened by this type of regulatory law. This would require a number of social support measures to prevent people ending in a hopeless financial situation.

Another problem with this type of policy could be the ‘bubble’ of work created if all houses suddenly had to be updated within a few years of a sale. Setting the level of energy efficiency at the same level for all houses would also require a very large renovation for some houses, while others might benefit from being upgraded to a yet higher level. This problem can be avoided if the regulations do not set a specific level of energy efficiency, but rather a maximum consumption that must not be exceeded. The maximum boundary could be reduced over a number of decades, only affecting the most energy-consuming buildings to begin with, and later ensuring a steady upgrading of the building stock. Making the policy very long-term means house owners are forewarned of coming requirements, which should prevent the risk of a large number of houses losing their value from one day to the next. In this way, the housing stock would be gradually improved as houses are sold and the rules are strengthened. Nevertheless, the policy might create large social and geographical imbalance because the people who live in the houses with the worst energy performance often do not have the money to renovate. Moreover, house prices in Denmark vary a lot depending on geography, which would make it more difficult to get a loan to upgrade houses in the less popular parts. This problem needs to be investigated further and proper solutions found before this type of policy could be implemented. If a maximum level of energy consumption was introduced, a dispensation scheme would also be needed for houses worthy of preservation, so that they would not have to be upgraded or replaced.

#### **4 Conclusion and Policy Implications**

In the light of this study, there are a number of elements that should be kept or included in Danish policy on the energy renovation of single-family houses. We have also identified a number of shortcomings in current Danish policy using a framework for known barriers and motivators. And we have pinpointed a number of issues that need to be addressed: focus, subsidies, planning and regulation.

A focus on energy savings as an investment can work against the implementation of the extensive energy improvements needed, because it puts economic feasibility in focus. Energy improvements can save both money and energy, but they can also create a better indoor climate with steady

temperatures, no draughts, fresh air, and fewer problems with moisture that can lead to mould. Our focus should therefore be on the non-energy benefits.

Lack of financial support can keep people from embarking in a renovation, which is a very large investment for the average household. Subsidies can be used actively to increase the desired level of renovation. Today the subsidies available in Denmark are close to symbolic for medium or large renovations. The current subsidy system should be expanded and targeted to promote the desired scale of renovation.

Today the initiative to start renovation lies with the house owners alone. Unless they actively seek advice, they will not receive proper information about what they should do to maintain their house or reduce its energy consumption. When a house is sold, the new owner should receive a relevant plan for how to renovate their new house in the coming years, with regard to both general maintenance and energy improvements. This could be done by combining and expanding existing systems, the EPC (energy performance certification) and the house condition report.

Finally, to achieve the political goals of reduced energy consumption and CO<sub>2</sub> emissions, more regulation may be needed as well as motivation. There are already some regulations on house renovation, but strengthening these might simply keep people from renovating. A better approach could be to set maximum levels for how much energy a house may consume. This would require careful consideration of social imbalance and a very long timeframe. Otherwise it could cause problems, e.g. for people living in old houses with a high energy consumption in areas of the country with low house prices, because they often do not have funds available to renovate. However, this type of regulation might help to systematically reduce housing energy consumption.

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There is a large energy saving potential among Danish single-family houses. In a case study the effect of using a One-Stop-Shop concept to guide the renovation process was found to contribute to a larger saving. It also showed benefits of holistic renovation based on necessary maintenance, as it resulted in a reduced energy consumption and better indoor climate while increasing the value of the house. A framework of barriers and motivators helped evaluate current policy, and four areas in need of improvement was found: change of focus, financial support, renovation plans and regulation.

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