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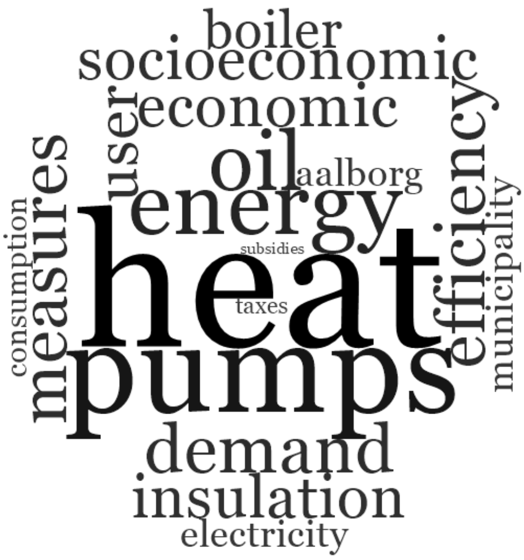
Master project: Sustainable Energy Planning and Management



Implementation of energy efficiency in the individual heating sector - how can it be done?

A socio- and user economic assessment on converting oil boilers in Aalborg municipality

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STUDENTERRAPPORT

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Synopsis:

The purpose of this project have been to answer the problem formulation:

How can oil supplied houses in Aalborg municipality reach higher energy efficiency and can the socio- and user economy benefit from the implementation of heat pumps and insulation?

Aalborg municipality has areas where oil boilers are still being used as an individual heating solution, which has to be phased out. Denmark has the goal of removing oil from the heating sector before 2030, where the implementation of other technologies has to happen. Based on respected institutes have the project assumed that the best course of action would be with the implementation of heat pumps. Another source where it would be beneficial to do something is the insulating of the existing houses, based on SBi insulating rapport.
A heating demand analysis was made for further use in the socioeconomic- and user economic analysis where the differences between an oil boiler and heat pumps are found. The data found is illustrated in beneficial values of insulating with a belonging heat unit, which could be two different heat pump types; air to water and ground to water.
The results showed that implementing greater levels of insulation together with a heat pump were rarely socioeconomic beneficial where the users could gain great benefits from insulating and converting to a heat pump.

Summary

Danmark har siden oliekriserne i 1970'erne haft fokus på at ikke at blive afhængig af en enkelt energikilde og sikre forsyningssikkerheden, så en lignende krise ikke vil opstå igen. Med udviklingen i det danske energisystem har fokus skiftet fra en primær forsyningssikkerhed til et mere miljømæssigt fokus, som i dag er vigtigt af flere årsager. Udviklingen har også betydet at sammensætningen i varmesektoren har ændret sig betydeligt, hvor den i 1970'erne var afhængig af olie, er der på nuværende tidspunkt flere forskellige energikilder, som producerer den nødvendige energi. Den miljø- og klimamæssige politik har afsat flere mål af forskellige tidshorisonter, hvor et af dem er en fossilfri varmesektor inden 2035. På baggrund af dette mål skal oliefyrene i den individuelle bygning erstattes af en anden energikilde. Danmark har også et mål om at gøre Danmarks varmesektor mere energieffektiv, hvilket kan ske gennem energibesparelser eller forøgelse af energieffektiviteten.

I den forbindelse har flere institutioner, såsom Rambøll og IDA 2050, udarbejdet en mulig varmeplan for fremtidens Danmark, der også har været vigtig for den afgrænsning, projektet har taget. Der findes flere forskellige individuelle varmekilder, hvor der på baggrund af varmeplanerne er blevet afgrænset til kun at fokusere på varmepumper, da en række rapporter mener, at det er varmepumperne, som vil blive brugt i de individuelt opvarmede husstande. Udover at ændre varmeforsyningerne i husstandene er der også et stort potentiale i energieffektivisering af eksisterende bygninger. Statens Byggeforskningsinstitut (SBi) har udarbejdet en analyse af potentielle varmebesparelser i Danmark ved at isolere en bygning med forskellige niveauer af isolering. Studiet af SBi er blevet brugt i nærværende rapport for at finde de mulige varmebesparelser, der findes i de eksisterende olie-forsynede bygninger i Aalborg kommune, samt hvilke samfunds- og brugerøkonomiske fordele energieffektivisering af bygningen vil medføre.

Selvom der er store økonomiske fordele ved at implementere en varmepumpe og isolering af bygningen, er investering til disse energieffektiviseringer høje. Det høje startindskud til en varmepumpe kan skræmme borgerne, da de enten ikke har den nødvendige kapital eller ikke kan se varmepumper som værende en langvarig løsning, hvilket også formodes er tilfældet for implementering af isolering.

Dette medfører til den nærværende rapports problem formulering: *How can oil supplied houses in Aalborg municipality reach higher energy efficiency and can the socio- and user economy benefit from the implementation of heat pumps and insulation?*

For at kunne svare på problemstillingen er det nødvendigt at kende et estimat på det nuværende varmebehov. Estimatet af varmebehovet findes ved hjælp af Danmarks varmeatlas, nøgletal for varmebehovet i bygninger pr. m2 samt studiet fra SBi, der estimerer, hvilke varmebesparelser der forventes ved at implementere forskellige niveauer af isolering. Vurderingen om hvorvidt en investering af varmepumper og isolering kan betale sig, bliver vurderet ud fra et samfunds- og brugerøkonomisk perspektiv. For at resultaterne kan blive sammenlignet med lignende energiprojekter, bruges vejledninger

og beregningsforudsætninger udstedt af Energistyrelsen for henholdsvis samfunds- og brugerøkonomiske analyser.

Resultaterne af analyserne viser at der oftest ikke er samfundsøkonomiske fordele ved konvertere olieforsynet husstande til en varmepumper, hvor det kun er få andele af bygningsperioder, der kan medføre samfundsøkonomiske fordele. Derudover vil der være samfundsøkonomiske fordele ved at implementere isolering i husstande, hvor det mest optimale isoleringsniveau afhænger af bygningsperioden, samt den installerede varmeforsyning. Derimod viser de brugerøkonomiske analyser, at konverteringen til en varmepumpe over en tidsperiode på x år vil medføre økonomiske besparelser i forhold til et oliefyr. Dermed vurderes konverteringen til en varmepumpe som en god investering for borgeren, men en dårlige investering for samfundsøkonomien.

Selvom det vurderes til at være et dårligt alternativ med varmepumper for samfundet, er denne konvertering nødvendig, hvis delmålet om oliefyrets udfasning i 2030 skal opnås. Den dansk regering og kommunerne har en stor rolle for at gøre varmepumper det attraktive valg og har også stor mulighed for dette. Regeringen har mulighed for at øge tilskuddet, hvor kommunen har mulighed for at skabe et samarbejde mellem borger og relevante virksomheder om en varmepumpeabonnementsordning.

Der findes derfor store muligheder for at fremme udrulningen af varmepumper og energieffektiviseringer. Men før dette bliver en realitet, er det nødvendigt at regeringen og kommunerne hjælper borgerne over den stopklods, som er den høje startinvestering. Det er dog i sidste ende borgerens valg, om hvorvidt der skal investeres i energieffektivisering af bygningen.

Preface

This project is made by Mads Wagner Dahl and Oliver Mangelsen for our graduate project in the civil engineering degree in Sustainable Energy Planning and Management at Aalborg University.

The Harvard referencing method is used in the report. This means, that references in the report appear with an author followed by a year. In the bibliography, at the end of the report, the references are also presented, and additional information regarding the source can be found. In some of the references in the report, the author is followed by "et. al", which means that there are additional authors. Furthermore, some references may appear with "n.d", which means that no publication date was stated in the source.

The report is written in English, where the English number formatting is used. This means, that commas represent thousands while dots represent decimals.

The report includes figures and tables made by the group. These illustrations are not given a reference in the caption. In the caption, the illustrations made by the group will be highlighted with the notation "Own illustration..".

The appendix of the project contains:

- Interview with Automatic V/S

External appendixes are three Excel Sheets containing the calculations and results for the heat demand, and socio- and user economics.

Finally, the group would like to thank supervisors and interviewees.

- Associate Professor Steffen Nielsen for providing literature, data set, and exciting and instructive guidance.
- Kasper from Automatic V/S for providing information about citizens barriers of implementing heat pumps.
- Aalborg Forsyning for the use of their setup of socio-economic analysis.

Signatures

By signing below each group member confirms that all members have participated equally in the project work and that all take responsibility for it, collectively. Furthermore, all group members are responsible for no plagiarism in the report.

Mads Wagner Dahl

Oliver Mangelsen

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1 Problem Analysis

1.1 Denmark's parliament climate goals

Denmark has a national goal of being independent of fossil fuels in the energy sector before 2035, but before Denmark can reach the goals of being independent of fossil fuels, a series of political actions with a focus on the climate has to be implemented. The climate policy in Denmark is developed to follow Denmark's international climate commitments to the EU and the UN, as well as national goals in the energy field. (Energistyrelsen 2019*a*) Denmark is committed to one of the EU's climate targets for a climate-neutral EU in 2050, which has resulted in a long-term national goal for Denmark to be independent of fossil fuels and a climate-neutral society in 2050. A climate-neutral society means that no more greenhouse gas can be emitted than can be absorbed. To meet the target, the EU has set a central aim for reducing CO_2 emissions by at least 40 percent in 2030 compared to 1990, but the Member States have individually pushed the EU to a more ambitious level. The Danish Government has set a national target of a 70 percent CO_2 reduction in 2030, in contrast to the EU target of 40 percent. Although Denmark's greenhouse gas emissions have fallen since 1990, there is still a long way to go before a climate-neutral society is met.

The approach being used by the EU to reduce CO_2 emissions is through the CO_2 quota system for the quota sector and the burden-sharing principle for the non-quota sector. The quota sectors are the most energy-intensive companies in the energy sector, such as energy in electricity generation, district heating, large industrial plants, oil and gas production and air traffic in a pan-European regulation, where the non-quota sectors are individual heating, transport, agriculture, machinery, process energy consumption and other small sources.(Klima-, Energi- og Forsyningsministeriet 2019)

The EU regulates the quota-covered sectors through the CO_2 quota system, which fundamentally is a greenhouse gas emission trading system. The trading system is based on energy-intensive companies being allocated a CO_2 quota for how much can be emitted and if a company emits more than the quota allows, they are fined, but if they emit less, they can sell the surplus quotas to other companies.(Folketingets EU-Oplysning 2019)

The non-quota sector is regulated through a burden-sharing between the Member States. The burden distribution is based on a distribution principle based on the country's GDP and gives an insight into how the reductions should be distributed in the Member States. In 2016, the European Commission presented its proposal for the burden-sharing agreement, which is valid for 2021-2030. In the agreement, each Member State is imposing a national target of a reduction in the non-quota sector between 0-40 percent compared to 2005, with Denmark imposing a reduction target of 39 percent in the non-quota sector in 2030.(Klima-, Energi- og Forsyningsministeriet 2019*b*)

This goal requires a massive effort throughout Danish society if the CO_2 goals are to be achieved. Therefore, the Government has already initiated several measures to ensure a clear target framework, a broad anchoring of climate action in Danish society, and the integration of climate considerations across policy areas. At the same time, the Government has signed a climate law agreement, a historic green finance law agreement, and allocated funds for climate research. These are changes that must form the basis for the Government's climate action.(Klima-, Energi- og Forsyningsministeriet 2019*c*)

The Danish energy system is required to convert current energy technologies and implement more energy savings before Denmark can achieve its goal of being independent of fossil fuels. (Energistyrelsen n.d*a*) Sectors that have been of focus in Denmark are the energy sector, heat and electricity, which is because climate-friendly technologies are competitive with the current technologies that already exist and can reduce CO_2 emissions if implemented.(Radobi Nenadovic 2019) Electricity and heat production are closely connected by the use of fuel or the products produced in separate systems such as CHP (Combined Heat and Power) plants, which produces electricity and heat of which some technologies are using electricity to produce heat such as heat pumps and heating element. (Energistyrelsen 2018*a*)

1.2 The Danish heating sector

The oil crisis in the 1970s impacted how the Danish energy system was structured since a similar situation is to be avoided in the future. In the heating sector, this led to natural gas, and the district heating was being used or implemented where the district heating is much favored today. The 1970s crisis led to an increased focus on having a more significant variation of fuel types, which did not rely on the emissions but was the first step towards the composition seen in the heating sector today.

Danish heat sector in the 1980s In this period used the district heating coal and oil boilers to deliver the demanded heat and the surplus heat was rarely used. The surplus heat is produced by industries and other processes which produce heat as a byproduct, which can be used in the district heating network. The decentralized district produced heat from coal, oil and natural gas, where the buildings outside the reach of the district heating network used natural gas if possible or individual oil boilers The increased focus on changing the composition of the system led to a development where natural gas became the new sought solution. (Dansk Energi 2018)

Danish heat sector at the end of the 1990s

At this point, district heating plants changed the fuel usage to a mixture of coal, natural gas, and biomass. Coal was still the main source of energy, wherein the 1980s had low or no co-production of heat and electricity, an increase of that happened in the 1990s in the form of CHPs. The decentralized district heating plants were no longer using oil but now mainly using natural gas, and for areas without natural gas, biomass was being used. Natural gas was becoming more common in the individual heating, and areas without natural gas oil boilers were the most common heating technology. (Dansk Energi 2018)

2020

From the end of the 1990s to now have the composition of energy sources in district heating changed again where biomass such as wood chips, tree pellets, and straw was added to the variety of fuels. The CHP technology is still of use with the co-production of heat and electricity, where the district heating today also uses electricity to produce heat by using heat pumps and heating elements. The decentralized heating has also changed in the variety of fuels and technologies where natural gas, biomass, and biogas are used with a shift in technologies as well, where heat pumps and heating elements are implemented. In the 1990s had the households primarily two solutions, oil boiler, and natural gas, where they now can choose between oil, natural gas, wood chip boiler, and heat pumps where oil boilers no longer are the main energy source. (Dansk Energi 2018)

Since the 1970s oil crisis, have a variety of energy types increased, and some of the earlier used have been excluded, which is sought to meet the goals of the fossil-free heating sector. The focus has changed from being independent for a few energy sources to a higher security of supply, where it now is focused on being environmentally aware of the removal of fossil fuels in the heating sector. With a closely connected heating and electricity sector, a complete focus on one or another is not possible, this project will focus on heating, and by excluding electricity in many ways, the complete exclusion is not possible.

1.2.1 The energy consumption in Denmark

A 70% reduction of greenhouse gases in 2030 compared to the 1990 emissions is an ambitious goal. In 1990 was the Danish emission at 70.3 million tons CO_2 equivalents, which means a 70% reduction in 2030 is 21 tons CO_2 equivalents. The emissions were in 2017 at 47.9 tons CO_2 equivalents, a reduction of 31.9%, which means that in the next decade, a reduction of 26.9 tons CO_2 should be made. So far has the reductions primarily been in the electricity- and district heating sector where they in 2017 emitted 12 million tons CO_2 equivalents. The individual heating sector using oil and natural gas contributed with another 2.6 million tons of CO_2 equivalents. This means that around half of the 26.9 tons CO_2 could be reduced by focusing on the electricity- and district heating sector and implementing other and greener solutions for the areas using individual heating. (Dansk Fjernvarme 2019)

The energy consumption in households is highly dependable on the weather and the ambient temperature, which means that years with hot or cold weather will affect the buildings' energy consumption with either a decrease or an increase in consumption. (Energistyrelsen 2018*a*) Households had an energy consumption of 197.2 PJ in 2018, which was 30.6% of the total energy consumption where 166 PJ were used for heating and 31.2 PJ for a mixture of electric devices. The consumption in 2018 had increased with 6.6% compared to the consumption in 1990, while the difference between 2018 and 2017 was an increase of 1.6%. (Energistyrelsen 2018*a*)

As mentioned, the composition of heat supply changed, and multiple technologies are now used to supply the needed heat. The usage of oil boilers has since the 1990s decreased in favor of district heating and natural gas, and in the 2000s, an increase in the usage of firewood and wood pellets. The 197.2 PJ energy consumption in households is consumed by different technologies of where district heating as the favored technology used 36.4%, renewable energy 28%, electricity 17.9%, and the last 17.7% is consumed by natural gas 12.3%, oil 5.2% and city gas 0.2%. (Energistyrelsen 2018*a*) With the goals of emitting 70% less than 1990 and fossil fuels still are a part of the heating sector, a reduction could be made here, where oil uses 5.2% of the total energy consumption. There could be a potential in removing oil boilers from the heating sector since there already exist greener technologies that can compete with the oil boiler.

Since the oil crisis in the 1970's been a development in the composition of the energy system and the technology types which have been used. The development meant that oil boilers had been replaced by technologies that were greener or more effective. District heating and natural gas have been important in the search for removing oil boilers from the households. In 2018 was the 2.8 million heat installations divided like this (Energistyrelsen 2018*a*): Other covers technologies such as heat pumps, electric heating, and burning boiler.

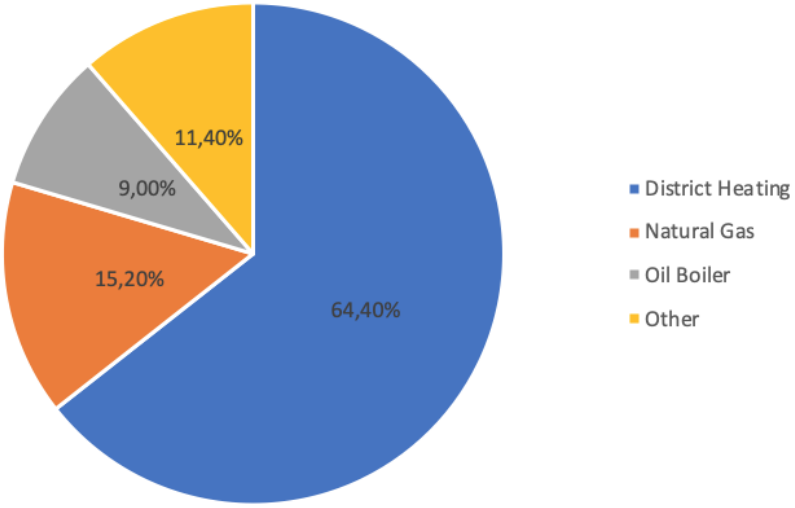

*Figure 1.1: Own figure; heat share on different technologies (Energistyrelsen 2018*a*)*

The average energy consumption in a household increased with 0.8% from 2017 to 2018 with an average energy consumption in 2018 at 73.6 GJ, where 62 GJ, 84.2%, was used for space heating and domestic hot water. Although the consumption increased from 2017 to 2018, it is still lower than the consumption in 1990 by 10.7%. The average electricity consumption in a single household for the use of devices and light was 11.6 GJ in 2018. This is 1.4% lower than in 2017 and 8.5% lower than in 1990. (Energistyrelsen 2018*a*)

The energy consumption used for heating was in 2018, 6.1% more than what used in 1990, where this has fluctuated between 0.2% and 6.7%. This has to be taken into account when the heated area in households has increased with 24.6%. (Energistyrelsen 2018*a*) Although the energy consumption for heating has increased since 1990 have the energy consumption per $m^{2,}$ decreased where it in 2018 had decreased with 14.6% compared to 1990. The reason behind it is improvements of insulation in households, change in technologies that supply heat with higher efficiency, and building regulations that have higher insulation and climate demand for new buildings. (Energistyrelsen 2018*a*)

1.3 Possible heating types for buildings outside collective heating

However, many buildings are still located outside the collective supply, since the municipal energy planning is focused on collective supply, as significant energy savings can be obtained when using district heating, a potential exists in buildings outside the collective supply. Therefore, the buildings outside the collective heat supply are left to be regulated at a national rather than a municipal level, as seen with district heating. The regulation for individual heated buildings is made through requirements for the choice of heat supply, where the buildings can choose their fuel type legally, and with the typical technical lifetime of individual heat supplies being 18-20 years, the choice of heat supply will affect the national sub-targets in 2030.

As mentioned earlier, Denmark wants a fossil-free energy supply for the individually heated buildings, where the choices to achieve this goal is minimal. The following sections describe some of the heating options that can replace oil boilers. The description of the types of heat supply presented is quite brief as a more in-depth description of the relevant aspects for the heat supplies will be described later in the report.

The following heating options are heat supplies that can cover a building's room heating and hot water demand. Therefore, it is limited to heat supplies that can be used in a water-borne system. Also, the use of biomass is delimited, as the report will investigate which heat supplies can reduce emissions as much as possible. Biomass is currently considered CO_2 neutral, but combustion of biomass will still cause a CO_2 emission, and other greenhouse emissions, whereby it is not considered a long-term solution for conversion, but a temporary solution for the Danish energy system. (Dansk Kompetencecenter for Affald og Ressourcer 2018)

The following heating types are also picked because these are also the favored heating types for these buildings in IDA 2050 (Aalborg Universitet 2015) heating plan and Ramböll heating plan (Ramboll 2008).

Oil boiler
Two different types of oil boiler systems exist, one of which is mandatory to install in Denmark. By burning the oil, it heats the water-based system, which delivers the heat around the house through either radiators or floor heating and is also used to heat the domestic hot water.(Energistyrelsen 2018*b*) The reason for using this technology so far is the households' location and the fact that they are outside the district heating and natural gas range, where many of these houses are single-family houses. Also, an oil boiler has low investment, but high operating costs. This means that the oil boiler will have a low cost in the first years compared to other heat options, such as a heat pump, but will become more expensive to operate over a more extended period due to the high operating costs. The oil boiler is an old reliable technology with simple control ability and high thermal efficiency. However, the fuel price makes the technology potentially expensive since the oil prices can

variate and not be predicted for the future. (Energistyrelsen 2018*b*)

Pros	**Cons**
Easy control ability	Expensive fuel
High Thermal efficiency	Uncertainty in fuel prices

Heat pumps

A heat pump uses electricity to utilize the ambient temperature to produce heat inside the house, though each type of heat pump has different working methods. There are three types of heat pumps, air to air or air to water, brine to water and ventilation heat pumps. These heat pumps work with a high COP value (coefficient of performance), meaning that the electricity input (the energy consumption) is being greatly utilized. If the heat pump can convert 2 kW of electricity to 6 kW heat, the heat pump will have a COP value of 3, of which a heat pump technology has a COP value between three and five typically. This value will change over the year because of the ambient temperatures, where a big difference in the outdoor temperature and delivered heat will decrease the COP, which will change when the temperature is closer to each other. (Energistyrelsen 2018*b*)

Two of these can function in two ways: heating the air or by heating water to deliver it through radiators or floor heating. Ventilation heat pumps can function both ways, by drawing out the heat from the ventilation outlet system and produces heat which can be used to heat the ventilation systems intake. This system can also use a combination of air to air heating and air to water. However, given that the system needs a ventilation system to function, this type of heat pump will not be used for further analysis. (Energistyrelsen 2018*b*)

Brine to water heat pumps (will now be referred to as ground to water) absorb the heat from the ground and deliver the heat through a water-based system. The system requires pipes in the ground with anti-freeze water running through them. This draws out the heat from the ground and delivers it to the water-based system to heat through radiators or floor heating and heat the domestic water. This system is expensive to acquire because of the installation of the pipe system, which requires digging for the placement of the pipes. Though this type is more efficient than the air-based system, the difference is small, and the investment difference is greater than that of other heat pumps. (Energistyrelsen 2018*b*)

The last heat pumps draw the heat from the ambient air and produce heat through either air or a water-based system. The type which only uses the air as the supply source will not be used for this project either since air to air heat pumps only can supply one room of a house unless the house uses an air circulation system or keeps the door open. Furthermore, it can not heat domestic water. (Energistyrelsen 2018*b*)

The air to water heat pumps also draws the energy from the ambient air and delivers the heat through a water-based system. This ensures that every room with radiators or floor heating can be supplied, and the fact that it can be connected to the already installed water system makes the change easy. The efficiency may variate depending on whether the house is using radiators or floor heating, where its efficiency is 325% or 390%. (Energistyrelsen 2018*b*)

Air to water heat pumps, which will be further analyzed for the project is easy to install and have the possibility to be connected to the already existing water-based system. The fact that the technology uses the outside air to heat can also cause some trouble during the winter if it is too cold, which can affect the efficiency of the heat exchanger and will have less efficiency if installed incorrectly. (Energistyrelsen 2018*b*)

Pros	**Cons**
Easy to install	Less effective during cold winters
Connectable to the water-based system	Less efficiency if installed incorrect
If installed correct, high efficiency	

1.4 What is being done in the heating sector?

Denmark is trying to achieve a more energy-efficient energy system that Denmark does through the conversion of energy technologies, renovation of existing buildings, legal energy requirements, and information to citizens regarding new energy-savings opportunities.

Instead of adding more energy production to the energy system, there can be a significant advantage in making the energy system more efficient and reducing consumption. By energizing the energy system and therefore lowering the energy consumption, will it:

- *Reduce the impact on climate and the environment*
- *Reduce the cost of the green transition*
- *Become less vulnerable to fluctuations in energy prices*
- *Increase security of supply*

(Energistyrelsen n.d*b*)

Although Denmark has focused on energy efficiency in the Danish energy system in recent decades, Denmark has only decreased energy consumption by 0.4 percent. This means that energy consumption has remained almost unchanged in recent decades, although Denmark has experienced significant growth over the same period.

Several forms of energy efficiency depend on which production stage is examined. For example, there may be energy efficiency in energy production, the management of the produced energy, and the consumer of the energy. An example of an energy efficiency improvement of electricity production is the utilization of surplus heat for district heating. When district heating distributes heat to consumers, an energy-efficiency improvement can be the insulation of the distribution system. For consumers, an energy-efficiency could be to switch heat supply, for example, from an oil boiler to district heating, thus using an already available energy source more efficiently rather than producing new energy through oil boiler. The two production stages mentioned above are energy efficiencies improvement;

the municipality can make where the latter is a decision the citizens themselves make, and the project will delimitate for the former two production stages.

Energy efficiency with the consumer is most often the consumer taking the initiative to improve the energy efficiency measures the building. The municipalities, or utility companies, can make the implementation of energy efficiency more attractive by providing subsidies for various energy efficiency. The supplies can provide subsidies for the installation of heat supply and insulation of households, where the change in electricity price depends on the government charge structure. Denmark makes excellent efforts to make heat pumps an attractive choice, for example, by making electricity for heating cheaper, subsidies for investment, and information on the possibility of conversion and benefits of these.

1.4.1 What is done to make heat pumps an attractive choice for users?

In order to increase the energy efficiency of buildings and reduce energy consumption, Denmark has three main tools: economic, normative, and informative. (Klima-, Energi- og Forsyningsministeriet 2019*a*)

- Financial tools are subsidies for energy efficiency improvements and energy tariffs. It will create a motive for the users to seek these solutions by making it economically attractive to implement energy improvements.
- Normative tools are the regulations and legal requirements that can directly impact energy consumption through injunctions or prohibitions. Normative tools could be, for example, an injunction on the energy requirements in the building regulations or a ban on installing oil boilers if a building has the possibility of being connected to a collective heat supply.
- Informative tools are increased information to the user regarding energy consumption to influence the users' behavior. This includes information about potential energy savings, as well as information on websites such as sparenergi.dk.

There are primarily two main ways to optimize the energy in an oil-powered household: Reduce heat demand through insulation or converting to a heat pump, which has higher energy efficiency. Therefore, there is a great potential in the household's electrification outside of the collective heat supply, and thereby reducing CO_2 emissions in the heating sector.

As shown in figure 1.2, about 25% of households that are not connected to a collective heating supply are supplied by oil boilers where electricity accounts for just under a third.

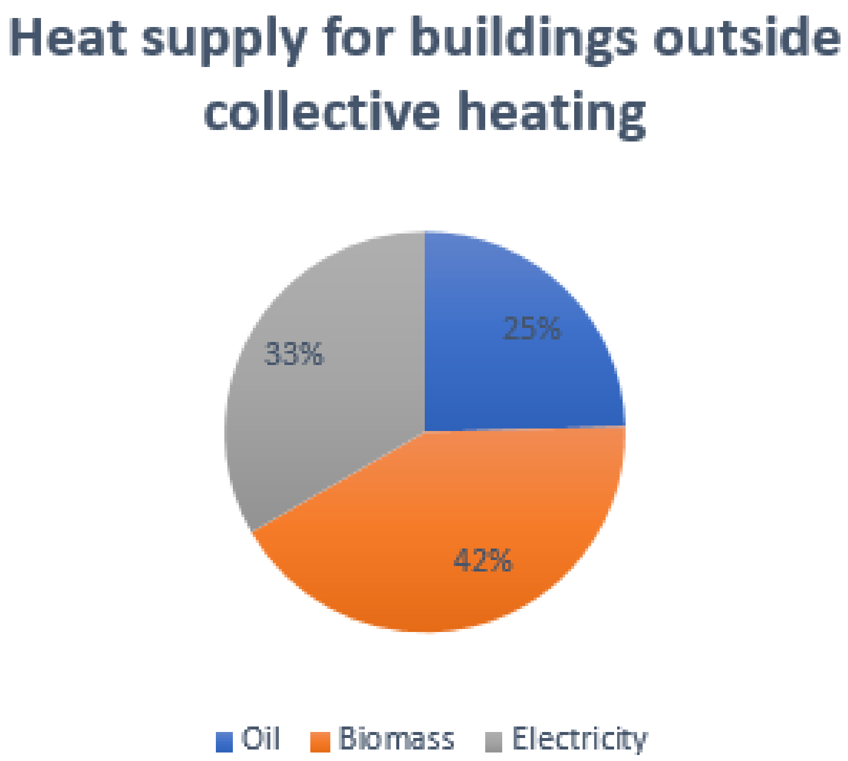

Figure 1.2: Heat supply for buildings outside of collective heating.(Dansk Fjernvarme 2019)

Thus, there is a great potential to convert to greener technologies, such as heat pumps. Conversion will lower not only CO_2 emissions but also improve the energy efficiency for the household, as heat pumps are about three times as energy-efficient as oil boilers. (Energistyrelsen 2018*b*)

In the buildings outside collective heating, there are still oil boilers, which can advantageously be replaced by a heat pump if viewed from an environmental perspective, but from a user-economic perspective, it may be considered a massive investment. This may be because the necessary funds are not available, or the household does not see the investment of a heat pump as an excellent long-term investment. As an interview with an energy supervisor from Automatic V/S, the cost is one of the significant factors in switching an oil boiler to a heat pump, where not all households can see it as a long-term solution or that replacement is not an economically attractive solution.A.1

The Danish Energy Agency has used several measures to promote heat pumps as an alternative to oil boilers and is aware of the considerable investment price problem and has therefore agreed to a new business concept to support the expanse of heat pumps. This business concept is for a heat pump to be installed in the building, but is owned and operated by a company. The company agrees with the building owner on a payment agreement for the heat usage, which covers operating costs and purchases for the heat pump. Thus, the building owner avoids a high start-up investment, uncertainty about heat economy, and technical choice of heat pump model. (Energistyrelsen n.d*c*)

This project will further investigate this concept, where it is not a company, but the municipality responsible for the purchase of the heat pumps, to ensure that the economy is for the user's intent.

Another measure is higher subsidies for converting to a heat pump. In the Energy Agreement, it has been agreed that a support pool of DKK 20 million is allocated for converting individual oil boilers to heat pumps in areas outside collective heat supply in an attempt to phase out oil boilers. However, even though grants and support pools are allocated for individual heat pumps, installing heat pumps as a green solution is not being sought enough. The installation of heat pumps has been increasing in recent years, but not enough if the goal of phasing out oil boilers is to be achieved. (Dansk Fjernvarme 2019).

Danish households can also seek subsidies and advice from energy companies if the heat supply is to be replaced. The subsidy depends on the existing heat supply and which heat supply is being replaced. The greater the energy optimization conversion will entail, the higher the subsidy. (SparEnergi.Dk 2019)

Thus, Denmark's approach to replacing the heat supply in the existing buildings is very economical and informative. These measures should make it more attractive to replace the oil boiler with, for example, a heat pump. The reason for the financial subsidies is that Denmark wants to phase out the oil boilers out of the heating sector to reduce CO_2 levels and energy consumption and have a more integrated energy system since heat pumps make it possible to convert electricity into heat.

Therefore, exist significant heat savings in converting the oil supply to a heat pump, which the Danish Government is also aware of and thus tries to make the heat pumps more attractive through subsidies and information. Nevertheless, as described in (Dansk Fjernvarme 2019) , there are not enough citizens who choose the heat pump as a heat solution.

Energy savings in buildings

In addition to converting heat supply, there is also a focus on energy savings in buildings. As 40% of Denmark's total energy needs are used for light, heating, and ventilation, there is a great potential to lower the consumption with energy efficiency. Denmark is using the three methods to optimize the energy efficiency of households. If an already established household is to be renovated, there are specific energy requirements that must be met and the newly constructed buildings in Denmark must comply with several regulations regarding buildings and energy requirements, which is one of the normative methods that Denmark uses in the sense of optimizing the energy efficiency in buildings. Insulating houses improve the indoor climate and lower the energy consumption, which can be beneficial to the building owner and the energy sector. When renovating the house, legislation requires that newly installed windows need to be of energy label A or B or that specific insulation has to be placed when renovating specific areas of the house. Reinsulating the house can be expensive and, therefore, beneficial if done when the house is renovated. Even though legislations demand that houses need specific amounts of insulation or specific energy labeled windows, this only has to be done if it is beneficial. Old houses that meet the newest requirements will not necessarily be required to meet the newest standards of houses that are being built today have to meet the requirements. (SparEnergi N.D)

Also, Denmark provides information on savings by optimizing energy as well as what opportunities the household has. To make energy optimization an even more attractive option, Denmark also provides initiatives for several different energy optimizations in the household, such as insulation, window and door replacement, and optimization of the heating system. As with the heat supply, the size of the subsidy depends on the size of the household's energy saving.

Since oil boilers are to be phased out, and not allowed to be installed if, near collective heating, it is primarily households outside collective heat that are still being heated by oil boilers because households may consider oil boilers as the best economic decision. Thus, no requirement for the change of heat supply nor the condition of the existing buildings, which means that it is the occupants themselves who must stand to optimize the energy efficiency, whether it is either by isolating the building or converting the heating supply. (Energistyrelsen n.d*b*)

Denmark is aware that there is a great potential for energy savings in buildings outside a collective heat supply. Energy Agreement, there is a consensus that a long-term renovation strategy should be made for existing buildings, as there is excellent potential in this area. (Klima-, Energi- og Forsyningsministeriet 2018) In the Energy Saving Council's recommendation for the Renovation Strategy, it is mentioned that about 65 % of the buildings are from before 1980 and thus before large energy requirements were set. There are estimated to be around 400,000 buildings that have an energy mark D or worse. An energy renovation from energy labels D to B will halve the heat demand per m^2. (Energisparerådet 2019)

Electricity price

In addition to heating pumps that lower energy consumption and emissions, heat pumps will also be a significant factor in Denmark's future energy system. " *"Denmark must have the most integrated, market-based, and flexible energy system in Europe with efficient use of energy across the electricity, heating, and gas sectors and with continued high security of supply."* "

This is how it is described in the Energy Agreement 2018. Energy technology for a more flexible energy system is a technology such as heat pumps since the heat pump can convert electricity into heat, which is also one of the reasons why a more significant roll-out of heat pumps is desired. The possibility of this energy conversion is something the Government will analyze further by looking at the current legislation in the tariff area about flexible electricity consumption and economic subsidies to make the heat pump a more attractive choice. Here will they investigate interruptible electricity customers, such as heat pumps, about the possibility of a dynamic electricity charge.

Furthermore, in Denmark, a charge per kWh of electricity is paid by consumers. If the household's primary form of heating is electric heating, it is possible to get a reduced electricity charge of the consumption which exceeds 4,000 kWh. By reducing the electricity heating tax, the Government hopes that the tax on electric heat will be more balanced compared to the tax on fossil fuels for the same use. They hope that this will promote the green transition and spread more heat pumps to the individual household and district heating production. In the tax reduction, the Government hopes that it will be attractive to choose the heat pump rather than the oil boilers or biomass boilers, thereby reducing CO_2 emissions and particles. (Klima-, Energi- og Forsyningsministeriet 2018)

Henrik Lund from Aalborg University has stated to Ingeniøren.dk that a reduction in the charge will not necessarily lead to the spread of heat pumps. He does not believe it is the price of electricity that hinders consumers from converting to a heat pump, but the significant start-up investment. (Ingeniøren 2018)

By reducing electricity taxes, the Government believes it can promote a more flexible and integrated energy system, as electricity is converted into heat will be a more attractive solution. The political parties agree that variation in electricity charges over, for example, the day should be investigated, so that electricity prices are low when RES production is high. (Klima-, Energi- og Forsyningsministeriet 2018)

1.5 Summary

Although Denmark has switched from using fossil fuels to more environmentally friendly fuel sources, there is still great potential in the heating sector that is not yet utilized. At present, several environmentally friendly technologies can compete with current fossil technologies. This could, for example, be seen in the individual heating sector, where there are still oil boilers that can be converted for heat pumps to lower CO_2 emissions.Thus, Denmark has a keen interest in implementing more heat pumps in the individual heat sector, where several measures are used to make the heat pump a more attractive choice. The development of the heat pump number is growing, but not high enough if the partial goal of phasing out oil boilers is to be achieved. Although Denmark has several incentives for citizens to choose a heat pump as a heating method, they are either not sufficient enough or does Denmark has a focus on the wrong measures. In this report, it is estimated that finances have a significant influence on the choice of heat pump, which is also the case for the interview with an energy consultant, who mentions that the installation of heat pumps has decreased after the subsidy for the implementation of heat pumps has also fallen. In addition to reducing emissions, implementation can reduce the socioeconomic costs of not using oil boilers.

Problem Formulation 2

In the following decade, Denmark must reduce their energy consumption and emissions. Several reports say that the distribution of heat pumps in individually heated households, as well as energy efficiency existing buildings, if the future Danish energy system is to become fossil-free and more energy efficient. The municipality is considered to influence the development, as the municipality has the opportunity to act as a facilitator and thus provide assistance to the citizens in terms of information and the accessibility of means. This results in the following problem formulation:

How can oil supplied houses in Aalborg municipality reach higher energy efficiency and can the socio- and user economy benefit from the implementation of heat pumps and insulation?

In order to answer problem formulation, it is considered necessary to answer the following sub-questions:

1. What is the current heat demand in the project scope and how will this demand be affected through energy efficiency measures?
2. What will the socioeconomic cost be at the different insulation levels and heat supply scenarios?
3. What will the user economic cost be for the citizens and can the insulation level benefit cost wise?
4. How should Aalborg municipality implement heat pumps and insulation for oil based household?

2.1 Delimitation

- It is delimited from heat supplies other than heat pumps and also limited to studying the heating sector. The assessment of the energy system's effects following the implementation of heat pumps is considered to be outside the focus of the project.
- It is delimited to existing buildings in the municipality of Aalborg with an oil fire.

2.2 Structure of the report

Chapter 3: Chapter 3 describes the theoretical considerations for what the analysis and discussion should contain.

Chapter 4: Chapter 4 describes the methodological considerations to answer the problem statement.

Chapter 5: Chapter 5 examines the heat demand for oil-supplied households in the municipality of Aalborg. The analyzes contain both the heat demand with and without insulation.

Chapter 6: In Chapter 6, the socioeconomic savings potential by converting oil supply to water to air or ground source heat pumps is assessed.

Chapter 7: In Chapter 6, the user economic costs of using oil, air to water, and ground source heat pumps, with either level 4 or 5 insulation being implemented, are assessed.

Chapter 8: In Chapter 8, conclusions which can be drawn from the results found in Chapters 6 and 7 are discussed, as well as what initiatives Aalborg municipality can take to make the heat pumps more attractive to users.

Chapter 9: Chapter 9 concludes the findings in the analysis and the discussion.

Theoretical Framework 3

3.1 Choice awareness

This chapter will introduce the theory of choice awareness and how it has been used throughout the project. The theory has two different theses where both of them will be presented, although only one of them will be used in this project. A more in-depth presentation of the second thesis will be made since this has been used throughout the analysis and discussion. The theory concerns awareness in situations where radical changes should happen, which is the case for this project where the oil boiler is sought to be converted to heat pumps.

Choice awareness is a theory about being aware of the distinction between a true choice and a false choice. A true choice is defined by a choice between two or more, where a false choice is the illusion of a choice. One concept of a false choice is a Hobson's choice, which gives one option or no option and can be an illusion for the citizens that only one heating option is possible. In other words, the solutions given are not necessarily the best option, and the choice awareness is, therefore, about how to pursue and ensure that a true choice is made. (Lund 2014)

Two different theses are of focus when using choice awareness. The first thesis state that when society seeks to implement new technologies which would be stated as radical change where the influence and discourse of existing institutions or technologies will hinder the development of new technologies. This can create a picture that society has no option but to make use of or implement technologies that will constitute existing technologies. This is done by excluding alternative technologies and the debates concerning these possibilities. The thesis states that existing technologies are hindering the development and the implementation of new alternative technologies, which is not the case for this project, as there is an agreement to phase out oil boilers.

The second thesis is about the awareness that other solutions exist and a choice on which solution to choose is possible. Creating awareness for the citizens can be made from feasibility studies, which include relevant political aspects. This relates to the project in that it seeks to show the citizens the feasibility in changing the household heat source and is a process over time. (Lund 2014)

Therefore, it can be discussed whether the project and the small area of focus creates a Hobson's choice since it highlights heat pumps as the only solution to the existing oil boilers and, therefore, does not give the citizens a true choice. The project has chosen heat pumps as the only solution for these individual heated areas based on literature studies, which assumes that heat pumps will be the favored technology in these areas. The project is aware of the other choices which can be chosen but has been delimited from all other heating options through literature studies.

Creating awareness for alternative solutions are of high importance for this project in the sense that the focus is making a radical change from oil boilers to heat pumps. The second thesis has three strategies which seek to raise awareness of the better choice and results in a new democratic infrastructure, such as illustrated in figure 3.1. The three strategies:

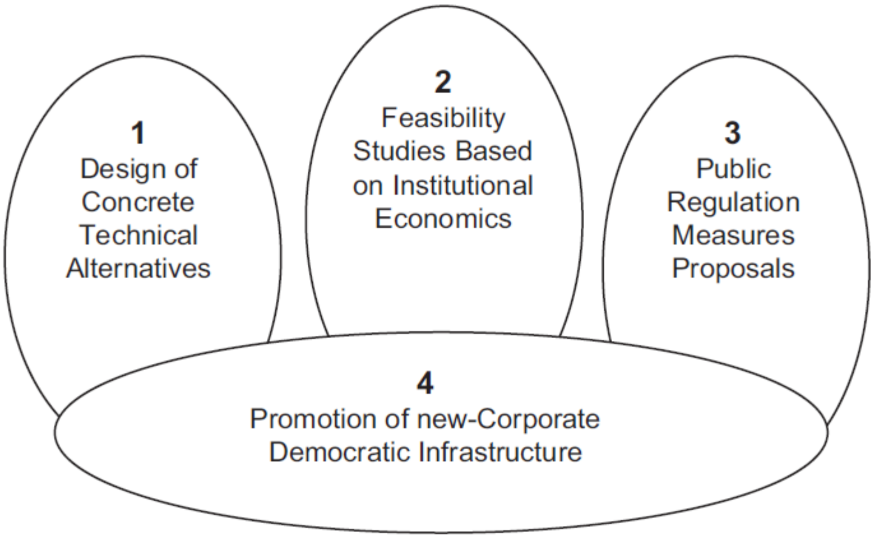

Figure 3.1: Choice Awareness strategies (Lund 2014)

The project has used the first strategy with an awareness of alternative technologies through a specific choice made through literature study and political goals. The alternatives have been designed in a way that they are equally comparable, such as energy demand and insulation cost. The alternatives are also including the savings in demand, efficiency improvements, and implementation of RES.

The second strategy was made during the analysis, where the feasibility of the alternative technology was calculated at a socio- and user economic level compared to the existing technology. With a feasibility study of this character, an awareness of the benefits on multiple levels have been created and how a choice like this can benefit the users and how it affects on a national scale as well. The analysis will have a long calculation period to find the best solutions independent of the existing technological energy system.

The third strategy, public regulations, are being discussed based on the results in the analysis. With an increased awareness of the alternatives, some citizens may take action and change where some may need further awareness but will also be met with resistance from the support of the old technologies. With the public's awareness of the feasibility steps to enroll, such a change may happen through their choice of actions and how other actors may be necessary for the enrolment of the alternative technology. Also, the project will discuss which measures can be taken, such as subsidies or changes in taxes, to promote the alternative heat options that meet the political objectives.

The fourth strategy is about further identifying the general barriers or define the institutional lack of information service for the decision making process and a design proposal for the long-term institutional changes in the democratic infrastructure and organizations. Because the fourth strategy focuses on design proposals and the decision-making, it will not be included in the project since this is not the focus in the report.

Methodology 4

The following chapter will describe the methodological choices made to answer the problem formulation. First, the considerations on the problem are described and what considerations have been for the data collection. Then the method for calculating an estimate of the heat demand, as well as the heat demand after implementation of the insulation levels. Next, the method of sizing of heat supply and cost of energy regeneration is presented. Finally, the technical assumptions of the socioeconomic and user economic assessments will be presented. The methodological approach are illustrated in figure 4.1

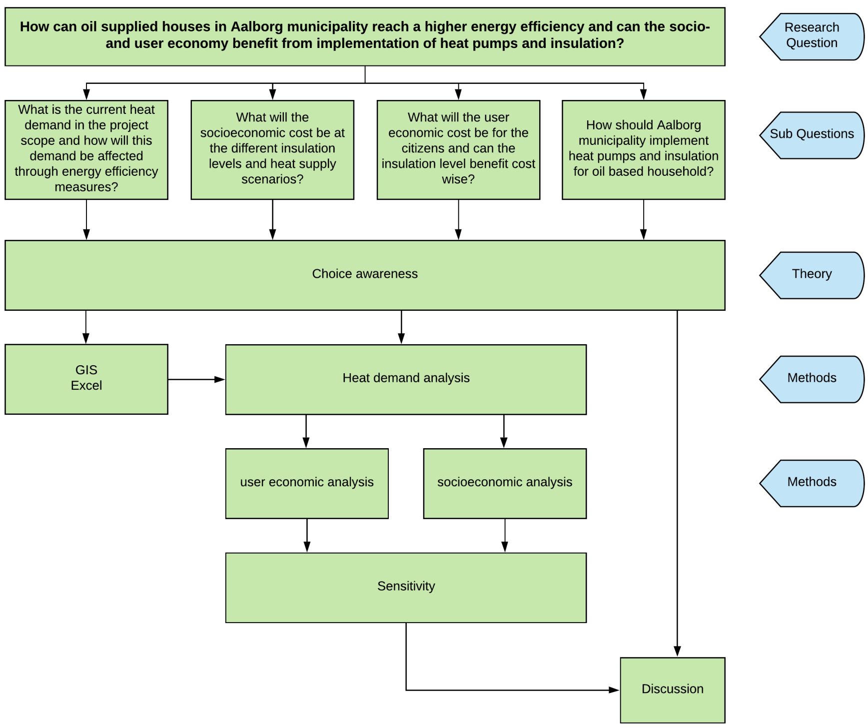

Figure 4.1: Research design

4.1 Literature Study

Literature studies have been an essential method for the project since much knowledge on the subject was needed. The knowledge gained through the literature study has been used on different project stages, where some have been used to build and delimit the project problem. Rambøll heating plan (Ramboll 2008) and IDA energy vision 2050 (Aalborg

Universitet 2015) have both been influential in the delimitation of technologies that should be analyzed for the comparison of oil boilers and alternative technologies. Both plans are published by respected institutions whom both mention heat pumps as the sole solution in the individual heating, which is why the project relies on their expertise. SBi and their report on insulation improvements (Kim B. en, Jesper Kragh, Søren Aggerholm 2017) have also played a significant part in the process of defining the insulation levels and what each level meant for the building. The report sees significant opportunities in heat savings in existing buildings where different measures are taken in steps with belonging financial costs. Throughout the analysis, this has been used to calculate the heat demand 5 and the financial cost by improving the insulation levels where value-added taxes have been included in the user economic analysis. These reports have been important in the assembling of the scenarios where a lot of technical data have been obtained through data collection and processed with data handling.

4.2 Data collection

In the project, different sources of information have been used to make the analysis. The sources for the used data are the BBR register, OIS (public information service), and GIS data set from (Steffen Nielsen, Jakob Zinck Thellufsen, Peter Sorknæs, Søren Roth Djørup, Karl Sperling, Poul Alberg Østergaard, Henrik Lund 2020). Since the data rely on user data, there can be uncertainty in whether the information is up to date or correct.

The BBR register information can be found for all buildings in Denmark and is a full information register on each building with location, usage, size, age, and more. The BBR register relies on the citizens' information to keep every detail about the different buildings up to date. Even though the citizens can receive fines of DKK 5,000, the data on BBR be unreliable where much uncertainty has been seen in the actual count of oil boilers in buildings. (Petersen n.d.) The uncertainty of the data can in the BBR register have not been accounted for, as it is assessed not to have a significant impact on the socio- and user economic results. It will not affect the results of the socioeconomic results, although it will affect the total cost in user economic.

The BBR codes used in this project;

- 110 -> Farmhouses
- 120 -> Single family houses
- 130 -> Terrace house
- 140 -> Apartment

The public information service is a state-owned database that collects information on properties in Denmark. It is based on information from registers owned by the municipalities, regions and the state. Information is regularly updated to ensure that the data is correct, there may still be some error in the data since its being collected from registers which require the citizens to inform about the details. This also means that owners can experience wrong information regarding their properties, which they have to contact the authorization owning the specific register that has the information.

SBi's report on potential heat savings has been a significant source of inspiration for this project, where the report focuses on how insulation improvements can benefit buildings and energy consumption in Denmark. For this project, Aalborg municipality has been chosen as the project scope. Aalborg municipality had in 2019 215,328 citizens (Aalborg Kommune 2019) spread out on an area of 1,152 km2 (Aalborg Kommune 2012) where only some of the buildings are of interest for the report. The project scope is looking specifically on buildings supplied with oil boilers since these should change their heating source due to the legislations which are mentioned earlier. The buildings that are using the oil boilers are of different ages and have been using this technology since, until now, they had no other options than using individual heating where oil boilers were the only option.

4.3 Calculation of the heat demand.

Two reports have been used to calculate the heat demand; The Danish heat Atlas (Aalborg Universitet 2016) and an SBi report (Kim B. en, Jesper Kragh, Søren Aggerholm 2017) on the potential heat savings by the insulation the buildings. The SBi report is being used to gain knowledge on the insulation topic and gaining the correct data which can be used for this project.

The Danish Heat Atlas method is used to estimate the heat demand for the selected buildings. The Danish Heat Atlas allows the estimation of the heat demand on a local, municipal, regional or national scale. The data used in the Heat atlas is based on the information from the "The utilities' Reporting Model for Energy Data" or the FIE data set, which shows the annual heat consumption of most energy supply companies, such as district heating, natural gas, and fuel oil. Since there is no information on all the buildings, a static analysis is done to find an estimation of heat demand for 24 building types and nine building periods. This static analysis results in an average heat demand (kWh / m^2) of the heated floor area. For a more in-depth explanation of calculating the average heat demand by building type and year of construction, this can be found in the documentation of heat atlas (Aalborg Universitet 2016).

The heat demand for the selected buildings type and building period is shown in table

	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007<
110	137	156	173	179	138	126	115	106	82
120	152	185	197	163	123	110	97	82	65
130	170	180	192	172	130	112	80	69	67
140	143	139	144	148	117	116	84	76	68

Table 4.1: Annual heat demand in kWh by building usage code, construction period and renovation level. (Aalborg Universitet 2016)

The calculation of the selected building heat demand is determined by two tools: Excel and ArcGIS. ArcGIS is used to determine the building size, building type, building period, and heat supply, where the data is further processed in Excel for the determination of the heat demand. The used data set in the analyzes has been made available by (Steffen Nielsen, Jakob Zinck Thellufsen, Peter Sorknæs, Søren Roth Djørup, Karl Sperling, Poul Alberg Østergaard, Henrik Lund 2020), which contains the buildings in Aalborg municipality.

The dataset contains information of 76,179 buildings demanding heat differentiated on multiple heat solutions. An estimate is made for the heat demand, as the data collection for the individual buildings' fuel consumption is too comprehensive. Calculating the heat demand is considered appropriate, as this is the method for determining the heat demand by planners in Denmark.

4.3.1 Heat demand after implementing insulation levels.

In the SBI report (Kim B. en, Jesper Kragh, Søren Aggerholm 2017), seven scenarios have been made to show the difference between the different standards of insulation in the houses. The study ranks the scenarios according to which are the most cost-effective, where the most cost-effective is the lowest. These scenarios will be used in the analysis to find the building's best insulation level compared to the socio- and user economic cost. The seven scenarios:

0. No actions made
1. Minimum insulation to meet the acceptable technical standards
2. Scenario 1 + insulation of space in cavity walls
3. Scenario 2 + Energy label A windows
4. Scenario 3 + insulation of ceiling and roof
5. Good practice for insulation when renovating
6. Focus on energy savings when insulating renovated structural parts
7. Scenario 6 + re-insulation of ceiling and roof similar to scenario 6

Each scenario focuses on different types of building renovation, such as insulation of cavity walls, window replacement, or post-insulation. Level 1 is similar to the building's basic renovation, where the minimum requirements for building technology and indoor climate are met.

Level 2 is like level 1, where empty cavity walls are further isolated.

Level 3 is similar to level 2, where the windows are further replaced with more energy-efficient windows. The windows are replaced by energy label B to energy label A. The window labeling is another way of describing how many layers the window has, where label B has two layers and label A windows have three layers. Windows function in two ways, insulation to keep heat inside the house and as a heat supplier by reflecting the heat of the sun-rays inside the house. (Jydsk vindueskompagni 2020)

Level 4 is like level 3, where more insulation is added to the roofs.

Level 5 is equivalent to adding additional insulation throughout the building. Also, level 5 corresponds to the insulation level's good practice regarding building regulations requirements.

Level 6 is an increase in the insulation thicknesses from level 5. In this level, there is additional insulation in the ceiling and floors.

In Level 7, all insulation that has not achieved the highest possible insulation will be post-insulated.

Table 4.2 shows the development of the heat demand savings, as it can be observed in the figure, the heat demand savings follows a pattern where there is a large percentage saving in the first four steps, except level 2, and the later steps have a lower percentage saving. The figure also shows that there is the highest heat saving in older buildings.

Building Component	Level	Initiative	Building Component	Level	Initiative
Facade			**Windows**	1 3	Energy label B Energy label A
Hollow outer walls	1 2	None Filled	**Floors**		
Solid outer walls	1 5	25 mm if bad 125 mm if bad	Ground deck	1 5 6	100 mm 200 mm 300 mm
Light outer walls	1 5	75 mm 100 mm	Crawl space	1 5 6	75 mm 150 mm 200 mm
Basement outerwalls	1 5	None 100 mm	Basement floor	1 5 6	100 mm 200 mm 300 mm
Roofs			Ground deck with floor heating	1 5 6	100 mm 200 mm 300 mm
Ceiling	1 4 5 6	75 mm 200 mm 250 mm 350 mm	Crawl space with floor heating	1 5 6	75 mm 150 mm 200 mm
Flat roof	1 4 5 6	100 mm 150 mm 200 mm 300 mm			

Table 4.2: Overview of energy savings measures and concrete initiatives for the energy levels (Kim B. en, Jesper Kragh, Søren Aggerholm 2017)

With the increasing energy efficiency associated with energy renovations, the heat demand in buildings will decrease. The heating demand reduction potential is based on the study of (Kim B. en, Jesper Kragh, Søren Aggerholm 2017). The saving percentage in heating demand depends on the type of building and year of construction, as well as which energy renovation carried out on the building, and the analysis will use the results found in the study where a percentage of saving has been determined by building type and year of construction.

The heat savings percentage is found by determining the difference between the heat demand if no energy renovation is done and the heat demand to the desired energy renovation level. For example, it is assumed in the study that farmhouses with a construction year before 1890 have a heating demand of 0.889 TWh, where it will fall to 0.685 TWh, which is correspondingly a reduction of approximately 23%. Thus, an assumption has been made as to what energy savings will be achieved by implementing energy renovation for each building type and period.

Building type	Building year	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7
	<1850	23%	5%	6%	9%	8%	5%	1%
	1850-1930	22%	8%	6%	9%	6%	5%	1%
	1931-1950	20%	9%	7%	9%	6%	5%	1%
	1951-1960	21%	9%	7%	9%	6%	5%	1%
Farmhouse	1961-1972	17%	4%	7%	8%	6%	5%	1%
	1973-1978	17%	0%	7%	8%	5%	5%	1%
	1979-1998	18%	0%	8%	2%	5%	5%	1%
	1999-2006	12%	1%	9%	1%	3%	3%	3%
	2007<	9%	0%	12%	0%	1%	1%	3%
	<1850	20%	4%	6%	8%	7%	5%	1%
	1850-1930	19%	8%	6%	8%	6%	4%	1%
	1931-1950	18%	7%	6%	7%	6%	4%	1%
	1951-1960	17%	7%	6%	7%	6%	4%	1%
Single Family	1961-1972	17%	2%	7%	7%	6%	5%	1%
	1973-1978	16%	0%	7%	6%	5%	5%	1%
	1979-1998	16%	0%	8%	2%	4%	4%	1%
	1999-2006	10%	0%	9%	0%	2%	2%	4%
	2007<	8%	0%	11%	0%	1%	1%	4%
	<1850	22%	3%	7%	8%	8%	4%	1%
	1850-1930	22%	6%	7%	9%	8%	4%	0%
	1931-1950	19%	6%	7%	7%	8%	4%	1%
	1951-1960	20%	5%	8%	7%	8%	5%	1%
Terrance	1961-1972	19%	2%	8%	7%	7%	5%	1%
	1973-1978	19%	0%	9%	7%	5%	4%	1%
	1979-1998	17%	0%	7%	1%	5%	5%	1%
	1999-2006	10%	0%	9%	0%	3%	3%	3%
	2007<	8%	0%	11%	0%	1%	1%	4%
	<1850	18%	1%	7%	3%	3%	1%	0%
	1850-1930	19%	4%	6%	4%	3%	2%	0%
	1931-1950	18%	6%	6%	4%	3%	2%	0%
	1951-1960	18%	8%	8%	2%	3%	2%	0%
Apartments	1961-1972	21%	3%	9%	3%	3%	2%	0%
	1973-1978	21%	1%	9%	3%	4%	2%	1%
	1979-1998	17%	0%	7%	1%	2%	2%	0%
	1999-2006	10%	0%	9%	0%	1%	1%	1%
	2007<	10%	0%	11%	0%	1%	0%	1%

Table 4.3: Heat savings percentage between insulation levels. (Kim B. en, Jesper Kragh, Søren Aggerholm 2017)

Table 4.3 displays the heat savings in percentage for each insulation level and each building type and period. The table should be understood that a farmhouse from before 1850 and attains the criteria for a level 2 insulation will have a heat saving of 28%.

4.3.2 Insulation level cost

A prerequisite in the study from Wittchen, Kragh, and Aggerholm (Kim B. en, Jesper Kragh, Søren Aggerholm 2017) is that insulation improvements are an extension with the general renovation of the building, in order to achieve the highest energy savings per DKK. Therefore, it is assumed that heat-savings in level 1 can be achieved by an investment of 0 since the insulation is an extension of the building's general renovation. This is important for the socioeconomic analysis since it is assumed that the citizens themselves pay for the general renovation. Costs for insulation scenarios used in the report are thus additional costs for higher energy efficiency in the building.

The investments for buildings insulation improvements are based on the report (Kim B. en, Jesper Kragh, Søren Aggerholm 2017) and will be used in the socioeconomic analyses and the user-economic analyzes.

Table 4.4 provides an overview of energy investments for the different types of buildings, building periods, and insulation levels.

Energy Effiency measures DKK/m2									
Level 1									
kr/m²	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-2016
110	0	0	0	0	0	0	0	0	0
120	0	0	0	0	0	0	0	0	0
130	0	0	0	0	0	0	0	0	0
140	0	0	0	0	0	0	0	0	0
Level 2									
110	11	17	19	20	9	1	0	1	0
120	8	18	18	17	6	1	0	0	0
130	5	11	13	11	4	1	0	0	0
140	3	8	13	17	6	1	0	0	0
Level 3									
110	26	33	35	36	26	19	17	20	20
120	23	34	35	36	26	21	18	20	20
130	21	27	30	30	24	22	17	20	19
140	20	24	29	34	25	19	15	21	22
Level 4									
110	63	69	70	74	62	55	30	22	22
120	58	68	68	70	57	52	29	21	21
130	51	59	56	55	46	49	25	20	20
140	32	39	43	43	33	27	20	21	22
Level 5									
110	145	139	134	137	134	119	109	67	36
120	139	134	131	141	136	128	110	52	30
130	122	126	125	134	114	109	114	71	36
140	58	65	72	73	61	55	61	37	29
Level 6									
110	228	218	210	215	219	200	183	104	48
120	220	208	200	219	224	215	185	78	39
130	190	193	189	210	189	181	193	112	49
140	85	94	101	101	87	81	97	50	36
Level 7									
110	252	239	229	236	241	222	209	186	138
120	243	226	220	243	254	245	228	208	143
130	206	207	208	234	214	202	210	213	153
140	90	99	108	113	101	97	110	92	64

Table 4.4: Investment needs in DKK / m2 of floor area to implement the energy improvement of the building components for the different types of buildings, building periods, and insulation level.(Kim B. en, Jesper Kragh, Søren Aggerholm 2017)

4.3.3 Dimensioning of heat supply

To calculate an estimate for the size of the heat supply, the study by (Kim B. en, Jesper Kragh, Søren Aggerholm 2017) is used to analyze the required heat effect for the individual building types, building periods, and insulation levels.

The dimensioning of the heat supply is found for the individual building and then categorized into sizes according to which heat supply is examined. The size of the heat supplies is determined according to the Danish Energy Agency's technology catalog (Energistyrelsen 2018*b*) and will be further elaborated in section 4.4.1

Dimensioning of heat supply W/m²									
Level 0									
W/m²	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-2016
110	43	42	42	43	44	37	34	29	26
120	44	44	46	49	43	40	37	31	27
130	38	39	41	42	40	37	32	31	27
140	35	40	40	35	33	32	30	31	26
Level 1									
110	43	42	42	43	44	37	34	29	26
120	44	44	46	49	43	40	37	31	27
130	38	39	41	42	40	37	32	31	27
140	35	40	40	35	33	32	30	31	26
Level 2									
110	42	39	38	39	41	37	34	29	26
120	42	41	43	46	42	40	37	31	27
130	38	37	39	39	39	37	32	31	27
140	35	39	39	34	32	31	30	31	26
Level 3									
110	40	37	36	37	39	35	32	27	23
120	41	39	41	43	40	38	35	29	25
130	36	35	37	37	36	34	30	28	24
140	33	37	37	32	29	29	28	29	24
Level 4									
110	37	35	34	35	36	33	31	27	23
120	38	37	38	41	38	36	34	29	25
130	33	33	35	35	34	33	30	28	24
140	32	36	36	31	29	28	27	29	24
Level 5									
110	34	33	32	33	34	31	29	26	23
120	35	35	37	39	36	34	33	28	25
130	31	31	33	33	32	31	28	28	24
140	32	35	35	30	28	27	27	28	24
Level 6									
110	33	32	31	32	33	30	28	26	23
120	34	34	36	38	35	33	31	28	25
130	30	30	32	32	31	30	27	27	24
140	31	35	34	30	28	27	26	28	23
Level 7									
110	33	32	31	32	32	30	28	25	22
120	34	34	35	38	35	33	31	27	24
130	30	30	32	32	31	30	27	26	23
140	31	35	34	30	27	27	26	28	23

Table 4.5: Dimensioning heating effect in W per m² floor area for the different building types, building periods, and insulation levels.(Kim B. en, Jesper Kragh, Søren Aggerholm 2017)

4.4 Economic calculations assumptions

The analysis will examine the effects of converting oil boilers for heat pumps and the effects of insulation levels. The economy plays a significant factor in the result and will be assessed from two angles: social and user economics. The socioeconomic will be examined based on the economic impact of the conversion of the building's heat supply and making the building more energy efficient. Also, the social economy will be used to assess whether it is financially profitable that Denmark held responsible for the costs of investing and are based on the principle of the Heat Supply Act that the most socioeconomic alternative is to prefer. Once the socioeconomic consequences are determined, the user economic ones will be found. This is done to motivate the buildings to choose the solution if it is assumed that the socioeconomic consequences are lower than if the citizens themselves continued to stand for energy optimization of the building. Both economic analyzes expressed in net present values of the total cost of the heat supply.

4.4.1 Socio-economic calculations assumption

The socioeconomic consequences of the selected insulation scenarios are calculated from the Danish Energy Agency's guide to socioeconomic analyzes of energy projects. The guidelines are primarily used for energy projects that must comply with the Heat Supply Act and the Projektbekendtgørelsen and are most often used for district heating projects but are considered useful in the report since the principle of having the most socioeconomic alternative is also applicable in the report. The socio-economic consequences are assessed according to the following formula:

$$NPV_{t=0} = \sum_{t=1}^{T} \frac{B_t - C_t}{(1+r)^t}$$

Where:

- Bt = Benefit/income [DKK]
- Ct = Disadvantage/cost [DKK]
- r = Discount rate [%]
- t = Calculation period [Year]
- T = Last calculation year [Year]

Heat supply

The first part of the analysis is to find the economic effect of converting individual heating technologies from oil to a heat pump. The two different solutions that will be included in this analysis is the ground source heat pump and the air to water heat pump. Working with heating technologies and their way of functioning includes a variety of important key numbers. Such key numbers are for the technology investment cost, operation and maintenance, and COP value. As mentioned earlier, the COP value depends on the ambient temperature and the conditional temperatures the specific heat pump is constructed to work with. This also means that efficiency during a year will change depending on the season. (Energistyrelsen) For this project, an overall COP value given by the Danish Energy Agency (Energistyrelsen 2019*c*) will be used though there may be some uncertainty regarding these efficiencies.

The areas using an oil boiler as an individual heating solution shall change to a ground source or air to water heat pump. The buildings which should change are different in type and age and will also affect the required size of a heat pump. Apartment buildings require a bigger heat pump than houses, where there is a difference in the efficiencies and prices between the individual and collective heat pumps.

Heat pumps are delineated dedicated to supplying several apartments, as their size is too large concerning the required capacity. The studied terrace houses and apartments can be covered by a smaller heat pump than the one assigned in the Danish Energy Agency's catalog.

Furthermore, a difference in heat efficiency can also be found depending on buildings using radiators or floor heating, where floor heating is more efficient than radiators. In this project, an average between these two will be used, since it is unknown whether a building uses radiator or floor heating. Investment cost, fuel/electricity prices, COP/efficiency values, taxes, VAT, O&M, and insulation values are being used to calculate the socioeconomic and user economic scenario differences in changing to a heat pump. The analysis of the socioeconomic and user economic values of all the technologies which the project investigates is necessary to compare and present the benefits from changing.

Technology type	**Air to water heat pump**			
Heat production capacity (kW)	5	10	15	<15
Investment cost (1000 DKK/unit)	53	70	84	4.5/kW
Lifetime in years	18			
O&M (1000 DKK/unit)	2			
COP	3.68			
Technology type	**Ground to water heat pump**			
Heat production capacity (kW)	5	10	15	<15
Investment cost (1000 DKK/unit)	87	112	133	7/kW
Lifetime in years	20			
O&M (1000 DKK/unit)	2			
COP	4.05			
Technology type	**Oil boiler**			
Heat production capacity (kW)	15		<15	
Investment cost (1000 DKK/unit)	44		3	
Lifetime in years	20			
O&M (1000 DKK/unit)	1.8			
COP	0.92			

*Table 4.6: Overview of the information for the selected heating supplies. (Energistyrelsen 2018*b)

An essential factor in the differences between oil boilers and heat pumps is their operation cost, which has a significant cost difference. These operation costs are relevant since they affect the heating technology cost to meet the heat demand. A significant difference in the prices on the "fuel" can, therefore, significantly impact the total cost of using a specific heating technology, shown in the sensitivity analysis. Implementing heat pumps in these areas still using oil boilers is not something that will happen all at once. Therefore, this project's assumption has been made, where 10% of the buildings change each year. In 2029 all buildings will have changed from using oil boilers to heat pumps, where the first part of the analysis will outline which technology there will be a solution without renovating the buildings.

Energy cost

The analyzes will use the fuel prices and electricity prices from the Danish Energy Agency's socio-economic calculation assumptions (Energistyrelsen 2019*c*) to ensure that the socio-economic analyzes are comparable.

2018 prices DKK./MWh	**An building**	**Gasolie**
2020	573	32
2021	588	32
2022	607	33
2023	623	33
2024	628	34
2025	630	34
2026	637	35
2027	639	35
2028	644	36
2029	645	36
2030	650	37
2031	646	37
2032	646	38
2033	646	38
2034	646	39
2035	646	39
2036	646	40
2037	646	40
2038	646	41
2039	646	41
2040	646	42

Table 4.7: Energy cost used in the socioeconomic analysis. (Energistyrelsen 2019c)

The discount rate

The socio-economic analysis uses a discount rate of 4 %, which is set by the Ministry of Finance. The discount rate would reflect the lost profits if the invested resources were spent on alternative projects.

The net tax factor

A net tax factor of 1.325 is used in the analyzes. The factor is used for the conversion of factor prices to market prices and indicates the size of indirect taxes, levies, and subsidies imposed on private consumption.

The tax distortion factor

If an energy project results in lower income from taxes, this must be funded from elsewhere in the community. Therefore, there will be a distortion of activity in the social economy, called the tax distortion factor. A tax distortion factor of 10 % is used and expresses the loss that occurs for the community's income by replacing one taxable item with another.

4.4.2 User economic calculations assumption

The user economy is built after the Danish Energy Agency's prescription and their guideline of a user economic control analysis (Energistyrelsen n.d.). When a change in the heating supply for an existing area is planned, a project proposal is made. With a composition of a new project proposal, the impact of the alternatives has to be investigated on multiple levels, user-, business- and socioeconomic effects. The guideline used is for small district areas with the use of biomass boiler and therefore has some elements which will not be included for this project. The purpose of this is to analyze the economic value of changing individual oil boilers to a heat pump, and the structure is made so that the results can be reproduced and used for other municipalities as well. It will also be used as a tool to compare the effects of a change on a user- and socioeconomic. The goal of the user economic analysis is to show the citizens the economic values that can benefit them through investments and changes in the building. It has been made in the extension of the socioeconomic analysis where the steps are sought to be transparent so that the analysis can be reproduced. Socioeconomic and user economic analysis are both calculating the values of the heating supplies, of which the values used for the two sorts of analyses are different. The user economic analysis is focused on the economic values of the citizens and, therefore, has to include taxes, value-added tax (VAT), and subsidies.

The first part of the analysis has been done in the same way as the socioeconomic analysis 4.4.1 where some of the elements in the socioeconomic analysis and the user economic analysis are similar to a lot of it are not. As it can be seen in table 4.8

	User economic analysis	Socioeconomic analysis
Investment cost	X	X
Operation and maintenance	X	X
Fuel cost	X	X
Electricity cost	X	X
Quota CO2	X	X
Emissions		X
Energy savings	X	X
Tax distortion loss from tariffs and subsidies		X
Net tax factor		X
Taxes	X	
Value added tax	X	

Table 4.8: Similarities between socioeconomic analysis and user economic analysis. (Energistyrelsen n.d.)

Investment cost The investment cost of the different units is found in the individual heating technology catalog (Energistyrelsen 2018*b*). The cost is specified in euros and without value-added tax, which during the analysis will be included.

Operation and maintenance The cost is specified in euros and is a yearly cost which by law has to be done. The operation and maintenance will, therefore, be included each year over the 20 years.

Fuel cost The buildings with an oil-based heating installation pay four different taxes: CO2 tax, NOx tax, Energy tax, and Energy saving tax, which are shown in Figure 4.9.

Tax	**DKK / 1000 litre oil**
CO2	469
NOx	9
Energy	2,035
Energy Saving	90
Total	2,603

Table 4.9: Overview of taxes on oil fuel (Skat.dk 2020) (DCC Energi 2020)

Electricity cost Electricity cost is a combination of the raw electricity price, taxes, and subsidies through energy savings. Using heat pumps as a heating solution reduces the electricity taxes, which can be deducted from the electricity cost. In Denmark, an electricity tax is added to the electricity used in a building. For 2020, the electricity tax amounts to DKK 0.892 / kWh.(Skat.dk 2020) Utilizing heat pumps in a building changes the composition of electricity where more than 50% is used for heating, in connection with the electricity usage being mainly used for heating a reduced electricity tax can be added instead. In 2020 amounts the reduced electricity taxes from DKK 0.892 / kWh to DKK 0.21 / kWh (Norlys 2020)

The total electricity cost, after taxes, per kWh is multiplied with the heat demand and divided by COP to find the total electricity consumption cost.

The electricity cost is assumed to differentiate over the 20 years when the price in the first year has been an actual price from Norlys, where the rest of the cost has been a projection. (Norlys 2020)

Electricity spot price	DKK/kWh
2020	0.36
2021	0.33
2022	0.33
2023	0.34
2024	0.35
2025	0.36
2026	0.35
2027	0.35
2028	0.35
2029	0.36
2030	0.35
2031	0.35
2032	0.35
2033	0.35
2034	0.35
2035	0.35
2036	0.35
2037	0.35
2038	0.35
2039	0.35
2040	0.35

Table 4.10: Electricity spot prices in DKK/kWh.

Energistyrelsen (2019*b*)

Energy savings Changing from an oil boiler to a heat pump gives the house owner a subsidy of 6,326.25 DKK. Other subsidies can be gained through insulating the building where different rates can be received depending on whether the doors, windows, walls, or floors are being reinsulated or changed. The subsidies for insulation have not been used for this project since the subsidy rates on insulation optimization are house-specific. (Aalborg Forsyning 2020) Without the benefits in the analysis, the total cost is higher than it actually could be if it is included. Although it has not been included, it would not affect the results since it would be included in all the scenarios.

Value added tax Relating to energy renovation and heat installation conversion, consumers will pay VAT on the investments. VAT is set at 25 %, which is charged on investments and running costs

Analysis of heat demand. 5

The following chapter will present the results of the heat demand analysis and the possible heat savings for the selected households in Aalborg. Thus, answer the sub-question number 1 for the problem formulation: *What is the current heat demand in the project scope and how will this demand be affected through energy efficiency measures?*

5.1 Extraction of data

This report wants to investigate the socioeconomic and user economic, a conversion of oil supplied farmhouses, single family houses, terrace houses, and apartments will result in. The dataset from (Steffen Nielsen, Jakob Zinck Thellufsen, Peter Sorknæs, Søren Roth Djørup, Karl Sperling, Poul Alberg Østergaard, Henrik Lund 2020) contains all the buildings in Aalborg municipality, which means that to use the data set correctly, it is necessary to select the buildings of interest. After the data selection is made, the number of buildings using oil boilers to cover their heat demand is down to 4,298. The table below shows the distribution of oil boilers by different types of buildings and periods.

Oil Boilers	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-	Total
Farmhouse	71	971	169	77	78	41	63	24	13	1507
Single Family	67	960	403	295	476	197	130	32	12	2572
Terrance	1	27	2	4	4	5	104	0	0	147
Apartments	1	43	14	2	11	0	1	0	0	72

Table 5.1: Oil boilers in project scope by building usage code and construction period

Floor area in m2	<1850	1850-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	1999-2006	2007<
110	13,436	135,946	20,862	8,325	11,625	6,460	10,528	5,361	2,535
120	9,846	115,949	41,511	30,584	67,068	27,786	18,633	4,699	1,806
130	186	4,220	200	2,100	1,546	534	11,036	0	0
140	199	8,937	4,136	247	4,863	0	135	0	0

Table 5.2: Floor area in m2 by building usage code and construction period

Table 5.1 shows that most of the types of building studied are either categorized as a farmhouse or single family house, where the majority of households is listed in the 1890 to 1929 building period. In addition to the type of building, another critical factor for the energy needs of buildings is their year of construction. The building period is also essential for saving of energy consumption each building achieves. To get a more accurate estimate of the heating demand in Aalborg municipality, the provided floor area from the dataset (Steffen Nielsen, Jakob Zinck Thellufsen, Peter Sorknæs, Søren Roth Djørup, Karl Sperling, Poul Alberg Østergaard, Henrik Lund 2020) will be used for the individual buildings, and thus no average size is made for each type of building.

It is not possible to determine whether the heat demand is covered by a single or multiple individual oil boilers for terrace houses and apartments. It is also not possible to determine how many flats there are in these types of buildings. Therefore, are the analyzes based on the fact that the heat demand is covered by a single oil boiler, where the size of the heat supply is determined in 6.1.

Table 5.3 shows the estimated heat demand for the selected building types and building periods. As the table shows, the heat demand is higher for older buildings, due to the tighter building regulations for energy optimization in newer buildings.

	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007<
110	137	156	173	179	138	126	115	106	82
120	152	185	197	163	123	110	97	82	65
130	170	180	192	172	130	112	80	69	67
140	143	139	144	148	117	116	84	76	68

Table 5.3: Annual heat demand in kWh/m^2 by building usage code and construction period

Table 5.2 shows the number of m^2 of the selected households in Aalborg, where it can be observed that most of the space-heated area has a correspondingly high heat demand per m^2. This makes the analysis relevant as it is these households with a high heating demand per m^2, which can obtain a large heat saving at a municipal level. The heat requirement is shown in table 5.4.

	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007<
110	1841	21208	3609	1490	1604	814	1211	568	208
120	1497	21451	8178	4985	8249	3056	1807	385	117
130	32	760	38	361	201	60	883	0	0
140	28	1242	596	37	569	0	11	0	0

Table 5.4: Annual heat demand in MWh by building usage code and construction period

5.2 Heat demand saving after insulation

To calculate the heat demand for the individual building type and building period for the different energy efficiency levels, the savings presented in table 4.3 are applied to the heat demand in 5.4. Table 5.5 shows the heat demand for the individual households whose 100 % has been renovated to the corresponding renovation level.

	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-	
					Farmhouse					Total
Level 0	1,841	21,208	3,609	1,490	1,604	814	1,211	568	208	32,553
Level 1	1,444	16,638	2,832	1,169	1,259	639	950	446	163	25,539
Level 2	1,302	14,996	2,552	1,054	1,134	576	856	402	147	23,019
Level 3	1,187	13,672	2,327	961	1,034	525	781	366	134	20,986
Level 4	1,021	11,767	2,002	827	890	452	672	315	115	18,061
Level 5	902	10,394	1,769	730	786	399	593	278	102	15,954
Level 6	813	9,372	1,595	659	709	360	535	251	92	14,386
Level 7	801	9,234	1,571	649	698	354	527	247	91	14,174
					Single Family					Total
Level 0	1,497	21,451	8,178	4,985	8,249	3,056	1,807	385	117	49,726
Level 1	1,174	16,829	6,416	3,911	6,472	2,398	1,418	302	92	39,013
Level 2	1,058	15,168	5,783	3,525	5,833	2,161	1,278	272	83	35,162
Level 3	965	13,829	5,272	3,214	5,318	1,970	1,165	248	76	32,057
Level 4	830	11,901	4,537	2,766	4,577	1,696	1,003	214	65	27,589
Level 5	733	10,513	4,008	2,443	4,043	1,498	886	189	58	24,370
Level 6	661	9,479	3,614	2,203	3,646	1,351	799	170	52	21,975
Level 7	652	9,340	3,561	2,171	3,592	1,331	787	168	51	21,651
					Terrace					Total
Level 0	32	760	38	361	201	60	883	0	0	2,334
Level 1	25	596	30	283	158	47	693	0	0	1,832
Level 2	22	537	27	255	142	42	624	0	0	1,651
Level 3	20	490	25	233	130	39	569	0	0	1,505
Level 4	18	421	21	200	112	33	490	0	0	1,295
Level 5	15	372	19	177	98	29	433	0	0	1,144
Level 6	14	336	17	160	89	26	390	0	0	1,032
Level 7	14	331	17	157	88	26	384	0	0	1,016
					Apartmens					Total
Level 0	28	1,242	596	37	569	0	11	0	0	2,483
Level 1	22	975	467	29	446	0	9	0	0	1,948
Level 2	20	878	421	26	402	0	8	0	0	1,756
Level 3	18	801	384	24	367	0	7	0	0	1,601
Level 4	16	689	330	20	316	0	6	0	0	1,378
Level 5	14	609	292	18	279	0	6	0	0	1,217
Level 6	13	549	263	16	251	0	5	0	0	1,097
Level 7	12	541	259	16	248	0	5	0	0	1,081

Table 5.5: Annual heat demand in MWh by building, construction period and renovation level

	Farmhouse	Single Family	Terrace	Apartments
Level 0	0	0	0	0
Level 1	7,013	10,713	503	535
Level 2	9,534	14,564	684	727
Level 3	11,567	17,669	830	882
Level 4	14,492	22,137	1,039	1,105
Level 5	16,599	25,356	1,190	1,266
Level 6	18,167	27,751	1,303	1,386
Level 7	18,379	28,075	1,318	1,402

Table 5.6: Annual reduction in heat demand in MWh by building and renovation level

5.3 Sub Conclusion

After an estimate of the heating demand for the individual building types and the heat demand has been found after the different energy levels have been obtained, it is possible to find the socioeconomic and user-economic costs of buildings with either an oil boiler or heat pump.

As can be seen, the heat demand in the period 1850 to 1930 for farmhouses and single family houses constitutes a large percentage of the total heating demand. This means that the socioeconomic assessments will be affected by this building period if an overall heat demand for each building type is considered. Therefore, building types will remain separate to assess the most optimal assessments for each building period.

Socioeconomic analysis 6

The chapter will begin with an analysis of the required dimension of the heat supply for each building type and period, as well as the considerations of the implementation projecting of insulation and heat supplies. Then a presentation of the socioeconomic results for oil boilers, water to air, and ground sources as well as the impact the different levels of insulation have on the socioeconomic results. The results will be analyzed and interpreted and concluded with a comparison between oil boilers and heat pumps and will, therefore, answer working question two: *"What will the socioeconomic cost be at the different insulation levels and heat supply scenarios?"*.

6.1 Peak load for individual heating

When installing a new heating supply in a building, it is necessary to know the required heating effect. If the required heating effect is not known, it will lead to a heat pump there can either not cover the heat demand or a heat pump with a too high kW capacity and, therefore, too high of an investment cost. The study of (Kim B. en, Jesper Kragh, Søren Aggerholm 2017) determines the required heat effect for the heat supplies in the socio- and user economic analysis as the study describes the required W effect for the building type and construction period—It further explains the significant W effect for each insulation level.

The dimensioning is categorized into groups of 5 kW, 10 kW, 15 kW, and greater than 15 kW. The division is due to the Danish Energy Agency's (Energistyrelsen 2018*b*) determined sizes of the air to water heat pump and the ground source heat pump. The catalog only presents an oil boiler with a heat capacity of 15 kW.

Table 6.1 shows a simplified distribution of heating installations for building types and renovation levels. As expected, more buildings need a smaller heat effect with increased insulation level, and thus a less investment is needed for the chosen heating installation. This means that investing in insulation will lower the investment cost for the heat supply.

110	**5 kW**	**10 kW**	**15 kW**	**>15 kW**	**120**	**5 kW**	**10 kW**	**15 kW**	**>15 kW**
L0	174	1,042	239	52	**L0**	610	1,677	248	37
L1	534	872	83	18	**L1**	1,201	1,292	76	3
L2	626	799	66	16	**L2**	1,314	1,191	64	3
L3	704	736	55	12	**L3**	1,454	1,067	48	3
L4	850	609	42	6	**L4**	1,665	866	39	2
L5	954	513	34	6	**L5**	1,859	689	22	2
L6	1,018	454	31	4	**L6**	1,943	610	17	2
L7	1,018	455	30	4	**L7**	1,964	591	15	2
130	**5 kW**	**10 kW**	**15 kW**	**>15 kW**	**140**	**5 kW**	**10 kW**	**15 kW**	**>15 kW**
L0	87	43	12	5	**L0**	9	29	21	13
L1	95	38	9	5	**L1**	16	32	12	12
L2	98	35	9	5	**L2**	16	33	11	12
L3	104	30	8	5	**L3**	19	33	8	12
L4	109	27	6	5	**L4**	20	32	8	12
L5	115	27	0	5	**L5**	22	30	8	12
L6	115	27	0	5	**L6**	22	31	7	12
L7	115	27	0	5	**L7**	22	32	6	12

Table 6.1: Number of heat installations categorized by building type, renovation level, and heat effect.

6.2 Projections of heat demand, heat supply and implementation of insulation levels

It is assumed that the buildings will convert the heat supply in the extension of the oil boiler lifetime and insulate to get the most efficient sizing of the heat pump. An estimate has been made that the technical lifetime of all the oil boilers will expire over the next 10 years, as the remaining technical lifetime of the oil boilers is unknown.

In the first 10 years for the socioeconomic analyses, a yearly 10% of the total investment for insulation is imposed for the building period and building type. This means that in the first year, 10 percent of buildings will be energy renovated to the current renovation stage, and the remaining 90 percent will have the same heating needs. The buildings converting from an oil boiler to a heat pump are the same buildings in which the insulation level increases. The same percentage of distribution also applies to the cost of insulation improvements.

Projections in the oil scenario are made by taking 10 % of buildings with a 15 kW and 10 % of the buildings supplied with a larger than 15 kW oil boiler annually, where the oil boiler dimension is equivalent the dimension corresponding to the level of insulation in the building.

The projections in scenarios with water to air and ground source follow the same principle where 10 % of buildings with a 5 kW, 10 kW, 15 kW, and greater than 15 kW converters from oil supply. Similarly to oil scenarios, the size of the heat pumps is determined by the level of insulation.

6.3 Socioeconomic results

Based on the socioeconomic assumptions and the above regarding sizing the heat supply and projection of the heat demand and energy renovations, the net present value of the socioeconomic costs is determined. The results of the socioeconomic cost are arranged according to the heat supply examined.

To make the tables more manageable, they are color-graded, where the insulation levels with the lowest socioeconomic for the building period is marked green, and the insulation level with the highest socioeconomic cost is marked red.

The results presented in the tables are the net present value of the socioeconomic costs over a 20-year calculation period. It can be seen that there are some cells in the terrace house and apartments where there is no value, which is because there are no buildings with the building period in the project scope.

Results of oil boilers

In the following tables, the socioeconomic costs will be presented for the selected building types if oil boilers continued to be used as a heating supply, as well as the socioeconomic costs if the households implement the various insulation levels.

Farmhouse Oil boiler	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-	Total
Level 0	kr. 11,279	kr. 138,529	kr. 23,860	kr. 10,370	kr. 10,801	kr. 5,598	kr. 8,497	kr. 3,652	kr. 1,649	kr. 214,234
Level 1	kr. 10,240	kr. 127,800	kr. 22,029	kr. 9,628	kr. 10,003	kr. 5,181	kr. 7,861	kr. 3,318	kr. 1,529	kr. 197,588
Level 2	kr. 9,990	kr. 125,476	kr. 21,634	kr. 9,467	kr. 9,782	kr. 5,038	kr. 7,641	kr. 3,214	kr. 1,489	kr. 193,733
Level 3	kr. 9,837	kr. 123,722	kr. 21,320	kr. 9,336	kr. 9,676	kr. 4,994	kr. 7,577	kr. 3,189	kr. 1,489	kr. 191,139
Level 4	kr. 9,743	kr. 122,363	kr. 21,016	kr. 9,221	kr. 9,606	kr. 4,972	kr. 7,407	kr. 3,071	kr. 1,444	kr. 188,844
Level 5	kr. 10,346	kr. 125,158	kr. 21,316	kr. 9,331	kr. 9,885	kr. 5,107	kr. 7,752	kr. 3,128	kr. 1,432	kr. 193,455
Level 6	kr. 10,633	kr. 129,547	kr. 21,913	kr. 9,572	kr. 10,324	kr. 5,343	kr. 8,105	kr. 3,188	kr. 1,427	kr. 200,052
Level 7	kr. 10,804	kr. 131,011	kr. 22,110	kr. 9,658	kr. 10,465	kr. 5,423	kr. 8,254	kr. 3,455	kr. 1,566	kr. 202,746

Table 6.2: The NPV socioeconomic cost for Farmhouses in DKK 1000

Single-Family Oil boiler	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-	Total
Level 0	kr. 9,713	kr. 138,393	kr. 55,471	kr. 37,462	kr. 61,121	kr. 24,173	kr. 15,293	kr. 3,577	kr. 1,258	kr. 346,461
Level 1	kr. 8,938	kr. 127,622	kr. 51,388	kr. 34,981	kr. 56,985	kr. 22,643	kr. 14,390	kr. 3,385	kr. 1,198	kr. 321,530
Level 2	kr. 8,718	kr. 125,098	kr. 50,398	kr. 34,419	kr. 55,757	kr. 22,115	kr. 14,068	kr. 3,316	kr. 1,177	kr. 315,065
Level 3	kr. 8,591	kr. 123,181	kr. 49,665	kr. 34,052	kr. 55,404	kr. 22,016	kr. 14,018	kr. 3,320	kr. 1,183	kr. 311,429
Level 4	kr. 8,489	kr. 121,193	kr. 48,805	kr. 33,674	kr. 54,999	kr. 21,925	kr. 13,768	kr. 3,243	kr. 1,159	kr. 307,256
Level 5	kr. 8,759	kr. 122,779	kr. 49,239	kr. 34,299	kr. 57,079	kr. 22,791	kr. 14,450	kr. 3,276	kr. 1,153	kr. 313,825
Level 6	kr. 9,093	kr. 125,711	kr. 50,116	kr. 35,236	kr. 59,881	kr. 23,968	kr. 15,118	kr. 3,308	kr. 1,149	kr. 323,581
Level 7	kr. 9,209	kr. 126,700	kr. 50,509	kr. 35,616	kr. 61,012	kr. 24,439	kr. 15,598	kr. 3,686	kr. 1,265	kr. 328,035

Table 6.3: The NPV socioeconomic cost for single family houses in DKK 1000

Terrance Oil boiler	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-	Total
Level 0	kr. 173	kr. 4,378	kr. 268	kr. 1,524	kr. 1,020	kr. 558	kr. 10,533	kr. -	kr. -	kr. 18,454
Level 1	kr. 157	kr. 4,000	kr. 249	kr. 1,315	kr. 902	kr. 528	kr. 10,079	kr. -	kr. -	kr. 17,230
Level 2	kr. 152	kr. 3,894	kr. 244	kr. 1,261	kr. 868	kr. 517	kr. 9,919	kr. -	kr. -	kr. 16,856
Level 3	kr. 150	kr. 3,827	kr. 241	kr. 1,223	kr. 852	kr. 516	kr. 9,903	kr. -	kr. -	kr. 16,710
Level 4	kr. 147	kr. 3,754	kr. 236	kr. 1,171	kr. 825	kr. 513	kr. 9,771	kr. -	kr. -	kr. 16,416
Level 5	kr. 150	kr. 3,816	kr. 239	kr. 1,210	kr. 854	kr. 524	kr. 10,250	kr. -	kr. -	kr. 17,043
Level 6	kr. 154	kr. 3,908	kr. 243	kr. 1,265	kr. 901	kr. 541	kr. 10,692	kr. -	kr. -	kr. 17,705
Level 7	kr. 156	kr. 3,934	kr. 244	kr. 1,289	kr. 921	kr. 547	kr. 10,800	kr. -	kr. -	kr. 17,893

Table 6.4: The NPV socioeconomic cost for Terrace houses in DKK 1000

Apartment Oil boiler	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-	Total
Level 0	kr. 163	kr. 7,114	kr. 3,001	kr. 263	kr. 2,737	kr. -	kr. 110	kr. -	kr. -	kr. 13,388
Level 1	kr. 149	kr. 6,472	kr. 2,667	kr. 244	kr. 2,382	kr. -	kr. 104	kr. -	kr. -	kr. 12,019
Level 2	kr. 144	kr. 6,295	kr. 2,593	kr. 240	kr. 2,296	kr. -	kr. 102	kr. -	kr. -	kr. 11,670
Level 3	kr. 142	kr. 6,200	kr. 2,538	kr. 238	kr. 2,250	kr. -	kr. 102	kr. -	kr. -	kr. 11,470
Level 4	kr. 138	kr. 6,021	kr. 2,447	kr. 232	kr. 2,151	kr. -	kr. 100	kr. -	kr. -	kr. 11,087
Level 5	kr. 137	kr. 5,983	kr. 2,430	kr. 231	kr. 2,143	kr. -	kr. 101	kr. -	kr. -	kr. 11,025
Level 6	kr. 137	kr. 6,001	kr. 2,436	kr. 231	kr. 2,155	kr. -	kr. 103	kr. -	kr. -	kr. 11,063
Level 7	kr. 152	kr. 6,617	kr. 2,704	kr. 251	kr. 2,532	kr. -	kr. 113	kr. -	kr. -	kr. 12,368

Table 6.5: The NPV socioeconomic cost for Apartment buildings in DKK 1000

As the tables show, there are quite a few scenarios where there will not be a socioeconomic benefit of the implementation of the insulation levels for buildings. It can be observed that it is primarily in the newer single family houses that energy investment in for the last levels of the energy measure will not be an attractive socioeconomic investment. The increase in socioeconomic costs is because the heat saving for energy measures is not high enough to offset investment costs for implementing the insulation levels.

Results of air to water

The following tables show the socioeconomic results where the selected buildings change from an oil supply to an air to water heat pump, as well as the socioeconomic effects by the implementation of insulation levels.

Farmhouse Air to Water HP	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-	Total
Level 0	kr. 11,133	kr. 136,243	kr. 23,074	kr. 9,983	kr. 10,928	kr. 5,765	kr. 8,840	kr. 3,830	kr. 1,870	kr. 211,667
Level 1	kr. 10,268	kr. 126,468	kr. 21,427	kr. 9,313	kr. 10,273	kr. 5,380	kr. 8,349	kr. 3,483	kr. 1,768	kr. 196,727
Level 2	kr. 10,118	kr. 125,655	kr. 21,237	kr. 9,219	kr. 10,129	kr. 5,261	kr. 8,193	kr. 3,426	kr. 1,750	kr. 194,989
Level 3	kr. 10,016	kr. 124,952	kr. 21,160	kr. 9,202	kr. 10,047	kr. 5,281	kr. 8,182	kr. 3,437	kr. 1,753	kr. 194,030
Level 4	kr. 10,110	kr. 124,808	kr. 21,061	kr. 9,232	kr. 10,052	kr. 5,289	kr. 7,994	kr. 3,375	kr. 1,610	kr. 193,531
Level 5	kr. 10,608	kr. 128,580	kr. 21,613	kr. 9,427	kr. 10,340	kr. 5,390	kr. 8,328	kr. 3,483	kr. 1,599	kr. 199,368
Level 6	kr. 11,140	kr. 133,902	kr. 22,418	kr. 9,730	kr. 10,781	kr. 5,676	kr. 8,688	kr. 3,531	kr. 1,626	kr. 207,492
Level 7	kr. 11,329	kr. 135,573	kr. 22,653	kr. 9,832	kr. 10,939	kr. 5,763	kr. 8,850	kr. 3,804	kr. 1,767	kr. 210,510

Table 6.6: The NPV socioeconomic cost for Farmhouses in DKK 1000

Single-Family Air to Water HP	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-	Total
Level 0	kr. 9,830	kr. 132,835	kr. 52,451	kr. 36,956	kr. 63,899	kr. 25,987	kr. 15,839	kr. 4,533	kr. 1,921	kr. 344,251
Level 1	kr. 9,023	kr. 122,766	kr. 48,954	kr. 34,652	kr. 59,845	kr. 24,463	kr. 15,996	kr. 4,268	kr. 1,546	kr. 321,513
Level 2	kr. 8,963	kr. 122,177	kr. 48,790	kr. 34,434	kr. 59,128	kr. 24,039	kr. 15,780	kr. 4,230	kr. 1,522	kr. 319,062
Level 3	kr. 8,877	kr. 121,423	kr. 48,615	kr. 34,391	kr. 58,942	kr. 24,041	kr. 15,758	kr. 4,135	kr. 1,420	kr. 317,600
Level 4	kr. 8,874	kr. 121,123	kr. 48,600	kr. 34,417	kr. 58,878	kr. 23,836	kr. 15,682	kr. 4,027	kr. 1,241	kr. 316,677
Level 5	kr. 9,152	kr. 123,880	kr. 49,517	kr. 35,297	kr. 60,988	kr. 24,486	kr. 16,084	kr. 4,047	kr. 1,318	kr. 324,769
Level 6	kr. 9,533	kr. 128,027	kr. 50,902	kr. 36,463	kr. 63,980	kr. 25,777	kr. 16,858	kr. 4,074	kr. 1,323	kr. 336,938
Level 7	kr. 9,647	kr. 129,174	kr. 51,350	kr. 36,825	kr. 65,075	kr. 26,210	kr. 17,356	kr. 4,456	kr. 1,441	kr. 341,534

Table 6.7: The NPV socioeconomic cost for single family houses in DKK 1000

Terrance Air to Water HP	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-	Total
Level 0	kr. 154	kr. 3,980	kr. 253	kr. 1,565	kr. 1,145	kr. 550	kr. 11,403	kr. -	kr. -	kr. 19,048
Level 1	kr. 149	kr. 3,752	kr. 247	kr. 1,405	kr. 1,014	kr. 524	kr. 11,201	kr. -	kr. -	kr. 18,292
Level 2	kr. 148	kr. 3,741	kr. 246	kr. 1,385	kr. 998	kr. 521	kr. 11,093	kr. -	kr. -	kr. 18,133
Level 3	kr. 148	kr. 3,718	kr. 229	kr. 1,358	kr. 987	kr. 525	kr. 11,083	kr. -	kr. -	kr. 18,048
Level 4	kr. 150	kr. 3,705	kr. 230	kr. 1,316	kr. 972	kr. 530	kr. 11,013	kr. -	kr. -	kr. 17,917
Level 5	kr. 157	kr. 3,760	kr. 237	kr. 1,366	kr. 1,005	kr. 548	kr. 11,470	kr. -	kr. -	kr. 18,542
Level 6	kr. 164	kr. 3,910	kr. 244	kr. 1,435	kr. 1,060	kr. 570	kr. 11,974	kr. -	kr. -	kr. 19,356
Level 7	kr. 165	kr. 3,944	kr. 246	kr. 1,462	kr. 1,081	kr. 577	kr. 12,091	kr. -	kr. -	kr. 19,566

Table 6.8: The NPV socioeconomic cost for Terrace houses in DKK 1000

Apartment Air to Water HP	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-	Total
Level 0	kr. 149	kr. 6,879	kr. 3,009	kr. 250	kr. 3,131	kr. -	kr. 123	kr. -	kr. -	kr. 13,542
Level 1	kr. 145	kr. 6,401	kr. 2,709	kr. 244	kr. 2,760	kr. -	kr. 104	kr. -	kr. -	kr. 12,364
Level 2	kr. 144	kr. 6,362	kr. 2,705	kr. 245	kr. 2,738	kr. -	kr. 103	kr. -	kr. -	kr. 12,297
Level 3	kr. 144	kr. 6,300	kr. 2,681	kr. 228	kr. 2,695	kr. -	kr. 104	kr. -	kr. -	kr. 12,153
Level 4	kr. 144	kr. 6,277	kr. 2,667	kr. 228	kr. 2,659	kr. -	kr. 104	kr. -	kr. -	kr. 12,079
Level 5	kr. 146	kr. 6,329	kr. 2,703	kr. 231	kr. 2,693	kr. -	kr. 107	kr. -	kr. -	kr. 12,209
Level 6	kr. 149	kr. 6,427	kr. 2,750	kr. 234	kr. 2,740	kr. -	kr. 109	kr. -	kr. -	kr. 12,407
Level 7	kr. 163	kr. 7,054	kr. 3,010	kr. 254	kr. 3,121	kr. -	kr. 119	kr. -	kr. -	kr. 13,722

Table 6.9: The NPV socioeconomic cost for Apartments buildings in DKK 1000

Additionally, with the oil scenario, it can be observed that there are socioeconomic benefits by making the buildings more energy efficient. The same pattern as in the oil scenario can also be observed here, where the lowest socioeconomic cost is to insulate to level 4, where the socioeconomic cost subsequently increases. Here again, it is talked about that the heat saving from step 4 to step 5 cannot offset the investment costs.

Results of ground water heat pumps

Farmhouse Ground to water HP	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-	Total
Level 0	kr. 14,296	kr. 170,720	kr. 28,886	kr. 12,479	kr. 13,683	kr. 7,326	kr. 11,260	kr. 5,018	kr. 2,399	kr. 266,068
Level 1	kr. 13,037	kr. 158,331	kr. 26,816	kr. 11,685	kr. 12,896	kr. 6,774	kr. 10,760	kr. 4,457	kr. 2,268	kr. 247,023
Level 2	kr. 12,832	kr. 157,212	kr. 26,563	kr. 11,558	kr. 12,722	kr. 6,631	kr. 10,383	kr. 4,388	kr. 2,248	kr. 244,538
Level 3	kr. 12,650	kr. 156,150	kr. 26,458	kr. 11,537	kr. 12,602	kr. 6,649	kr. 10,351	kr. 4,387	kr. 2,242	kr. 243,025
Level 4	kr. 12,680	kr. 155,444	kr. 26,251	kr. 11,553	kr. 12,565	kr. 6,634	kr. 10,080	kr. 4,309	kr. 2,082	kr. 241,598
Level 5	kr. 13,135	kr. 158,909	kr. 26,779	kr. 11,732	kr. 12,810	kr. 6,699	kr. 10,376	kr. 4,408	kr. 2,061	kr. 246,908
Level 6	kr. 13,607	kr. 164,068	kr. 27,573	kr. 12,023	kr. 13,217	kr. 6,981	kr. 10,711	kr. 4,409	kr. 2,068	kr. 254,658
Level 7	kr. 13,796	kr. 165,742	kr. 27,810	kr. 12,126	kr. 13,376	kr. 7,069	kr. 10,873	kr. 4,682	kr. 2,208	kr. 257,682

Table 6.10: The NPV socioeconomic cost for Farmhouses in DKK 1000

Single-Family Ground to water HP	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-	Total
Level 0	kr. 11,991	kr. 163,943	kr. 65,250	kr. 46,496	kr. 80,270	kr. 32,785	kr. 21,346	kr. 5,196	kr. 1,940	kr. 429,218
Level 1	kr. 11,203	kr. 152,960	kr. 61,244	kr. 43,760	kr. 75,713	kr. 31,108	kr. 20,281	kr. 4,864	kr. 1,845	kr. 402,978
Level 2	kr. 11,145	kr. 152,244	kr. 61,059	kr. 43,477	kr. 74,869	kr. 30,610	kr. 20,034	kr. 4,822	kr. 1,816	kr. 400,077
Level 3	kr. 11,030	kr. 151,250	kr. 60,833	kr. 43,399	kr. 74,505	kr. 30,558	kr. 19,811	kr. 4,843	kr. 1,834	kr. 398,063
Level 4	kr. 11,002	kr. 150,678	kr. 60,760	kr. 43,354	kr. 74,216	kr. 30,192	kr. 19,559	kr. 4,708	kr. 1,759	kr. 396,228
Level 5	kr. 11,241	kr. 153,176	kr. 61,595	kr. 44,172	kr. 76,093	kr. 30,682	kr. 19,977	kr. 4,714	kr. 1,700	kr. 403,349
Level 6	kr. 11,603	kr. 157,251	kr. 62,967	kr. 45,302	kr. 78,966	kr. 31,944	kr. 20,587	kr. 4,731	kr. 1,705	kr. 415,057
Level 7	kr. 11,712	kr. 158,362	kr. 63,406	kr. 45,644	kr. 80,026	kr. 32,356	kr. 21,086	kr. 5,113	kr. 1,823	kr. 419,528

Table 6.11: The NPV socioeconomic cost for single family houses in DKK 1000

Terrance Ground to water HP	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-	Total
Level 0	kr. 187	kr. 4,881	kr. 315	kr. 1,624	kr. 1,263	kr. 701	kr. 14,622	kr. -	kr. -	kr. 23,594
Level 1	kr. 183	kr. 4,625	kr. 310	kr. 1,463	kr. 1,121	kr. 670	kr. 14,424	kr. -	kr. -	kr. 22,797
Level 2	kr. 182	kr. 4,617	kr. 310	kr. 1,445	kr. 1,106	kr. 667	kr. 14,304	kr. -	kr. -	kr. 22,631
Level 3	kr. 183	kr. 4,586	kr. 287	kr. 1,417	kr. 1,094	kr. 672	kr. 14,274	kr. -	kr. -	kr. 22,513
Level 4	kr. 184	kr. 4,561	kr. 288	kr. 1,369	kr. 1,079	kr. 677	kr. 14,192	kr. -	kr. -	kr. 22,351
Level 5	kr. 191	kr. 4,591	kr. 295	kr. 1,419	kr. 1,112	kr. 695	kr. 14,611	kr. -	kr. -	kr. 22,914
Level 6	kr. 198	kr. 4,744	kr. 302	kr. 1,489	kr. 1,166	kr. 717	kr. 15,118	kr. -	kr. -	kr. 23,734
Level 7	kr. 200	kr. 4,778	kr. 305	kr. 1,515	kr. 1,188	kr. 724	kr. 15,118	kr. -	kr. -	kr. 23,827

Table 6.12: The NPV socioeconomic cost for Terrace houses in DKK 1000

Apartment Ground to water HP	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-	Total
Level 0	kr. 183	kr. 8,280	kr. 3,420	kr. 313	kr. 3,340	kr. -	kr. 158	kr. -	kr. -	kr. 15,693
Level 1	kr. 179	kr. 7,798	kr. 3,092	kr. 308	kr. 2,952	kr. -	kr. 133	kr. -	kr. -	kr. 14,462
Level 2	kr. 178	kr. 7,759	kr. 3,091	kr. 308	kr. 2,931	kr. -	kr. 133	kr. -	kr. -	kr. 14,400
Level 3	kr. 179	kr. 7,673	kr. 3,067	kr. 287	kr. 2,887	kr. -	kr. 133	kr. -	kr. -	kr. 14,226
Level 4	kr. 179	kr. 7,651	kr. 3,056	kr. 286	kr. 2,853	kr. -	kr. 133	kr. -	kr. -	kr. 14,158
Level 5	kr. 181	kr. 7,697	kr. 3,094	kr. 289	kr. 2,888	kr. -	kr. 136	kr. -	kr. -	kr. 14,285
Level 6	kr. 183	kr. 7,792	kr. 3,142	kr. 292	kr. 2,936	kr. -	kr. 139	kr. -	kr. -	kr. 14,484
Level 7	kr. 198	kr. 8,420	kr. 3,397	kr. 313	kr. 3,318	kr. -	kr. 148	kr. -	kr. -	kr. 15,794

Table 6.13: The NPV socioeconomic cost for Apartments buildings in DKK 1000

The socioeconomic costs of the ground source heat pump are seen to be higher than the oil boilers and air to water. The reason for the higher cost is that there is a high investment cost in establishing ground source heat pumps, compared to an oil boiler or an air to water heat pump.

In addition to the high socioeconomic cost, the ground to water heat pump has the same patterns as air to water; the lowest socioeconomic cost at level 4 and ground source heat pumps have a high investment price with low energy consumption and emissions from the boiler emissions.

6.4 Comparison of the socioeconomic results

The socioeconomic results show a tendency in which the level of insulation has the lowest socioeconomic value and the effect that the levels of insulation have on the socioeconomic value. It is seen that buildings constructed between 1890 and 1998 have a higher socioeconomic cost after the building has achieved a level 4 insulation, and buildings after 1998 have a lower socioeconomic cost after implementation level 5 insulation. The reason for the shift in this building period is due to energy investment DKK / m^2 from (Kim B. en, Jesper Kragh, Søren Aggerholm 2017), where the buildings for these periods are significantly cheaper than the buildings from 1890-1998. As visualized in Table 4.4, it is seen that the energy investment price does not change as dramatically as it does in older buildings. Hence a lower DDK investment per heat saved.

These tables examine the total socioeconomic cost of all buildings of the same building type, categorized by building periods. Although the tables show that the lowest socioeconomic costs are obtained by having a level 4 insulation, it is not necessarily the best for all buildings. The tables presented in the tables are totals, and within each building period, there are differences totals to the size of the buildings.

It can also be seen that a generalization of the building type and level of insulation cannot be made, as seen, in single family houses constructed after 2007, where level 6 insulation is the best scenario, but where the overall socioeconomic shows that level 4 has the lowest socioeconomic cost. Also, the total number of heated space has massive significance for the total number, which is seen for buildings from 1890-1929 for both farmhouses and single family houses. Here, the socioeconomic costs make up about 65% and 40% of the total socioeconomic costs for farmhouses and single family houses. This means that the optimum insulation level for the whole building type will be characterized by which buildings period have the most heated floor area and, therefore, can not be used as a general representation of the optimal insulation level. The total cost provides a good indicator of which building in Aalborg provides the lowest socioeconomic cost for the municipality. However, to obtain the best socioeconomic cost, it is necessary to locate the optimal insulation level for each building period.

The illustration of the distribution of the best socioeconomic costs of oil-supplied building types and building periods is in the lower insulation levels as the fuel price has a high socioeconomic cost and therefore entails a high energy saving per DKK spent on insulation.

As the insulation level increases, it is also seen that the investment increases where the fuel price falls. A trend in which a higher insulation investment entails a lower socioeconomic cost, due to lower fuel consumption, also applies to the other types of buildings and periods supplied with oil. Since heat pumps have a lover operation cost than oil boilers, will the heat savings not change as much since heat pumps have a lower energy consumption. This can not be seen in the tables, where buildings with oil boilers do not significantly change for each level of implemented insulation, then heat pumps. This is because of the lower dimension of heat pumps, which can lead to a lower investment price.

If a single building is being investigated, where the change of heat pump size has changed, it will reduce the socioeconomic cost to be lower than oil boilers.

Socioeconomic comparison for farmhouses

In order to provide a clear overview of whether it is socioeconomic feasible to make a conversion of oil-based heating, the following sections will present a comparison of the socioeconomic costs of oil conversion to an air to water heat pump and ground source for the building types as well as the building periods.

The green numbers on the table mean that there is a better socioeconomic if there is a conversion of heat supply.

Oil boiler - Air to Water HP	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-
Level 0	kr. 146	kr. 2,286	kr. 785	kr. 387	kr. -127	kr. -168	kr. -344	kr. -178	kr. -221
Level 1	kr. -28	kr. 1,332	kr. 602	kr. 315	kr. -270	kr. -199	kr. -488	kr. -165	kr. -239
Level 2	kr. -128	kr. -179	kr. 397	kr. 248	kr. -347	kr. -223	kr. -552	kr. -212	kr. -261
Level 3	kr. -179	kr. -1,230	kr. 160	kr. 134	kr. -372	kr. -287	kr. -604	kr. -249	kr. -264
Level 4	kr. -367	kr. -2,446	kr. -44	kr. -11	kr. -446	kr. -317	kr. -586	kr. -304	kr. -166
Level 5	kr. -262	kr. -3,422	kr. -297	kr. -96	kr. -455	kr. -283	kr. -576	kr. -355	kr. -167
Level 6	kr. -507	kr. -4,355	kr. -505	kr. -158	kr. -457	kr. -332	kr. -582	kr. -343	kr. -199
Level 7	kr. -525	kr. -4,562	kr. -543	kr. -174	kr. -474	kr. -341	kr. -595	kr. -349	kr. -201

Table 6.14: The NPV difference in socioeconomic cost for the oil boilers and Air to Water Heat pump for farmhouses in DKK 1000

Reference - Ground to water HP	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-
Level 0	kr. -3,018	kr. -32,190	kr. -5,027	kr. -2,109	kr. -2,882	kr. -1,729	kr. -2,763	kr. -1,366	kr. -750
Level 1	kr. -2,796	kr. -30,531	kr. -4,788	kr. -2,057	kr. -2,894	kr. -1,593	kr. -2,899	kr. -1,139	kr. -739
Level 2	kr. -2,842	kr. -31,735	kr. -4,929	kr. -2,091	kr. -2,940	kr. -1,593	kr. -2,742	kr. -1,174	kr. -758
Level 3	kr. -2,813	kr. -32,428	kr. -5,138	kr. -2,200	kr. -2,926	kr. -1,655	kr. -2,774	kr. -1,198	kr. -753
Level 4	kr. -2,937	kr. -33,081	kr. -5,234	kr. -2,332	kr. -2,959	kr. -1,662	kr. -2,673	kr. -1,237	kr. -639
Level 5	kr. -2,789	kr. -33,751	kr. -5,463	kr. -2,401	kr. -2,926	kr. -1,592	kr. -2,623	kr. -1,280	kr. -629
Level 6	kr. -2,974	kr. -34,521	kr. -5,661	kr. -2,451	kr. -2,894	kr. -1,638	kr. -2,606	kr. -1,221	kr. -641
Level 7	kr. -2,992	kr. -34,732	kr. -5,700	kr. -2,467	kr. -2,911	kr. -1,647	kr. -2,619	kr. -1,227	kr. -643

Table 6.15: The NPV difference in socioeconomic cost for oil boilers and Air to Water Heat pump for farmhouses in DKK 1000

Socioeconomic comparison for One single family houses

Oil boiler - Air to Water HP	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-
Level 0	kr. -117	kr. 5,558	kr. 3,020	kr. 506	kr. -2,779	kr. -1,815	kr. -546	kr. -955	kr. -663
Level 1	kr. -85	kr. 4,856	kr. 2,434	kr. 329	kr. -2,860	kr. -1,820	kr. -1,606	kr. -883	kr. -348
Level 2	kr. -245	kr. 2,920	kr. 1,608	kr. -14	kr. -3,371	kr. -1,924	kr. -1,712	kr. -913	kr. -345
Level 3	kr. -286	kr. 1,758	kr. 1,051	kr. -339	kr. -3,538	kr. -2,025	kr. -1,740	kr. -815	kr. -237
Level 4	kr. -384	kr. 70	kr. 205	kr. -743	kr. -3,879	kr. -1,911	kr. -1,915	kr. -783	kr. -82
Level 5	kr. -393	kr. -1,101	kr. -277	kr. -998	kr. -3,909	kr. -1,695	kr. -1,634	kr. -771	kr. -165
Level 6	kr. -440	kr. -2,316	kr. -786	kr. -1,226	kr. -4,099	kr. -1,809	kr. -1,740	kr. -766	kr. -174
Level 7	kr. -438	kr. -2,474	kr. -840	kr. -1,209	kr. -4,064	kr. -1,771	kr. -1,759	kr. -770	kr. -175

Table 6.16: The NPV difference in socioeconomic cost for oil boilers and Air to Water Heat pump for single family houses in DKK 1000

Reference - Ground to water HP	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-
Level 0	kr. -2,277	kr. -25,550	kr. -9,780	kr. -9,034	kr. -19,150	kr. -8,612	kr. -6,053	kr. -1,619	kr. -682
Level 1	kr. -2,265	kr. -25,339	kr. -9,856	kr. -8,779	kr. -18,728	kr. -8,466	kr. -5,891	kr. -1,479	kr. -647
Level 2	kr. -2,427	kr. -27,146	kr. -10,662	kr. -9,058	kr. -19,113	kr. -8,496	kr. -5,966	kr. -1,505	kr. -639
Level 3	kr. -2,439	kr. -28,069	kr. -11,168	kr. -9,347	kr. -19,101	kr. -8,541	kr. -5,793	kr. -1,522	kr. -651
Level 4	kr. -2,512	kr. -29,484	kr. -11,955	kr. -9,680	kr. -19,217	kr. -8,267	kr. -5,791	kr. -1,465	kr. -600
Level 5	kr. -2,481	kr. -30,398	kr. -12,355	kr. -9,873	kr. -19,014	kr. -7,891	kr. -5,527	kr. -1,438	kr. -547
Level 6	kr. -2,510	kr. -31,540	kr. -12,851	kr. -10,066	kr. -19,085	kr. -7,976	kr. -5,468	kr. -1,423	kr. -556
Level 7	kr. -2,503	kr. -31,661	kr. -12,897	kr. -10,028	kr. -19,014	kr. -7,917	kr. -5,488	kr. -1,427	kr. -558

Table 6.17: The NPV difference in socioeconomic cost for oil boilers and Ground to Water Heat pump for single family houses in DKK 1000

Socioeconomic comparison for Terrace houses

Samfundsøkonomiske resultater i 1000 DKK forskel på reference									
Oil boiler - Air to Water HP	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-
Level 0	kr. 19	kr. 398	kr. 16	kr. -41	kr. -124	kr. 7	kr. -870	kr. -	kr. -
Level 1	kr. 8	kr. 248	kr. 2	kr. -90	kr. -112	kr. 4	kr. -1,122	kr. -	kr. -
Level 2	kr. 4	kr. 154	kr. -2	kr. -125	kr. -131	kr. -3	kr. -1,174	kr. -	kr. -
Level 3	kr. 1	kr. 109	kr. 11	kr. -135	kr. -135	kr. -9	kr. -1,180	kr. -	kr. -
Level 4	kr. -3	kr. 48	kr. 6	kr. -145	kr. -147	kr. -18	kr. -1,242	kr. -	kr. -
Level 5	kr. -7	kr. 57	kr. 2	kr. -156	kr. -151	kr. -24	kr. -1,220	kr. -	kr. -
Level 6	kr. -9	kr. -2	kr. -1	kr. -171	kr. -158	kr. -29	kr. -1,282	kr. -	kr. -
Level 7	kr. -10	kr. -10	kr. -2	kr. -173	kr. -160	kr. -29	kr. -1,290	kr. -	kr. -

Table 6.18: The NPV difference in socioeconomic cost for oil boilers and Air to Water Heat pump for Terrace houses in DKK 1000

Reference - Ground to water HP	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-
Level 0	kr. -14	kr. -503	kr. -47	kr. -100	kr. -243	kr. -143	kr. -4,090	kr. -	kr. -
Level 1	kr. -26	kr. -625	kr. -61	kr. -149	kr. -219	kr. -142	kr. -4,345	kr. -	kr. -
Level 2	kr. -30	kr. -723	kr. -66	kr. -184	kr. -238	kr. -150	kr. -4,385	kr. -	kr. -
Level 3	kr. -33	kr. -759	kr. -47	kr. -194	kr. -242	kr. -156	kr. -4,372	kr. -	kr. -
Level 4	kr. -38	kr. -807	kr. -53	kr. -199	kr. -254	kr. -165	kr. -4,421	kr. -	kr. -
Level 5	kr. -41	kr. -775	kr. -57	kr. -209	kr. -258	kr. -171	kr. -4,361	kr. -	kr. -
Level 6	kr. -44	kr. -835	kr. -60	kr. -224	kr. -265	kr. -176	kr. -4,425	kr. -	kr. -
Level 7	kr. -44	kr. -844	kr. -60	kr. -226	kr. -266	kr. -177	kr. -4,317	kr. -	kr. -

Table 6.19: The NPV difference in socioeconomic cost for oil boilers and Ground to Water Heat pump for Terrace houses in DKK1000

Socioeconomic comparison for Apartments

Oil boiler - Air to Water HP	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-
Level 0	kr. 14	kr. 235	kr. -9	kr. 13	kr. -394	kr. -	kr. -13	kr. -	kr. -
Level 1	kr. 4	kr. 71	kr. -42	kr. 0	kr. -378	kr. -	kr. 0	kr. -	kr. -
Level 2	kr. 1	kr. -67	kr. -112	kr. -4	kr. -442	kr. -	kr. -1	kr. -	kr. -
Level 3	kr. -2	kr. -100	kr. -144	kr. 9	kr. -445	kr. -	kr. -2	kr. -	kr. -
Level 4	kr. -6	kr. -257	kr. -220	kr. 4	kr. -508	kr. -	kr. -4	kr. -	kr. -
Level 5	kr. -9	kr. -346	kr. -273	kr. 0	kr. -551	kr. -	kr. -5	kr. -	kr. -
Level 6	kr. -11	kr. -425	kr. -314	kr. -2	kr. -585	kr. -	kr. -6	kr. -	kr. -
Level 7	kr. -12	kr. -438	kr. -306	kr. -3	kr. -589	kr. -	kr. -6	kr. -	kr. -

Table 6.20: The NPV difference in socioeconomic cost for oil boilers and Air to Water Heat pump for Apartment buildings in DKK 1000

Reference - Ground to water HP	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-
Level 0	kr. -20	kr. -1,166	kr. -419	kr. -50	kr. -602	kr. -	kr. -48	kr. -	kr. -
Level 1	kr. -30	kr. -1,326	kr. -425	kr. -63	kr. -570	kr. -	kr. -29	kr. -	kr. -
Level 2	kr. -33	kr. -1,465	kr. -498	kr. -68	kr. -635	kr. -	kr. -31	kr. -	kr. -
Level 3	kr. -36	kr. -1,473	kr. -530	kr. -49	kr. -637	kr. -	kr. -32	kr. -	kr. -
Level 4	kr. -41	kr. -1,631	kr. -609	kr. -54	kr. -702	kr. -	kr. -34	kr. -	kr. -
Level 5	kr. -44	kr. -1,714	kr. -664	kr. -58	kr. -746	kr. -	kr. -35	kr. -	kr. -
Level 6	kr. -46	kr. -1,791	kr. -706	kr. -61	kr. -781	kr. -	kr. -36	kr. -	kr. -
Level 7	kr. -46	kr. -1,804	kr. -692	kr. -61	kr. -786	kr. -	kr. -36	kr. -	kr. -

Table 6.21: The NPV difference in socioeconomic cost for oil boilers and Ground to Water Heat pump for Apartment buildings in DKK 1000

As the tables clearly show, there are no socioeconomic benefits of converting to a ground source heat pump, which applies to all types of building, building period, and insulation levels. This may be due to the high investment cost of this technology, which is too high compared to the savings ground source heat pumps can provide. As mentioned earlier, the benefits of a ground source heat pump are a high COP factor compared to other heat supplies. However, a lower energy consumption does not compensate for the higher socioeconomic cost compared to other energy technologies. The oil boilers achieve a lower socioeconomic than air to water heat pumps, the higher implemented insulation level. This is because the highest socioeconomic cost for oil supplied buildings are fuel prices and emissions, and by reducing the heat demand, these costs are heavily reduced. The oil-supplied households thus have the most significant socioeconomic savings by investing in insulation. However, it should also be mentioned that having a higher level of insulation, which is also seen in the tables, is not always the most socioeconomic for oil-based households. as seen in the tables 6.2, 6.3, 6.4 and 6.5.

With reduced heat consumption, the oil boilers become more beneficial as the fuel purchase is reduced, which is the primary cost factor in the socioeconomic analysis of the oil boilers. The tables also show that the oil boilers receive the most significant socioeconomic savings by insulation, where the savings for heat pumps are not as significant. This can be observed in the green cells where the NPV difference between air and water and oil boilers is lessened when an increase of insulation level is implemented. One effect the household's efficiency has on the heat pump scenario is the sizing of the heat pump, which can result in a smaller size and, therefore, a lower investment. Nevertheless, the reduction of the heat pump, and thereby the socioeconomic cost, do not compensate for the effect of a lower energy consumption for oil boilers.

There is also a pattern with the annual heat demand and which building types and building periods have the lowest socioeconomic. As seen in table 5.3, the building periods with the highest heat demand per m^2 are also periods where a heat pump is a more attractive choice. The highest heat demand in the tables is during the periods between 1850 and 1960, which are also the building periods that most often show that the air to water heat pump has the lowest socioeconomic cost.

6.5 A more in-depth analysis of socioeconomic results for insulation

To get a breakdown of the various socioeconomic costs of a building type and building period, a more in-depth analysis of a scenario of oil boilers and air to water heat pumps pump will be examined to see the development of the costs after being more energy-efficient.

The choice of a building type is not of great importance, as the individual heat supply tendency is the same for the building types and periods. Therefore, the total cost is also considered, since it is not considered necessary to delve into the specific building period.

The table will be based on the single family houses building type, which will present the socioeconomic costs of level 0, 1, and 2 insulation. The remaining insulation levels will be delineated as the development of costs follows the same trend regardless of the level of insulation. The same applies to the choice of building type, as the development of costs does not depend on the type of building being examined.

Level 0	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-
Fuel purchase	1,170	16,774	6,395	3,898	6,451	2,390	1,413	301	92
Electricity consumption	1,058	15,165	5,781	3,524	5,832	2,161	1,278	272	83
Operation and Maintenance	2,414	34,589	14,520	10,629	17,150	7,098	4,396	1,297	540
Investments	5,128	65,454	25,429	18,706	34,138	14,217	8,681	2,646	1,201
Distortion Loss	-72	-1,032	-393	-240	-397	-147	-87	-19	-6
CO_2 costs	107	1,535	585	357	590	219	129	28	8
NO_x and SO_2 costs	23	332	126	77	128	47	28	6	2
Particle emission Cost	1	19	7	4	7	3	2	0	0
Total	9,830	132,835	52,451	36,956	63,899	25,987	15,839	4,533	1,921
Level 1	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-
Fuel purchase	1,170	16,774	6,395	3,898	6,451	2,390	1,413	301	92
Electricity consumption	830	11,898	4,536	2,765	4,576	1,695	1,003	214	65
Operation and Maintenance	2,414	34,589	14,520	10,629	17,150	7,098	4,720	1,297	468
Investments	4,549	58,658	23,180	17,163	31,342	13,159	8,789	2,441	916
Distortion Loss	-68	-979	-373	-228	-377	-140	-83	-18	-5
CO_2 costs	104	1,496	570	348	575	213	126	27	8
NO_x and SO_2 costs	22	313	119	73	120	45	26	6	2
Particle emission Cost	1	19	7	4	7	3	2	0	0
Total	9,023	122,766	48,954	34,652	59,845	24,463	15,996	4,268	1,546
Level 2	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-
Fuel purchase	1,170	16,774	6,395	3,898	6,451	2,390	1,413	301	92
Electricity consumption	748	10,724	4,088	2,492	4,124	1,528	904	193	59
Operation and Maintenance	2,414	34,589	14,520	10,629	17,150	7,098	4,720	1,297	468
Investments	4,572	59,246	23,465	17,218	31,077	12,902	8,672	2,424	898
Distortion Loss	-67	-960	-366	-223	-369	-137	-81	-17	-5
CO_2 costs	103	1,481	565	344	570	211	125	27	8
NO_x and SO_2 costs	21	306	117	71	118	44	26	5	2
Particle emission Cost	1	19	7	4	7	3	2	0	0
Total	8,963	122,177	48,790	34,434	59,128	24,039	15,780	4,230	1,522

	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-
	4,370	62,641	23,881	14,558	24,090	8,926	5,278	1,125	343
	0	0	0	0	0	0	0	0	0
	2,196	31,466	13,209	9,669	15,602	6,457	4,261	1,049	393
	2,833	39,778	16,662	12,187	19,695	8,148	5,374	1,322	497
	-193	-2,762	-1,053	-642	-1,062	-394	-233	-50	-15
	444	6,359	2,424	1,478	2,445	906	536	114	35
	59	845	322	196	325	120	71	15	5
	5	65	25	15	25	9	6	1	0
	9,713	138,393	55,471	37,462	61,121	24,173	15,293	3,577	1,258
	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-
	3,681	52,759	20,114	12,261	20,290	7,518	4,445	948	289
	0	0	0	0	0	0	0	0	0
	2,196	31,466	13,209	9,669	15,602	6,457	4,261	1,049	393
	2,801	39,682	16,649	12,187	19,665	8,139	5,371	1,322	496
	-163	-2,337	-891	-543	-899	-333	-197	-42	-13
	368	5,280	2,013	1,227	2,031	752	445	95	29
	50	715	273	166	275	102	60	13	4
	4	55	21	13	21	8	5	1	0
	8,938	127,622	51,388	34,981	56,985	22,643	14,390	3,385	1,198
	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-
	3,433	49,208	18,760	11,436	18,924	7,012	4,146	884	269
	0	0	0	0	0	0	0	0	0
	2,196	31,466	13,209	9,669	15,602	6,457	4,261	1,049	393
	2,849	40,995	17,121	12,517	19,912	8,157	5,372	1,322	496
	-152	-2,184	-833	-508	-840	-311	-184	-39	-12
	341	4,893	1,865	1,137	1,882	697	412	88	27
	47	669	255	155	257	95	56	12	4
	4	52	20	12	20	7	4	1	0
	8,718	125,098	50,398	34,419	55,757	22,115	14,068	3,316	1,177

Table 6.22: A more in-depth overview of the NPV socioeconomic costs for single family house supplied with a heat pump and an oil boiler, level 1, 2, and 3 insulation and building periods in DKK 1000

The table below shows the difference in the socioeconomic factors of air to water heat pump and oil boiler. If the number in a cell is negative, it is the saving that will happen by converting from an oil boiler to an air to water heat pump. If looked at level 0 and building period 1890, it will mean saving DKK 3.2 million by switching from oil boiler to water to air heat pump, but on the other hand, investments in water to air are DKK 2.4 million more expensive than oil boilers.

Level 0	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-
Fuel purchase	-3,200	-45,868	-17,486	-10,660	-17,640	-6,536	-3,865	-824	-251
Electricity consumption	1,058	15,165	5,781	3,524	5,832	2,161	1,278	272	83
Operation and Maintenance	218	3,123	1,311	960	1,548	641	135	248	147
Investments	2,296	25,675	8,767	6,518	14,443	6,069	3,306	1,324	703
Distortion Loss	121	1,731	660	402	666	247	146	31	9
CO_2 costs	-337	-4,823	-1,839	-1,121	-1,855	-687	-406	-87	-26
NO_x and SO_2 costs	-36	-513	-196	-119	-197	-73	-43	-9	-3
Particle emission Cost	-3	-47	-18	-11	-18	-7	-4	-1	0
Total	117	-5,558	-3,020	-506	2,779	1,815	546	955	663
Level 1	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-
Fuel purchase	-2,511	-35,986	-13,719	-8,363	-13,839	-5,128	-3,032	-646	-197
Electricity consumption	830	11,898	4,536	2,765	4,576	1,695	1,003	214	65
Operation and Maintenance	218	3,123	1,311	960	1,548	641	459	248	75
Investments	1,748	18,976	6,531	4,976	11,677	5,020	3,418	1,119	420
Distortion Loss	95	1,358	518	316	522	193	114	24	7
CO_2 costs	-264	-3,785	-1,443	-880	-1,455	-539	-319	-68	-21
NO_x and SO_2 costs	-28	-403	-154	-94	-155	-57	-34	-7	-2
Particle emission Cost	-3	-37	-14	-8	-14	-5	-3	-1	0
Total	85	-4,856	-2,434	-329	2,860	1,820	1,606	883	348
Level 2	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-
Fuel purchase	-2,263	-32,434	-12,365	-7,538	-12,473	-4,621	-2,733	-583	-177
Electricity consumption	748	10,724	4,088	2,492	4,124	1,528	904	193	59
Operation and Maintenance	218	3,123	1,311	960	1,548	641	459	248	75
Investments	1,722	18,251	6,343	4,701	11,165	4,745	3,300	1,102	403
Distortion Loss	85	1,224	467	284	471	174	103	22	7
CO_2 costs	-238	-3,411	-1,300	-793	-1,312	-486	-287	-61	-19
NO_x and SO_2 costs	-25	-363	-138	-84	-140	-52	-31	-7	-2
Particle emission Cost	-2	-33	-13	-8	-13	-5	-3	-1	0
Total	245	-2,920	-1,608	14	3,371	1,924	1,712	913	345

Table 6.23: The NPV cost difference between a heat pump and an oil boiler, level 1, 2, and 3 insulation and building periods in DKK 1000

The tables clearly show the patterns of insulating the building. To illustrate the socioeconomic patterns, the following text is based on single family houses built before 1890 and the difference between insulation level 1 and level 2. The choice of insulation level does not matter, as the patterns are the same for each level.

By insulating, the most significant changes in the social economy happen at these factors; Fuel purchase, Electricity consumption, and Investments.

Lowering the heat demand will result in less oil, and electricity needed to fulfill the heat demand. The difference in fuel purchase becomes smaller for each insulation level since fuel purchase does not change in water to air, as households supplied with oil, in the air to water scenario, do not implement insulation and therefore do not change the heat consumption over the calculation period. Electricity consumption, on the other hand, falls by DKK 82,000, but in contrast to the reduction of DKK 248,000 in fuel purchases, it can be seen that the oil-supplied households have the most socioeconomic benefits of insulation of the building.

The investments show that the socioeconomic costs reduce more with the air to water heat pump than with the oil boiler by implementing insulation but, the change of DKK 27,000 is not enough to compete with the reduction of fuel purchase.

The tables show that socioeconomic costs have a more significant reduction in households with oil boilers than heat pumps due to the high socioeconomic costs of oil combustion.

6.6 Sensitivity analysis

To ensure the reliability of the socioeconomic analysis, sensitivity analyzes are carried out, emphasizing the factors that are considered to be of notable significance or associated with uncertainties. It is considered appropriate to limit the sensitivity analyzes to selected scenarios based on the size of the selected group, the most socioeconomic insulation level, and an insulation level that meets the building regulations for BR18. Therefore, the single family and farmhouses are assessed with energy efficiency measures for levels 4 and 5. Level 4 is chosen as it is seen in the analyzes that it is most often the level with the most socioeconomic benefits and level five is chosen as it meets building regulations for BR 18. (Kim B. en, Jesper Kragh, Søren Aggerholm 2017)

Further analyzes are delimited from terrace houses and apartment buildings. The report provides an overview of the most significant possible socioeconomic benefits, where the number of terrace houses and apartments is not considered to have the most considerable significance on a broader perspective municipal level. Furthermore, it is expected that the tendency is the same regardless of building type.

It is considered to limit sensitivity analyzes to the cost-heavy factors. Although investment for energy improvements is a cost-heavy factor, this will not be investigated as the price of energy improvements does not vary for the choice of heat supply.

Fuel price

Since fuel prices play an important role in households with oil supplies, it is appropriate to assess the effects of increasing fuel prices. It is also considered appropriate to investigate the effect of a decrease in fuel prices since the projection of the fuel price has a great deal of uncertainty. The effect of prices is assessed after a decrease and increase of 20 % and is carried out for all the scenarios.

Investments

Investment costs play a significant factor in converting to an air to water and a ground source heat pump. It is therefore considered appropriate to assess the significance of a decline and increase in socioeconomic analyzes. The investment cost is chosen from the Danish Energy Agency's technology catalog, where the Danish Energy Agency has an estimate of a higher and lower investment of water to air.

Operation and maintenance

From table 6.22, it can be seen that O&M is also a substantial cost factor. Although the cost of O&M is similar for the heat pump technologies and does not differ much for the oil boiler, it will be examined what significance a change of this will have on the final result.

The O&M cost is selected from the Danish Energy Agency's technology catalog, where the Danish Energy Agency has an estimate of higher and lower investment in the various technologies.

COP

One of the principles of choosing a ground source heat pump is the higher COP factor, and since it is not socioeconomic to choose ground source heat in some cases, it is considered necessary to investigate what an increase and decrease of the effect on the analyses are. This is done to see if it has a significant effect on geothermal heat.

The COP factors are chosen from the Danish Energy Agency's technology catalog, where the Danish Energy Agency has an estimate of higher and lower investment in the various technologies.

CO_2

One of the reasons for converting to heat pumps is the reduction of emissions, including CO_2 emissions. Also, there is considerable uncertainty about the quota price, where it is not assumed that the quota price will be lower than the current estimates. A high estimate of 1,000 DKK / ton is used (Energistyrelsen 2019*c*).

The cost used in the sensitivity analyzes shown in the table below.

	Capacity	Investment (DKK 1000)			O&M (DKK 1000)			COP		
Heat supply		L	N	U	L	N	U	L	N	U
Air to Water	5 kW	42.1	52.6	63.1	1.9	2.1	2.5	3.5	3.7	4.1
	10 kW	59.7	70.1	90	1.9	2.1	2.5	3.5	3.7	4.1
	15 kW	67.3	84.2	101	1.9	2.1	2.5	3.5	3.7	4.1
	>15 kW	5.6/kW	7/kW	8.4/kW	1.9	2.1	2.5	3.5	3.7	4.1
Ground source	5 kW	71.2	87.4	93.1	1.9	2.1	2.5	3.9	4.1	4.4
	10 kW	97	112	127	1.9	2.1	2.5	3.9	4.1	4.4
	15 kW	108.3	132.9	141.6	1.9	2.1	2.5	3.9	4.1	4.4
	>15 kW	9/kW	11/kW	11.7/kW	1.9	2.1	2.5	3.9	4.1	4.4
Oil boiler	15 kW	37.3	44.1	59.7	1.5	1.8	2.3	0.83	0.85	0.88
	>15 kW	2.5/kW	2.9/kW	4/kW	1.5	1.8	2.3	0.83	0.85	0.88

*Table 6.24: Overview of data input in the sensitivity analyzes. (Energistyrelsen 2018*b*)*

6.6.1 Sensitivity analysis results

In the sections below, the results of sensitivity analyzes are presented by the factors mentioned above. Two tables will be presented, showing the heat supply with the lowest socioeconomic value for single family houses and farmhouses. The reason for presenting only one value, and not all of them, is that it can be incomprehensible to compare so many building periods and heating supplies. The table is color-sorted, where a white background means that oil supply has the most significant socioeconomic advantage, while a blue background means a water to air has the most significant socioeconomic advantage. There is not a color for the ground source heat pump since it has too high a socioeconomic in all the sensitivity analyzes.

Farmhouse	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-
Level 4 Lower Invest	kr. 9,282	kr. 114,556	kr. 19,273	kr. 8,429	kr. 9,114	kr. 4,714	kr. 7,010	kr. 2,917	kr. 1,361
Level 4 Normal Invest	kr. 9,743	kr. 122,363	kr. 21,016	kr. 9,221	kr. 9,606	kr. 4,972	kr. 7,407	kr. 3,071	kr. 1,444
Level 4 Upper Invest	kr. 9,743	kr. 122,363	kr. 21,016	kr. 9,221	kr. 9,606	kr. 4,972	kr. 7,407	kr. 3,071	kr. 1,444
Level 5 Lower Invest	kr. 9,856	kr. 118,348	kr. 19,825	kr. 8,623	kr. 9,528	kr. 4,950	kr. 7,654	kr. 3,128	kr. 1,432
Level 5 Normal Invest	kr. 10,346	kr. 125,158	kr. 21,316	kr. 9,331	kr. 9,885	kr. 5,107	kr. 7,752	kr. 3,128	kr. 1,432
Level 5 Upper Invest	kr. 10,346	kr. 125,158	kr. 21,316	kr. 9,331	kr. 9,885	kr. 5,107	kr. 7,752	kr. 3,128	kr. 1,432
Level 4 Lower O&M	kr. 9,743	kr. 121,375	kr. 20,463	kr. 8,960	kr. 9,606	kr. 4,972	kr. 7,407	kr. 3,071	kr. 1,444
Level 4 Normal O&M	kr. 9,743	kr. 122,363	kr. 21,016	kr. 9,221	kr. 9,606	kr. 4,972	kr. 7,407	kr. 3,071	kr. 1,444
Level 4 Upper O&M	kr. 9,743	kr. 122,363	kr. 21,016	kr. 9,221	kr. 9,606	kr. 4,972	kr. 7,407	kr. 3,071	kr. 1,444
Level 5 Lower O&M	kr. 10,346	kr. 125,147	kr. 21,015	kr. 9,154	kr. 9,885	kr. 5,107	kr. 7,752	kr. 3,128	kr. 1,432
Level 5 Normal O&M	kr. 10,346	kr. 125,158	kr. 21,316	kr. 9,331	kr. 9,885	kr. 5,107	kr. 7,752	kr. 3,128	kr. 1,432
Level 5 Upper O&M	kr. 10,346	kr. 125,158	kr. 21,316	kr. 9,331	kr. 9,885	kr. 5,107	kr. 7,752	kr. 3,128	kr. 1,432
Level 4 Lower Fuel price	kr. 9,018	kr. 114,014	kr. 19,596	kr. 8,635	kr. 8,974	kr. 4,652	kr. 6,931	kr. 2,848	kr. 1,362
Level 4 Normal Fuel price	kr. 9,743	kr. 122,363	kr. 21,016	kr. 9,221	kr. 9,606	kr. 4,972	kr. 7,407	kr. 3,071	kr. 1,444
Level 4 Upper Fuel price	kr. 10,195	kr. 124,808	kr. 21,061	kr. 9,232	kr. 10,052	kr. 5,289	kr. 7,884	kr. 3,295	kr. 1,526
Level 5 Lower Fuel price	kr. 9,472	kr. 117,396	kr. 19,995	kr. 8,786	kr. 9,297	kr. 4,809	kr. 7,309	kr. 2,920	kr. 1,356
Level 5 Normal Fuel price	kr. 10,346	kr. 125,158	kr. 21,316	kr. 9,331	kr. 9,885	kr. 5,107	kr. 7,752	kr. 3,128	kr. 1,432
Level 5 Upper Fuel price	kr. 10,688	kr. 128,580	kr. 21,613	kr. 9,427	kr. 10,340	kr. 5,390	kr. 8,195	kr. 3,336	kr. 1,508
Level 4 Lower COP	kr. 9,743	kr. 122,363	kr. 21,016	kr. 9,221	kr. 9,606	kr. 4,972	kr. 7,407	kr. 3,071	kr. 1,444
Level 4 Normal COP	kr. 9,743	kr. 122,363	kr. 21,016	kr. 9,221	kr. 9,606	kr. 4,972	kr. 7,407	kr. 3,071	kr. 1,444
Level 4 Upper COP	kr. 9,743	kr. 122,363	kr. 20,915	kr. 9,172	kr. 9,606	kr. 4,972	kr. 7,407	kr. 3,071	kr. 1,444
Level 5 Lower COP	kr. 10,346	kr. 125,158	kr. 21,316	kr. 9,331	kr. 9,885	kr. 5,107	kr. 7,752	kr. 3,128	kr. 1,432
Level 5 Normal COP	kr. 10,346	kr. 125,158	kr. 21,316	kr. 9,331	kr. 9,885	kr. 5,107	kr. 7,752	kr. 3,128	kr. 1,432
Level 5 Upper COP	kr. 10,346	kr. 125,158	kr. 21,316	kr. 9,331	kr. 9,885	kr. 5,107	kr. 7,752	kr. 3,128	kr. 1,432
Level 4 Normal CO2	kr. 9,743	kr. 122,363	kr. 21,016	kr. 9,221	kr. 9,606	kr. 4,972	kr. 7,407	kr. 3,071	kr. 1,444
Level 4 Upper CO2	kr. 10,620	kr. 129,700	kr. 21,893	kr. 9,576	kr. 10,422	kr. 5,477	kr. 8,230	kr. 3,457	kr. 1,585
Level 5 Normal CO2	kr. 10,346	kr. 125,158	kr. 21,316	kr. 9,331	kr. 9,885	kr. 5,107	kr. 7,752	kr. 3,128	kr. 1,432
Level 5 Upper CO2	kr. 11,063	kr. 132,901	kr. 22,348	kr. 9,730	kr. 10,667	kr. 5,556	kr. 8,479	kr. 3,469	kr. 1,557

Table 6.25: The NPV socioeconomic cost of the sensitivity analysis for Farmhouses in DKK 1000

Single-Family house	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-
Level 4 Lower Invest	kr. 8,062	kr. 110,925	kr. 44,383	kr. 31,340	kr. 53,873	kr. 21,767	kr. 13,768	kr. 3,243	kr. 1,159
Level 4 Normal Invest	kr. 8,489	kr. 121,143	kr. 48,600	kr. 33,674	kr. 54,999	kr. 21,925	kr. 13,768	kr. 3,243	kr. 1,159
Level 4 Upper Invest	kr. 8,489	kr. 121,193	kr. 48,805	kr. 33,674	kr. 54,999	kr. 21,925	kr. 13,768	kr. 3,243	kr. 1,159
Level 5 Lower Invest	kr. 8,353	kr. 113,746	kr. 45,298	kr. 32,219	kr. 55,999	kr. 22,427	kr. 14,450	kr. 3,276	kr. 1,153
Level 5 Normal Invest	kr. 8,759	kr. 122,779	kr. 49,239	kr. 34,299	kr. 57,079	kr. 22,791	kr. 14,450	kr. 3,276	kr. 1,153
Level 5 Upper Invest	kr. 8,759	kr. 122,779	kr. 49,239	kr. 34,299	kr. 57,079	kr. 22,791	kr. 14,450	kr. 3,276	kr. 1,153
Level 4 Lower O&M	kr. 8,489	kr. 117,679	kr. 47,175	kr. 33,374	kr. 54,999	kr. 21,925	kr. 13,768	kr. 3,243	kr. 1,159
Level 4 Normal O&M	kr. 8,489	kr. 121,143	kr. 48,600	kr. 33,674	kr. 54,999	kr. 21,925	kr. 13,768	kr. 3,243	kr. 1,159
Level 4 Upper O&M	kr. 8,489	kr. 121,193	kr. 48,805	kr. 33,674	kr. 54,999	kr. 21,925	kr. 13,768	kr. 3,243	kr. 1,159
Level 5 Lower O&M	kr. 8,759	kr. 120,439	kr. 48,092	kr. 34,254	kr. 57,079	kr. 22,791	kr. 14,450	kr. 3,276	kr. 1,153
Level 5 Normal O&M	kr. 8,759	kr. 122,779	kr. 49,239	kr. 34,299	kr. 57,079	kr. 22,791	kr. 14,450	kr. 3,276	kr. 1,153
Level 5 Upper O&M	kr. 8,759	kr. 122,779	kr. 49,239	kr. 34,299	kr. 57,079	kr. 22,791	kr. 14,450	kr. 3,276	kr. 1,153
Level 4 Lower Fuel price	kr. 7,900	kr. 112,749	kr. 45,586	kr. 31,712	kr. 51,751	kr. 20,722	kr. 13,056	kr. 3,092	kr. 1,113
Level 4 Normal Fuel price	kr. 8,489	kr. 121,143	kr. 48,600	kr. 33,674	kr. 54,999	kr. 21,925	kr. 13,768	kr. 3,243	kr. 1,159
Level 4 Upper Fuel price	kr. 8,899	kr. 121,143	kr. 48,600	kr. 34,417	kr. 58,246	kr. 23,128	kr. 14,479	kr. 3,395	kr. 1,205
Level 5 Lower Fuel price	kr. 8,211	kr. 114,928	kr. 46,247	kr. 32,474	kr. 54,060	kr. 21,673	kr. 13,788	kr. 3,135	kr. 1,110
Level 5 Normal Fuel price	kr. 8,759	kr. 122,779	kr. 49,239	kr. 34,299	kr. 57,079	kr. 22,791	kr. 14,450	kr. 3,276	kr. 1,153
Level 5 Upper Fuel price	kr. 9,176	kr. 123,898	kr. 49,517	kr. 35,297	kr. 60,099	kr. 23,910	kr. 15,111	kr. 3,417	kr. 1,196
Level 4 Lower COP	kr. 8,489	kr. 121,193	kr. 48,805	kr. 33,674	kr. 54,999	kr. 21,925	kr. 13,768	kr. 3,243	kr. 1,159
Level 4 Normal COP	kr. 8,489	kr. 121,143	kr. 48,600	kr. 33,674	kr. 54,999	kr. 21,925	kr. 13,768	kr. 3,243	kr. 1,159
Level 4 Upper COP	kr. 8,489	kr. 120,209	kr. 48,271	kr. 33,674	kr. 54,999	kr. 21,925	kr. 13,768	kr. 3,243	kr. 1,159
Level 5 Lower COP	kr. 8,759	kr. 122,779	kr. 49,239	kr. 34,299	kr. 57,079	kr. 22,791	kr. 14,450	kr. 3,276	kr. 1,153
Level 5 Normal COP	kr. 8,759	kr. 122,779	kr. 49,239	kr. 34,299	kr. 57,079	kr. 22,791	kr. 14,450	kr. 3,276	kr. 1,153
Level 5 Upper COP	kr. 8,759	kr. 122,779	kr. 49,226	kr. 34,299	kr. 57,079	kr. 22,791	kr. 14,450	kr. 3,276	kr. 1,153
Level 4 Normal CO2	kr. 8,489	kr. 121,143	kr. 48,600	kr. 33,674	kr. 54,999	kr. 21,925	kr. 13,768	kr. 3,243	kr. 1,159
Level 4 Upper CO2	kr. 9,245	kr. 126,091	kr. 50,486	kr. 35,567	kr. 60,602	kr. 24,001	kr. 14,995	kr. 3,505	kr. 1,239
Level 5 Normal CO2	kr. 8,759	kr. 122,779	kr. 49,239	kr. 34,299	kr. 57,079	kr. 22,791	kr. 14,450	kr. 3,276	kr. 1,153
Level 5 Upper CO2	kr. 9,481	kr. 128,269	kr. 51,183	kr. 36,313	kr. 62,028	kr. 24,625	kr. 15,534	kr. 3,508	kr. 1,223

Table 6.26: The NPV socioeconomic cost of the sensitivity analysis for Single family houses in DKK 1000

6.6.2 Summary of the sensitivity analysis

As table 6.25 and 6.26 show, a change in investment prices will make water to air the heat supply to the scenario with the lowest socioeconomic cost. As mentioned before, the investments in converting heat pumps are the highest socioeconomic cost factor, which means that a change in the investment costs can have a significant impact on the scenario with the lowest socioeconomic cost.

By increasing fuel prices for oil, the socioeconomic costs of oil-supplied households from the construction periods from before 1890 to 1959 will be higher than those of converting to a water to air heat pump. This is because the fuel prices of oil-supplied households are the highest socioeconomic cost factor, and a change of 20% has, therefor significant impact on the social economy.

The difference in the socioeconomic results is already so small, see table 6.14 and 6.16, which means that reducing the socioeconomic costs of the heat pumps or increasing the socioeconomic cost for oil boilers, can have a significant impact on which scenario has the lowest socioeconomic cost.

6.7 Sub Conclusion

The section thus answers the working question: "What will the socioeconomic cost be at the different insulation levels and heat supply scenarios?"

It can be concluded that most buildings receive a lower socioeconomic cost by insulation. This applies to both oil boilers, Air to water heat pumps, and Ground source and regardless of the construction period being investigated. This is because the cost of insulation is lower than the socioeconomic reductions that happen by implementing insulation.

The insulation level choice is most often seen by implementing a level 4 measure, but this cannot be generalized since the insulation level depends on the type of building and period. This is because the cost of energy renovation depends on the type of building being observed, as well as what periods.

Also, it can be concluded that not all building types and building periods achieve a lower socioeconomic cost of converting from an oil boiler to a heat pump. Therefore, it is not possible to generalize which heating technology is best for a type of building, but that the best socioeconomic choice depends on the building period.

The tables 6.25 and 6.25 clearly shows the robustness of oil boilers in buildings from 1979 to 2007 both for single family homes and farmhouses. The socioeconomic results of these are estimated to be robust. By contrast, there is not the same robustness of buildings from 1890 to 1978, where it can be observed that the heat supply with the most socioeconomic benefits is changing. The reason for this is because the socioeconomic benefits for oil boilers and heat pumps are already so dense that there is not much needed to push the choice of one heat supply for the other. For these types of buildings, the investment price, COP, and the fuel price must be carefully considered, with O&M being disregarded as differences in technologies are so small.

User economy analysis 7

This chapter will look at the user economic differences between heat pumps and the currently installed oil boilers, which are installed in the buildings. The differences will be illustrated in user economic cost for both insulation improvements and the converting for farmhouses and single family houses where the work question "*What will the user economic cost be for the citizens and can the energy efficiency measures benefit cost wise?*" will be answered.

The user economic analysis is made in extension of the socioeconomic analysis. Since the user economic analysis has been made in extension of the socioeconomic analysis, a large part of data input is the same. Based on results from the heat demand analysis, the most substantial part of the houses were farmhouses and single family houses where most of these were built between 1890 and 1929. The user economic analysis has, therefore, delimited from all the other building types and periods which have been analyzed in the socioeconomic analysis. The analysis will only show the user economy values for citizens living in these buildings where the user economic analysis will analyze the economy values between oil boilers, air to water heat pumps and ground to water heat pumps. The economy of heating with the three different heating units can be expected to be similar for other municipalities as long as it is the same building type and from the same period.

7.1 Structuring of the user economic analysis

Specific key data has been of use for the calculations of this economic analysis. The maximum house size was only of use at the beginning of the analysis to see the difference between building types and insulation level and which size the supply unit had to have. The two different heat pump types are being used with four sizes 5 kW, 10 kW, 15 kW, and 20 kW, of which 15 kW and 20 kW are the only sizes that the oil boilers have worked with. 20 kW has been chosen as the size that represents houses that have a demand more significant than the 15 kW units can supply.

The house sizes can be found by dividing the heating capacity with the needed heat effect per m^2, respectively, to the insulation level. There is a difference in how big a particular building type can be and the use of specific unit sizes. The house size that the unit can supply depends on house type and which level of insulation the house has because of dimensions which are found in the potential heat savings. With a level 5 insulation, the house can be a bit bigger and still use the same unit size. Even though a 5 kW air to water heat pump can supply a farmhouse at the size of 143 m^2, it is not recommended since this is the absolute maximum, and the unit may not be able to supply the needed demand during peak load hours.

Farmhouse - Scenario 4	Maximum house size in m2	Farmhouse - Scenario 5	Maximum house size in m2
5 kW, Air to water	143	5 kW, Air to water	152
10 kW, Air to water	286	10 kW, Air to water	303
15 kW, Air to water	429	15 kW, Air to water	455
20 kW, Air to water	571	20 kW, Air to water	606
5 kW, Ground to water	143	5 kW, Ground to water	152
10 kW, Ground to water	286	10 kW, Ground to water	303
15 kW, Ground to water	429	15 kW, Ground to water	455
20 kW, Ground to water	571	20 kW, Ground to water	606
15 kW, Oilboiler	429	15 kW, Oilboiler	455
Single family houses - Scenario 4	Maximum house size in m2	Single family houses - Scenario 5	Maximum house size in m2
5 kW, Air to water	135	5 kW, Air to water	143
10 kW, Air to water	270	10 kW, Air to water	286
15 kW, Air to water	405	15 kW, Air to water	429
20 kW, Air to water	541	20 kW, Air to water	571
5 kW, Ground to water	135	5 kW, Ground to water	143
10 kW, Ground to water	270	10 kW, Ground to water	286
15 kW, Ground to water	405	15 kW, Ground to water	429
20 kW, Ground to water	541	20 kW, Ground to water	571
15 kW, Oilboiler	405	15 kW, Oilboiler	429

Table 7.1: Unit size and the maximum house size they can supply

In order to compare the different houses and insulation levels, the maximum house sizes have not been used since this will affect the fuel and electricity usage and cost of heating the house. A set of standard sizes has been chosen instead which can be seen in table 7.2

Farmhouse - Level 4 insulation	Maximum house size in m2	Farmhouse - level 5 insulation	Maximum house size in m2
5 kW unit	130	5 kW unit	130
10 kW unit	260	10 kW unit	260
15 kW unit	390	15 kW unit	390
20 kW unit	520	20 kW unit	520
Single family houses - Level 4 insulation	Maximum house size in m2	Single family houses - Level 5 insulation	Maximum house size in m2
5 kW unit	130	5 kW unit	130
10 kW unit	260	10 kW unit	260
15 kW unit	390	15 kW unit	390
20 kW unit	520	20 kW unit	520

Table 7.2: The house sizes which the analysis has been working with

The sizes shown in table 7.2 are not built on data that suggest that the sizes are standard for the specific unit sizes but have merely been chosen based on the basis that all scenarios can supply the heat demand with the specific unit size. All 5 kW unit heat pumps will supply houses with a size of 130 m^2, 10 kW will supply houses with a size of 260 m^2, 15 kW houses with a size of 390 m^2, and 20 kW will supply houses with a size of 520 m^2. Oil boilers are made with 15 kW unit for the first three sizes and a 20 kW unit for houses with a size of 520 m^2.

The heat consumption has used the same method as the heat demand analysis where the heat consumption is based on house size and heat demand per m^2, which is essential for the calculation of fuel and electricity usage.

The investment price depends on heating type and size, the price of a heating unit is sensitive, and an analysis of this has been of use. Changing from an oil boiler to a heat pump gives a subsidy of DKK 6,326.25 and can be subtracted the 1st year (Aalborg Forsyning 2020).

Calculating the heat demand for level 4 and 5 insulation is the same as presented in 5 and the cost for insulation have used the same method as 6.

The setup of the analysis has a resemblance to the socioeconomic analysis with a few changes.

Electricity taxes are a total of all the different extra payments besides the electricity, of which the use of heat pumps can reduce the taxes since more than 50% of the electricity is being used as "fuel" for heating the household. (Norlys 2020)

Operation and maintenance is a yearly cost that by legislation are demanded A.1, and the cost depends on the unit type. (Energistyrelsen 2018*b*)

Each heating type works with different efficiencies, which affect fuel and electricity usage and, therefore, the price of this. Data like O&M, COP and, investment prices have been found in a technology catalog from the Danish Energy Agency (Energistyrelsen 2018*b*).

7.1.1 User economy results

Table 7.3 shows the total cost with net present value for the different units over 20 years and shows 12 different possibilities depending on house size and insulation level. As can be seen, farmhouses are cheaper because of the lower heat demand per m^2, of which both scenarios with level 5 insulation are more expensive than the scenarios with level 4 insulation. The fifth insulation level is more expensive to implement for the households, and therefore affects the total cost.

The difference between air to water heat pumps is beside their way of functioning and the efficiency of the technical lifetime. Where oil boilers and ground to water heat pumps have a technical lifetime of 20 years, air to water heat pumps has a technical lifetime of 18 years, which means that the scenarios with air to water heat pump need second investment during the calculation period of 20 years. Thus, scrap value has been used, where the linear scrap value has been used for this project. A linear scrap value means that the unit loses value at a linear percentage each year, and the years that it does not get used can be removed from the total cost.

Even though the heat pumps have a lifetime of 18 or 20 years, they should be changed after 15 years due to the development of heat pumps and the efficiencies in the production of heat A.1, but this is not accounted for in the calculations.

Farmhouses, Level 4 insulation	130	260	390	520
Air to water	kr. 162.056	kr. 253.981	kr. 341.103	kr. 484.426
Ground to water	kr. 189.867	kr. 281.979	kr. 369.888	kr. 536.809
Oil boiler	kr. 334.402	kr. 591.166	kr. 847.929	kr. 1.139.255
Farmhouses, Level 5 insulation	130	260	390	520
Air to water	kr. 170.724	kr. 271.316	kr. 367.105	kr. 519.096
Ground to water	kr. 198.742	kr. 299.729	kr. 396.513	kr. 572.308
Oil boiler	kr. 335.566	kr. 593.493	kr. 851.419	kr. 1.143.908
Single family houses, Level 4 insulation	130	260	390	520
Air to water	kr. 174.442	kr. 278.753	kr. 378.260	kr. 533.969
Ground to water	kr. 201.108	kr. 304.459	kr. 403.608	kr. 581.769
Oil boiler	kr. 388.249	kr. 698.859	kr. 1.009.469	kr. 1.354.642
Single family houses, Level 5 insulation	130	260	390	520
Air to water	kr. 181.911	kr. 293.691	kr. 400.667	kr. 563.844
Ground to water	kr. 208.836	kr. 319.917	kr. 426.794	kr. 612.683
Oil boiler	kr. 386.317	kr. 694.996	kr. 1.003.674	kr. 1.346.914

Table 7.3: Total NPV cost for user economy in DKK

Air to water heat pumps is the cheapest solution in all the scenarios, where the oil boiler is much more expensive. The high cost of oil boilers is the operation cost, which makes this particular heating unit expensive. The difference in total cost between air to water heat pumps and ground to water heat pumps is small though the investment price for ground to water heat pumps is higher than for the air to water. This is because of the higher COP value of the ground to water heat pump, which means it uses less electricity to produce the same amount of heat as the air to water heat pump. Oil boiled single family houses can benefit from insulating to a greater level of where farmhouses will have no benefit from implementing level 5 insulation. Single family houses can benefit from it because of the savings that are made on fuel consumption where farmhouses have a greater expense to reach the same insulation level.

A user economic analysis with public investment cost has been made in relation to the socioeconomic analysis. By public investment means that the insulation cost and investment cost of the unit have been spread out over 20 years with a yearly cost and accounted for in a total with net present value. The sum of the yearly cost is equivalent to the total cost of investment and insulation cost over the calculation period.

Farmhouses, Level 4 insulation	130	260	390	520
Air to water	kr. 136.486	kr. 217.779	kr. 295.763	kr. 412.468
Ground to water	kr. 155.887	kr. 236.207	kr. 313.557	kr. 446.745
Oil boiler	kr. 315.724	kr. 584.842	kr. 838.443	kr. 1.126.606
Farmhouses, Level 5 insulation	130	260	390	520
Air to water	kr. 141.945	kr. 228.698	kr. 312.141	kr. 434.306
Ground to water	kr. 161.553	kr. 247.541	kr. 330.558	kr. 469.412
Oil boiler	kr. 313.680	kr. 580.752	kr. 832.309	kr. 1.118.428
Single family houses, level 4 insulation	130	260	390	520
Air to water	kr. 148.918	kr. 242.643	kr. 333.058	kr. 462.195
Ground to water	kr. 167.172	kr. 258.779	kr. 347.415	kr. 491.888
Oil boiler	kr. 369.617	kr. 677.110	kr. 984.604	kr. 1.316.523
Single family houses, level 5 insulation	130	260	390	520
Air to water	kr. 153.362	kr. 251.531	kr. 346.390	kr. 479.971
Ground to water	kr. 171.876	kr. 268.187	kr. 361.527	kr. 510.704
Oil boiler	kr. 364.660	kr. 667.197	kr. 969.735	kr. 1.296.697

Table 7.4: Total NPV cost in DKK for user economy with public investment over a period of 20 years

The cheapest solution is still the air to water heat pump, but the cost difference between air to water and ground to water is smaller than it was in the standard user economic analysis. The oil boiler is still much more expensive where the difference variate depending on house type and unit size. By spreading out the payment over 20 years affects the cost because of the net present value. Oil boiled houses can benefit from implementing greater levels of insulation because the fuel consumption will decrease and it can further be seen that 7.4 both farmhouses and single family houses will benefit from insulating to level 5 compared to level 4 insulation.

Four different user economics have been made due to some of the key numbers' sensitivity to price and how the prices will develop in the future. These uncertainties are regarding investment prices, operation & maintenance, COP, and electricity prices. For this sensitivity analysis, the Danish Energy Agency has been of use with their data on upper and lower sensitivityEnergistyrelsen (2018*b*).

7.1.2 Sensitivity

The next two scenarios are made with uncertainties with an upper sensitivity and lower sensitivity of the investment, fuel price, COP, and O&M. The uncertainties are only made on the heat pumps since this is the unit type that the project focuses on and can help show the robustness of the user economic for the use of heat pumps.

The investment, O&M and, COP uncertainties prices have been taken from the Danish Energy Agency (Energistyrelsen 2018*b*), of which the electricity price has been assumed a 20% decrease or increase. The two tables 7.5 and 7.6, are presenting the total cost difference with a net present value between either air to water and oil boilers or ground to water and oil boilers. The two tables illustrate the sensitivity results from a farmhouse and single family houses with level 4 and 5 insulation. Each table is made so that the values illustrate the total economic difference compared to an oil boiler.

	Air to Water vs Oil boiler				Ground to Water vs Oil boiler			
Farmhouse	**130**	**260**	**390**	**520**	**130**	**260**	**390**	**520**
Level 4 Lower Invest	kr. 135.322	kr. 351.491	kr. 529.880	kr. 692.911	kr. 112.576	kr. 327.119	kr. 507.641	kr. 651.244
Level 4 Normal Invest	kr. 120.913	kr. 337.184	kr. 506.827	kr. 654.829	kr. 93.102	kr. 309.187	kr. 478.041	kr. 602.446
Level 4 Upper Invest	kr. 106.505	kr. 310.615	kr. 483.771	kr. 616.748	kr. 86.238	kr. 291.254	kr. 467.606	kr. 585.139
Level 5 Lower Invest	kr. 179.251	kr. 336.483	kr. 507.368	kr. 662.895	kr. 156.297	kr. 311.696	kr. 484.507	kr. 620.398
Level 5 Normal Invest	kr. 164.842	kr. 322.176	kr. 484.314	kr. 624.813	kr. 136.824	kr. 293.764	kr. 454.907	kr. 571.600
Level 5 Upper Invest	kr. 150.433	kr. 295.607	kr. 461.259	kr. 586.731	kr. 129.959	kr. 275.831	kr. 444.472	kr. 554.293
Level 4 Lower O&M	kr. 123.144	kr. 339.415	kr. 509.057	kr. 657.060	kr. 95.333	kr. 311.417	kr. 480.272	kr. 604.677
Level 4 Normal O&M	kr. 120.913	kr. 337.184	kr. 506.827	kr. 654.829	kr. 93.102	kr. 309.187	kr. 478.041	kr. 602.446
Level 4 Upper O&M	kr. 115.844	kr. 332.115	kr. 501.758	kr. 649.760	kr. 88.033	kr. 304.117	kr. 472.972	kr. 597.377
Level 5 Lower O&M	kr. 167.072	kr. 324.407	kr. 486.545	kr. 627.043	kr. 139.054	kr. 295.994	kr. 457.137	kr. 573.831
Level 5 Normal O&M	kr. 164.842	kr. 322.176	kr. 484.314	kr. 624.813	kr. 136.824	kr. 293.764	kr. 454.907	kr. 571.600
Level 5 Upper O&M	kr. 159.773	kr. 317.107	kr. 479.245	kr. 619.744	kr. 131.754	kr. 288.694	kr. 449.838	kr. 566.531
Level 4 Lower Fuel price	kr. 124.514	kr. 344.386	kr. 517.629	kr. 669.232	kr. 96.374	kr. 315.730	kr. 487.856	kr. 615.533
Level 4 Normal Fuel price	kr. 120.913	kr. 337.184	kr. 506.827	kr. 654.829	kr. 93.102	kr. 309.187	kr. 478.041	kr. 602.446
Level 4 Upper Fuel price	kr. 117.313	kr. 329.983	kr. 496.025	kr. 640.427	kr. 89.831	kr. 302.643	kr. 468.226	kr. 589.359
Level 5 Lower Fuel price	kr. 168.300	kr. 329.091	kr. 494.687	kr. 638.643	kr. 139.965	kr. 300.047	kr. 464.332	kr. 584.167
Level 5 Normal Fuel price	kr. 164.842	kr. 322.176	kr. 484.314	kr. 624.813	kr. 136.824	kr. 293.764	kr. 454.907	kr. 571.600
Level 5 Upper Fuel price	kr. 161.384	kr. 315.261	kr. 473.942	kr. 610.983	kr. 133.682	kr. 287.480	kr. 445.482	kr. 559.034
Level 4 Lower COP	kr. 117.105	kr. 329.567	kr. 495.401	kr. 639.595	kr. 91.106	kr. 305.194	kr. 472.052	kr. 594.460
Level 4 Normal COP	kr. 120.913	kr. 337.184	kr. 506.827	kr. 654.829	kr. 93.102	kr. 309.187	kr. 478.041	kr. 602.446
Level 4 Upper COP	kr. 126.766	kr. 348.889	kr. 524.383	kr. 678.238	kr. 97.232	kr. 317.445	kr. 490.429	kr. 618.963
Level 5 Lower COP	kr. 161.185	kr. 314.862	kr. 473.343	kr. 610.184	kr. 134.906	kr. 289.929	kr. 449.155	kr. 563.931
Level 5 Normal COP	kr. 164.842	kr. 322.176	kr. 484.314	kr. 624.813	kr. 136.824	kr. 293.764	kr. 454.907	kr. 571.600
Level 5 Upper COP	kr. 170.462	kr. 333.416	kr. 501.174	kr. 647.292	kr. 140.789	kr. 301.694	kr. 466.802	kr. 587.461

Table 7.5: Total NPV cost in DKK for farmhouses with upper, lower and normal cost values

	Air to Water vs Oil boiler				Ground to Water vs Oil boiler			
Single family house	**130**	**260**	**390**	**520**	**130**	**260**	**390**	**520**
Level 4 Lower Invest	kr. 186.755	kr. 351.491	kr. 529.880	kr. 692.911	kr. 164.009	kr. 327.119	kr. 507.641	kr. 651.244
Level 4 Normal Invest	kr. 172.346	kr. 337.184	kr. 506.827	kr. 654.829	kr. 144.535	kr. 309.187	kr. 478.041	kr. 602.446
Level 4 Upper Invest	kr. 157.937	kr. 310.615	kr. 483.771	kr. 616.748	kr. 137.670	kr. 291.254	kr. 467.606	kr. 585.139
Level 5 Lower Invest	kr. 179.251	kr. 336.483	kr. 507.368	kr. 662.895	kr. 156.297	kr. 311.696	kr. 484.507	kr. 620.398
Level 5 Normal Invest	kr. 164.842	kr. 322.176	kr. 484.314	kr. 624.813	kr. 136.824	kr. 293.764	kr. 454.907	kr. 571.600
Level 5 Upper Invest	kr. 150.433	kr. 295.607	kr. 461.259	kr. 586.731	kr. 129.959	kr. 275.831	kr. 444.472	kr. 554.293
Level 4 Lower O&M	kr. 174.577	kr. 339.415	kr. 509.057	kr. 657.060	kr. 146.765	kr. 311.417	kr. 480.272	kr. 604.677
Level 4 Normal O&M	kr. 172.346	kr. 337.184	kr. 506.827	kr. 654.829	kr. 144.535	kr. 309.187	kr. 478.041	kr. 602.446
Level 4 Upper O&M	kr. 167.277	kr. 332.115	kr. 501.758	kr. 649.760	kr. 139.466	kr. 304.117	kr. 472.972	kr. 597.377
Level 5 Lower O&M	kr. 167.072	kr. 324.407	kr. 486.545	kr. 627.043	kr. 139.054	kr. 295.994	kr. 457.137	kr. 573.831
Level 5 Normal O&M	kr. 164.842	kr. 322.176	kr. 484.314	kr. 624.813	kr. 136.824	kr. 293.764	kr. 454.907	kr. 571.600
Level 5 Upper O&M	kr. 159.773	kr. 317.107	kr. 479.245	kr. 619.744	kr. 131.754	kr. 288.694	kr. 449.838	kr. 566.531
Level 4 Lower Fuel price	kr. 175.947	kr. 344.386	kr. 517.629	kr. 669.232	kr. 147.807	kr. 315.730	kr. 487.856	kr. 615.533
Level 4 Normal Fuel price	kr. 172.346	kr. 337.184	kr. 506.827	kr. 654.829	kr. 144.535	kr. 309.187	kr. 478.041	kr. 602.446
Level 4 Upper Fuel price	kr. 168.745	kr. 329.983	kr. 496.025	kr. 640.427	kr. 141.263	kr. 302.643	kr. 468.226	kr. 589.359
Level 5 Lower Fuel price	kr. 168.300	kr. 329.091	kr. 494.687	kr. 638.643	kr. 139.965	kr. 300.047	kr. 464.332	kr. 584.167
Level 5 Normal Fuel price	kr. 164.842	kr. 322.176	kr. 484.314	kr. 624.813	kr. 136.824	kr. 293.764	kr. 454.907	kr. 571.600
Level 5 Upper Fuel price	kr. 161.384	kr. 315.261	kr. 473.942	kr. 610.983	kr. 133.682	kr. 287.480	kr. 445.482	kr. 559.034
Level 4 Lower COP	kr. 168.538	kr. 329.567	kr. 495.401	kr. 639.595	kr. 142.539	kr. 305.194	kr. 472.052	kr. 594.460
Level 4 Normal COP	kr. 172.346	kr. 337.184	kr. 506.827	kr. 654.829	kr. 144.535	kr. 309.187	kr. 478.041	kr. 602.446
Level 4 Upper COP	kr. 178.198	kr. 348.889	kr. 524.383	kr. 678.238	kr. 148.664	kr. 317.445	kr. 490.429	kr. 618.963
Level 5 Lower COP	kr. 161.185	kr. 314.862	kr. 473.343	kr. 610.184	kr. 134.906	kr. 289.929	kr. 449.155	kr. 563.931
Level 5 Normal COP	kr. 164.842	kr. 322.176	kr. 484.314	kr. 624.813	kr. 136.824	kr. 293.764	kr. 454.907	kr. 571.600
Level 5 Upper COP	kr. 170.462	kr. 333.416	kr. 501.174	kr. 647.292	kr. 140.789	kr. 301.694	kr. 466.802	kr. 587.461

Table 7.6: Total NPV cost in DKK for single family houses with upper, lower and normal cost values

Using air to water heat pumps will give the highest beneficial value for the building owners with a significant cost difference. Given that heat pumps have an expensive investment cost, it was also expected that the uncertainties regarding this would be the factor which would affect the total cost the most. The uncertainties of the COP value do not affect the total cost much but will, together with a lower electricity price, affect the cost of heating with heat pumps with a highly beneficial result for the building owners. It can further be seen in the sensitivity analysis that the robustness of the heat pumps is high, where the oil boilers cannot compete with the beneficial value which the building owners will receive if they convert.

7.2 Sub Conclusion

It can be concluded that even though the ground to water heat pump runs with higher efficiency, the air to water heat pump would be the cheapest and most beneficial solution in the buildings. Although the cost difference between the two heat pump types is small, is there a significant difference in installing the heat pumps. The ground to water heat pump needs pipes to be dug into the ground, which will ruin the garden and also affect the future garden, where an air to water heat pump just can be connected to the water-borne system.

If the municipality, utility company, or a 3rd party were to invest in the heating unit and insulation, the citizens would spread the total cost over 20 year period, which would make it easier for the citizens to invest in heat pumps. The calculations are made without interest rates, which will play a role in the cost because not all citizens have enough money to pay for the unit and insulation level. Although no interest rates have been used, the sensitivity analysis shows that oil boilers cannot compete with the heat pumps. Ground to water heat pumps is more efficient than air to water heat pumps but more expensive and harder to install, making the air to water heat pump the best solution.

Discussion 8

This chapter will discuss what opportunities Aalborg municipality has for implementing heat pumps and insulation in oil-supplied households. The discussion is divided into three topics; Economics, the municipality, and the citizens. The economic topic will discuss the results obtained in the analysis, and the two other topics will discuss their part in the transition.

8.1 The correlation between socio- and user economy

The socioeconomic analysis shows that converting the heating unit from an oil boiler to a heat pump is not a feasible solution for all buildings and depends on building period and type. The argument for converting the oil boilers to heat pumps rely on the reduction of operation cost and emission of CO_2 but since newer buildings had more strict energy requirements will the buildings, therefore, have a lower heat demand, and the reduction of operation cost in these buildings, is not feasible compared to reinvesting in an oil boiler. The investment cost for heat pumps is too high compared to the socioeconomic reduction a heat pump will lead to although it can be seen that some buildings will have a lower socioeconomic cost from converting the heating unit and implementation of energy efficiency measures up till level 5, where the choice of the heating unit will an oil supply be the best socioeconomic choice.

An anomaly is thereby created between the most socio- and user economic for the most beneficial choice of heating technology. As the user economic analysis concludes, the most beneficial heat supply is air to water heat pump, where the least beneficial supply is the oil boiler. Because the heat pumps are not a beneficial socioeconomic solution, it can be necessary for Aalborg municipality to ensure transparency by notifying the socioeconomic consequences of such a conversion. Aalborg can inform the user that a heat pump is the most environmentally friendly choice and is a significant factor in the future Danish energy system, even though it is not the most socioeconomic beneficial choice for now. The user economic model shows the total cost over a 20 year calculation period, allowing the users to choose the best economical heating solution. The analysis does not investigate multiple different individual heating solutions and can, therefore, appear as a Hobson choice as the only investigated solutions are the heat pumps and their economic values compared to oil boilers. Although it can be seen as a Hobson choice, this has not been the goal since other solutions exist and based on this project, it is impossible to say whether they are feasible.

It could be seen that converting the heating unit and insulation level was beneficial on the user economic level, but the investment of these is expensive, which could be a problem since not all citizens are expected to have the needed capital. A high investment price and low subsidies are two factors that have a significant impact on whether the citizens will invest in such a heat unit, especially when the citizens cannot see the long-term investment made. The citizens expect fast results, and although they have a reduction in the yearly payment in fuel cost, it is not something that can be noticed immediately (Interview), the same applies to the energy measures where the investment cost takes years to be earned back. Because of the citizens' insecurities, it would be safer to highlight the air to water heat pump because of its lower investment cost compared to the ground to water heat pump. Ground to water heat pumps is besides more expensive investment-wise, also harder to install. Many citizens may see it as a problem that the garden has to be ruined in order to install the pipes for the unit and, at the same time, have limits for the future garden. Therefore, ground to water heat pumps may have a higher success in new houses since the garden has not been "created" yet.

In May this year, Denmark's government presented the first part of a climate action plan, with a high agreement on oil and natural gas boilers phaseout in the individual heating. The plan presents an initiative where the taxes for fossil produced heat, and electric heat is made to make the heat pumps the most attractive choice. Subsidies for the converting of oil to heat pumps are also discussed where it before was DKK 6,200 will it now be DKK 15,000 - DKK 25,000. A third initiative is heat pumps on the subscription, which would decrease the 1st year payment and make it more possible for citizens to convert to heat pumps. The subscription initiative will be discussed later in this chapter. A problem with these high investment prices is that the citizens are committed to living in the house in a certain period of years if they wish to experience the benefits of converting.

Choice of heat supply The COP value has a significant impact on electricity usage and the economy of the used electricity. It is a value that has been hard to specify since the value fluctuates depending on the season and the ambient temperature. During the winter will the air to water heat pump work with a lower heat pump because of the lower ambient temperature where the ground to water heat pump has a higher COP value because of the warmer environment which the ground provides. During the summer, air to water heat pumps may experience higher COP values because the ambient temperature will reach higher degrees than the ground to water, but the heat demand is low in the summer, which results in a misleading COP. Therefore, it can be said that the COP values have been used with some uncertainty, and in a future project, it may be relevant to use a more precise valuation by using a season COP value (SCOP) The investment price has also been used with some uncertainty since the Danish Energy Agency has merely been used for this, which may have been imprecise. It can be assumed that the future investment cost may be lower than today because of the development of the technologies, which typically gets cheaper, the more prolonged the technology has been on the market.

The value of converting is different for the users who can save much money on this. Oil boilers are expensive to use as a heat supply because of the fuel cost and low efficiency that the oil boiler has.

8.2 The municipality as a facilitator

The municipality of Aalborg can have significant involvement in promoting energy renovations as well as converting the heat supply. Aalborg municipality's involvement can include information meetings, workshops, or citizen meetings, where the users are informed about the consequences of the choice of heating supplies, but the involvement can also be made through subsidy schemes. The municipality of Aalborg can thus act as a facilitator to create communication between the various parties.

Aalborg municipality as a facilitator in the concept presented in (Dansk Fjernvarme 2019) where the ownership of the heat pump is discussed. The article discusses whether utility companies should establish a cooperative society where consumers lease a heat pump and pay the operating costs of heat usage rather than the heat pump itself. With this concept, it may be possible to achieve economies of scale than the individual user buys and install heat pumps, which can be assessed for overall savings. The cooperative society should be a municipal-owned company, as these companies have no financial interest, and the roll-out of heat pumps should follow the same principle as with district heating, where the heat pumps must "Hvile-i-sig-selv" and thus not generate a profit. "Hvile-i-sig-selv" principle is a principle where public companies, including utility companies, are not allowed to generate deficits and profits as it will subsidize or tax customers. This will, therefore, not create a monopoly, as seen with the establishment of district heating, where it is still possible for other companies to compete with this concept. In this establishment of a cooperative society company, the company is responsible for the risk of purchases and where the citizens pay back over some time. This will also reduce or avoid the previously mentioned challenge for selected households to finance significant investments.

On the contrary, the same concept cannot be used for energy renovations of buildings. A heat pump can be installed and removed without significant problems where the insulation of a building is a more permanent implementation. Here, possible cooperation with banks could be made to make interest-free energy loans, which could entice citizens to take energy renovations or convert heat source without the banks' regular loan interest rates. This concept is already seen at several different consumer levels, such as glasses, bicycles, and electronics, and can be useful in the heating sector to make the citizens obtain the needed capital. There can be doubts as to who should be tasked with cooperating with the banks on interest-free loans from heat pumps, as this may be attributed more to the companies responsible for the sale of these units. As a facilitator, however, the municipality can help to put such an agreement in place with their political role and leadership role for the area.

8.3 The citizens make the final choice

There may be several different initiatives that make a heat pump an attractive choice, but the final choice is the consumers. However, individual citizens' choices may be altered by external factors, such as some of the concepts mentioned above, where consumer comfort and economy are assumed to be of high importance. Other measures that may affect the citizens, which the municipality already has the opportunity, are to enable the citizens to have an energy supervisor or adviser when the household is renovated. As mentioned earlier, the highest energy efficiency per DKK will be spent if efficiency improvements were made in the extension of the basic renovations. It is necessary to have an increased focus on the economic benefits that can come from converting so that citizens do not doubt that this is beneficial for them. This can be through information but also from utility companies that offer free advice for the citizen's household. Citizens need an energy supervisor's easy accessibility, and it may be an idea that it is an energy supervisor for the municipal so that citizens can feel confident that it is not a sales speech, but that they want the best of the citizens. By making the municipality available to an energy supervisor, citizens' choices about efficiency can be affected.

In order to influence citizens, it is necessary to make it clear to citizens that this is the attractive choice, which can be made through a change in the tax structure, subsidy scheme, or legislation, which is currently being discussed. Therefore, the Danish Parliament can have a significant influence on the user's choice, as it is the Danish Parliament that has set the taxes on fuel consumption and subsidies. The public can have that power and decide which heating supplies must not be installed. Such as the purchase of oil-fired boilers, where it is still legal to reinvest in an oil-fired boiler if the building cannot be connected to district heating or natural gas.

9 Conclusion

Throughout this report, the following research questions, with related sub-questions, has been answered:

How can oil supplied houses in Aalborg municipality reach higher energy efficiency and can the socio- and user economy benefit from the implementation of heat pumps and insulation?

1. What is the current heat demand in the project scope and how will this demand be affected through energy efficiency measures.
2. What will the socioeconomic cost be at the different insulation levels and heat supply scenarios?
3. What will the user economic cost be for the citizens and can the insulation level benefit cost wise?
4. How should Aalborg municipality implement heat pumps and insulation for oil based household?

With an estimate of the heating demand for the individual building types and the heat demand after the different insulation levels, it is possible to find the socioeconomic and user economic costs of buildings with either an oil boiler or heat pump. It can be seen that the heat demand in farmhouses and single family houses in the period 1850 to 1930 constitutes a large percentage of the total heating demand. This means that the socioeconomic assessments will be affected by this building period if an overall heat demand for each building type is considered. Therefore, building types will remain separate to assess the most optimal assessments for each building period.

Based on the socioeconomic analyzes, it can be concluded that the insulation of almost all types of buildings and building periods will result in a lower socioeconomic cost. This applies to buildings provided with oil or heat pumps. The choice of insulation level with the lowest socioeconomic cost depends on the type of building, building period, and installed heat supply, which means that a generalization of which insulation level society can benefit most cannot be made. The socioeconomic analysis shows it is not possible to generalize which heating technology is best for a specific type of building, but the best socioeconomic choice depends on the building period. The socioeconomic analyzes show that conversion of ground to water will result in higher socioeconomic costs for all types of buildings and periods, where conversion to an air to water heat pump will reduce socioeconomic costs in a few building types and periods. During the construction periods 1890 to 1978, air to water heat pumps have the lowest socioeconomic costs until the implementation of level 5 insulation. Buildings from 1979 to 2007 and older, oil boilers will have the lowest socioeconomic costs regardless of the insulation level. However, the sensitivity analyzes show that the choice between oil and air to water is not very robust in the buildings from 1890 to 1978, which means the socioeconomic costs of these heat supplies are very similar.

At a user economic level, are there significant benefits of converting from an oil boiler to a heat pump. The project has focused on two types of heat pumps of where the air to water heat pump is the most beneficial solution, although the total cost difference between air to water and ground to water heat pump is low. The heat pumps have different investment costs, where the ground source is more expensive, which affects the total cost difference. However, the COP value of the ground to water heat pump is higher than the air to water heat pump, which reduces the total cost since it lowers the usage of electricity. Because of the installation requirements of the ground to water heat pump, this type will be assumed to have a higher value for new buildings where it is possible to establish the pipelines without further digging.

It can also be concluded that the total cost of converting will be cheaper if a municipality, utility company, or another third party were to invest in the heat pumps since the net present value will affect the total cost over 20 years. With the robustness of heat pumps, the air to water heat pump will be the best solution for the citizens in Aalborg municipality with high beneficial values.

Converting the oil boiled buildings with heat pumps will reduce the energy consumption, which is of interest for Aalborg municipality and the political goal of changing the fuel consumption. With the results from the socioeconomic analysis, it can be seen that the energy consumption alteration from oil boilers to heat pumps will affect the society, which is a factor that has to be accounted for in the assessment of the best heat supply.

Aalborg municipality should act as a facilitator to ensure that the buildings reduce energy consumption and convert to other energy sources. With the facilitator role, they can help to provide energy guidance, such as allocating energy counselors to the citizens who plan to renovate and establishing cooperative societies, such as a heat pump subscription. By allocating an energy counselor, can it help the energy consumption in buildings and help the citizen receive beneficial value as a result of insulating the building. If the municipality provides heat pumps through a subscription program with the "Hvile-i-sig-selv" principle, and with no intentions to generate a profit, the citizens may gain a higher trust to the converting and the municipality can through this program secure a higher share of energy efficiency in buildings. However, if the municipality follows the "Hvile-i-sig-selv" principle, can it lead to a monopoly, such as district heating, since other companies can not compete with this concept and therefore not making it a fair solution for the companies. Therefore, it is considered that Aalborg municipality should act as a facilitator in a cooperative society where agreements can be made between companies and the citizens of the municipalities to get the best conditions for both.

With the facilitator role can the municipality also advocates for the banks to participate in the development with interest-free loans. In the user economic analysis, the total cost of converting from oil boiler to a heat pump over a 20-year payback agreement is cheaper because of the net present value, of which it will help the development since the citizens can avoid the expensive start-up cost. This same principle applies when insulating the building, as it allows the necessary capital to be raised, without the loan is so high that insulation will not result in savings. Therefore, different ways of spreading the cost are available, where they can all help the development and therefore increase efficiency.

The economic differences between the socioeconomic and user economy show that the conversion of heating technology is always beneficial for the citizens of which it is not necessary the best beneficial solution for the society when extensive renovations with high insulation levels are sought.

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Appendix A

A.1 Interview med Automatic V/S

Os: jamen så sagt så arbejder vi på det her med at skifte fra oliefyr til varmepumper, og nu ved jeg ikke om du er energirådgiver eller vejleder, men du har samtaler med borgerne?

Kasper: Jeg er i gang med at læse til energivejleder og har arbejdet med det de sidste 3 år

Os: Arbejdet med det sidste 3 år, så burde du kunne hjælpe med de spørgsmål vi har om ikke andet, så hvert fald nogen af dem. Og nu siger du at du lige har været ude og snakke med nogen kunder, hvilke indstillinger til omskiftning af varmeteknologier møder i når i præsentere mulighederne for at lave forbedringer hos kunderne?

Kasper: uuuh den skal jeg lige have igen

Os: Når du er ude og snakke med borgerne, hvilken indstilling har de til det her med omskiftninger af varmeteknologier, når i præsentere de forskellige muligheder for at lave forbedringer og det kan selvfølgelig både dreje som om isolering for at forbedre indeklimaet og men også selve udskiftning af varmeteknologi?

Kasper: Det er det med at spare penge og få et bedre indeklima

Os: Og de kan sagtens se ideen i det hele, der er ikke nogen der mener det er noget gøgl som ikke behøver at gøres?

Kasper: joo dem har vi også nogle enkelte af, og dem er jeg aldrig ude og mødes med, dem træffes jeg med over telefonen.

Os: Dem træffes i telefonen, okay, Så der er nogle er det så dem der sidder med oliefyr eller det ved i måske ikke?

Kasper: jo det er nogen der tror som tingene ikke koster ret meget, så enten har de oliefyr eller et gammelt pillefyr eller fastbrændselsfyr

Os: Ja okay, for det er også det vi kan se for der er jo væsentlig stor forskel på investeringspriserne når det oliefyr kontra varmepumpe. Og det er jo også det der vi kan se når vi laver de her beregninger at investering kommer til at spille en større rolle i forhold til at skulle lave en omstilling

Kasper: Det er jo investeringer for ca. 90.000 og så opad.

Os: Når det så drejer sig om varmepumper, hvilke typer erfarer i så typisk at borgerene vælger? Vi sidder og kigger på luft til vand og jord til vand varmepumper, hvad for en er den man typisk går med?

Kasper: Øhm vi laver mest luft til vand varmepumpe, for det kan vi bedre se der er økonomi i end at lave med jordvandvarme. Os: Okay, det er jo en større omgang med jord til vand

Kasper: Det koster ca. 40.000 mere at lave plus du skal ødelægge folks hjem næsten. Du er nødt til at ødelægge hele haven.

Os: Så det er mest luft til vand der er den hyppigste, og det giver jo også god nok mening i forhold til det der med at hvis det er borgere der har boet der længe og lagt meget energi i den have og de så skal til at rive den op, det er jo lidt synd.

Kasper: Ja eller fremtidige have for du kan ikke have ret meget der hvor du har de der jordvarmeslanger, buske og hække kan ødelægge slangerne

Os: Okay, det var vi faktisk ikke klar over men det var da sådan set meget rart at vide Så er der det her med at varmepumper har fået et forøget fokus med den her status som vedvarende energitype og fordi den er så effektiv som den er, og det bliver jo angivet i COP. Og som sagt så har det været noget der har været lidt svært at præcisere, nu sidder vi f.eks. og kigger på energistyrelsen og de bruger ret høje tal, 3.68 for luft til vand varmepumper f.eks. Er det også noget i går ind og kigger på når i skal anbefale kunderne

Kasper: Jamen COP, privatkunderne går altid ind og spørg hvad den der COP er og det er svært for det kommer an på hvad temperatursæt man er nødt til at kører med og hvor stor rørstørrelse man kører med i varmesystemet. Små rør er lig med ringe COP, store rør der kan du få lidt mere igennem.

Os: Okay, så der er stor forskellighed, og det har selvfølgelig meget med vejret at gøre også det var vi godt klar over, og der har vi også været inde og kigge på det de kalder SCOP der skulle være mere præcist.

Kasper: Mit eget anlæg derhjemme det kører 4,8

Os: Okay, er det så luft til vand?

Kasper: Ja og det er med gulvvarme

Os: Jamen så er vi måske ikke helt ved siden af hvad angår COP værdien Så er det der her med de nuværende lovgivninger og måden tingene gøres på, og ud fra det så er der jo det her mål 100% energi i energisystem hvad angår varme for den her periode, hvad ser i af problemer ift. Det her, hvordan skal man hjælpe udviklingen på vej?

Kasper: Der skal noget energitilskud til igen

Os: I kan godt mærke at der er forsvundet noget på kundebasis

Kasper: Man kan godt mærke at kunder først lige har fundet ud af det her med energitilskud, at der har været noget med det. Og nu er tilskuddet fra et oliefyr udskiftet til luft til vand varmepumpe under 2500 kr. hvor vi har lagt på næsten 10.000 kr før, for ca. et år tilbage.

Os: Så det forsvinder der kunder på, og det giver jo også god mening ift. At det ikke er lige så attraktivt mere. Vi har været lidt inde på det her med investering, men der er også det med at når man sidder og laver beregninger på det her så kigger man både på investeringspriser for de her anlæg men man kigger også Operation and maintainence altså vedligholdelse af sådan en varmepumpe, hvor meget ligger det ca.i, ved du det?

Kasper: Altså der jo lovkrav om at de skal have service hvert år, og så regner man med at en varmepumpe ca. har tjent sig hjem på 8 år or når man når 15 år så er man der hvor man burde få den skiftet ud.

Os: Så allerede efter 15 år burde man skifte den

Kasper: Ja, for så er der sket så meget på fronten at man burde få den skiftet

Os: Okay ja, så har vi det her ift. Varmepumper der jo også stor forskel på størrelsen af dem, så dimensionering af varmepumper? Når i går ud og installere dem er det så noget med at installere ekstra ved siden af, nu er der f.eks. det med varmepatroner som sidder i varmepumpen så vidt vi lige kan forstå. Men er det primært kun varmepumper der er nok til at forsyne et hus eller skal der nogle gange ekstra til?

Kasper: Nej det er kun varmepumper, ved en stor beboelses ejendom så tager man bare to.

Os: Okay, Og så er der det med borgerne som skifter til varmepumper, hvorfor er der nogle som ikke gør det? Er det pga. økonomien eller fordi de ikke ser det som en investering?

Kasper: Det er fordi syntes det er for dyrt, og det fordi folk ikke ser fremad. De regner med at det er en investering der er tjent hjem på et år eller to og det er luft vand varmepumpe jo ikke, der er du jo ude og kigge længere.

Os: 8 år er jo selvfølgelig også en del

Kasper: ja, men for nogle er det jo hurtigere

Os: Der vel også en fordel i at isolere i husene først

Kasper: ja men du når også en grænse, hvor du ikke kan isolere mere

Os: Ja der er jo en grænse, men det var faktsik de spørgsmål vi havde i forhold til de problematikker vi er stødt ind i forbindelse med at vi læst på de forskellige ting, så du skal have tusinde tak for lige at svare på de spørgsmål

Kasper: Er det fordi i er i gang med at læse til energivejleder eller hvad?

Os: Nej vi er i gang med at læse til Energiplanlægger og er i gang med vores speciale lige nu. Og det er altid godt at have inddraget nogle udefra som står med det til hverdag da i nogle gange kan tegne et lidt andet billede. Så tusinde tak for det.

Kasper: Det var så lidt og så