Danish Energy Agency

Heat as a Service

Evaluation of a Danish support scheme for dissemination of a new business concept for heat pumps

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Photo on front page from OK a.m.b.a.

Abbreviations

A/W	Air-to-water heat pumps
COP	Coefficient of Performance
DHW	Domestic hot water
DKK	Danish Crowns
HaaS	Heat as a Service
L/W	Liquid-to-water (ground source) heat pumps
SCOP	Seasonal Coefficient of Performance
SPF	Seasonal Performance Factor
PV	Photo Voltaic
VAT	Value-added tax

Foreword

Denmark has set high climate ambitions with a 70 % reduction in GHG-emissions by 2030 compared to 1990. By 2030, the power system and heating of buildings shall be climate neutral, while the Danish energy system shall be climate neutral in 2050.

Approximately 65 % of Danish buildings are heated by district heating. Outside the district heating systems, approx. 600,000 single-family households are still heated by oil, gas or wood pellet boilers. An estimate of the distribution of heating types in 2020 was:

Oil boilers: 80,000 units
Gas boilers: 380,000 units
Wood pellet boilers: 120,000 units

The strategy of the Danish Energy Agency is that households with oil and gas boilers shall be converted to either district heating or heat pumps. Houses with oil boilers are typically situated far from district heating systems, while houses with gas boilers often are situated in more dense areas which possibly can be converted to district heating.

Based on this, about 200-300,000 oil, gas and wood pellet boilers should be converted to heat pumps before 2030. This means that 20-30,000 new heat pumps should be installed annually in order to reach the goal. Up to 2015, there was a rather constant annual installation rate of new heat pumps in the order of 5,000 units. This has slowly increased so that the number of installed heat pumps in 2019 exceeded 11,000 units and in 2020 more than 15.000 units were installed. The installing rate, however, still needs to increase in order to reach the 2030 goals.

There are a number of reasons why so few heat pumps have been installed although the concept is well proven:

- Heat pumps are more expensive than the three boiler types (oil, gas and wood-pellets)
- Lack of knowledge among the house owners
- When a boiler breaks down, the house owner contacts the local plumber who may not have experience with heat pumps and thus prefers to sell a traditional boiler
- Uncertainty about the efficiency and the maintenance of heat pumps

Due to the slow rollout of heat pumps, the Danish Parliament decided in 2016 to investigate a new way of providing heat from heat pumps; "heat pumps on subscription" or "heat as a service", where the heat pump is not owned and serviced by the house owner. Instead, a company owns the heat pump, while the house owner pays for the heat delivered to the house as well as the benefit of someone else taking care of the maintenance of the heat pump.

The present report summarizes the findings from this scheme.

Executive summary

Heat pumps in individual homes are essential for the transition of the Danish energy system to become climate neutral by 2050. Heat pumps are assumed to be highly efficient and are able to convert heating of buildings from oil and gas to electricity, which is generated by wind turbines and PV systems.

However, the installation rate of heat pumps was in 2016 too low and the actual efficiency of installed heat pumps turned out to be lower than anticipated. A survey based on measurements from 2015-16 on 200 heat pumps showed that only 15 % of the heat pump installations could be considered as good installations having a sufficient high efficiency (see chapter 5).

The often rather poor efficiency of the installed heat pumps is due to several different issues but in the above mentioned survey it was concluded that the problems can be overcome by:

- Better education of the installers
- Quality insurance of the installations
- Regular (energy) inspections of the installations

Due to the slow rollout of heat pumps, the Danish Parliament decided in 2016 to investigate a new way of providing heat from heat pumps: "heat pumps on subscription" or "heat as a service", where the heat pump is not owned and serviced by the house owner but owned by an energy service company that sells the energy to the house owner.

Energy on subscription is a well known concept in Denmark since about 65 % of Danish buildings are heated by district heating. District heating is characterized by a small sign-on fee, an annual fee for insuring well running system, and payment for the actual used heating. Energy service companies can in the same way offer heat pumps on subscription in the form of Heat as a Service (HaaS).

This will solve several problems for the house owners such as:

- Which type of heat pump is best suited for my house
- How do I finance the heat pump? Can I obtain a mortgage/loan?
- Which size of heat pump should I choose?
- Where do I find a good installer?
- Can I be sure that the heat pump is as efficient as claimed?
- How should a heat pump be maintained?
- What happens at the end of the lifetime of the heat pump?

As the heat pumps are owned by the energy service companies, they are very interested in optimizing the heat pumps, as this will maximize their profit. The energy service companies are, thus, interested in only having very qualitied persons to install and check their systems. And since they already, for billing purposes, have to measure both electricity used by the heat pump and heat delivered from the heat pump, they are able to online follow the efficiency of their heat pumps. The energy service companies can, thus, early intervene if something seems to reduce the efficiency of the heat pumps.

Four companies with different background were selected to participate in a pilot project. The pilot project included a subsidy scheme where the companies were rewarded economically for each heat pump they installed. The subsidy was primarily for support of the development of business cases for the different companies.

The result of the pilot project were:

- 885 out of the - in the scheme - possible 1,900 heat pumps were installed
- The lower number of installations was because it took longer time than anticipated to develop the business cases and to engage with the customers. As it was a new concept more effort was often needed
- The company, which installed the foreseen 475 heat pumps, was already before the pilot project in contact with potential customers, as the company also sells oil and electricity to private customers
- The two companies with the lowest number of installations had no prior contact to private customers
- However, despite the lower number of installations than foreseen all four companies are now engaged in a new more permanent scheme for heat pumps on subscription
- The customers are happy with the concept due to the low sing-on fee and heating bill (compared to especially oil), the convenience of others taking care of the maintenance, and that it is climate friendly
- It is the impression that several customers otherwise would not be able to afford a heat pump
- It was not proven, but it seems that the installed heat pumps have an increased efficiency compared to more traditional heat pump installations. The reason is that the energy service companies use certified installers. These are not only skilled in installing heat pumps, but also in dimensioning heat pumps and correct adjusting the controllers of the heat pump and the heat-emitting systems. They can further pinpoint if there is something in a heating system that needs to be changed to make it better suited for heat pump operation
- The companies optimize the operation of the heat pumps based on continuously measurements of the performance of their heat pumps

It is too early to determine if HaaS for heat pumps will lead to the necessary number of installed heat pumps for reaching the ambitions Danish climate goals. However, the Danish Parliament has decided to start a new more permanent scheme on heat pumps on subscription. Interested companies can be pre-qualified to participate in the new scheme.

The Danish District Heating Association encourage their members to also consider HaaS via individual heat pumps, as they already are used to deal with customers buying heat on subscription. The concept of district heating is well known also by house owners outside heating districts. This may give HaaS a certain credibility which private company may not have.

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1.0 Introduction to Heat as a Service

Photo: OK a.m.b.a.

In the Danish Climate Action Plan from 2020 one of the strategies for reducing the CO_2 emissions from buildings is to convert oil and gas boilers (for space heating and hot water) to heat pumps. This conversion is on its way in Denmark, but the annual number of installed heat pumps has been too low in order to meet the target in the Climate Action Plan.

Since the price of installing a new heat pump can be a barrier for some house owners, the Danish Parliament decided in 2016 to introduce a new way of heat pump ownership. The proposed concept is similar to the conditions in district heating systems where a utility company owns and runs the heating system. Here customers pay for the used energy and for being connected to the district heating system.

In the proposed concept, hereafter called Heat as a Service (HaaS), the investment and operation of the heat pump is carried out by an Energy Service Company. The homeowner pays a smaller connection fee and pays for the heat delivered to the house from the heat pump. The Energy Service Company pays for the installation of the heat pump and takes care of the maintenance of the heat pump. The house owner does not have to worry about the technique or the maintenance of the heat pump. This addresses the barriers that normally restrict a major rollout of heat pumps and will expectably make heat pumps attractive to a larger group of building owners.

The Danish “Executive Order on subsidies for new business concepts for heat pumps” from June 2016 made a support scheme for new business concepts for heat pumps in single-family houses possible. A call for applications named “Distribution of heat pumps in rural areas” was launched in June 2016. The purpose was to find a number of energy service companies that each should develop a business concept for HaaS and install in total 1,900 heat pumps in single-family houses during the period 2017-2019. The conditions are described in the next chapter.

In July 2017, the scheme was enhanced via the “Executive Order on Subsidies for New Business Concepts for Heat Pumps for Building Heating and Process Purposes in Business”. The enhancement dealt with larger heat pumps for heating and process in business, rental properties and public buildings.

The focus of the present report will be on the scheme for Heat as a Service in single-family houses.

The structure of the report is: Chapter 2 describes the support scheme and looks at the requirements for efficient heat pumps. The companies involved in the scheme, the contract conditions and the economy of the scheme are also presented. Chapter 3 evaluates the scheme and chapter 4 introduces the current scheme replacing the first scheme. Chapter 5 and 6 gives the results from two studies carried out on the efficiency of installed heat pumps.

2.0 Support scheme for development of the concept – pilot project

Photo: Sustain, Klaus Gadeberg

The support scheme introduced in 2016 provided DKK 25 mill. (approx. €3.4 mill.) for five energy companies. Nine companies applied for funding among which the five best qualified were chosen to participate in the scheme/pilot project. However, one company left the scheme early.

The support scheme was for development of business concepts and not for supporting the purchase of the individual heat pumps. However, the final amount of funding to a company was dependent on the actual number of contracts with homeowners. The subsidy per contract decreased by number of concluded contracts in the following way:

0-100 contracts = DKK 20,000
(approx. €2,700) per installed heat pump
101-200 contracts = DKK 15,000
(approx. €2,050) per installed heat pump
201-475 contracts = DKK 10,000
(approx. €1,350) per installed heat pump

With four companies installing the same number of heat pumps, the scheme allowed for subsides for 475 heat pumps per company or 1,900 in total.

The installed heat pumps should replace existing oil or gas boilers and should deliver minimum 50 % of the demand for space heating and domestic hot water.

The energy service companies should take full ownership of the heat pumps for a minimum of 10 years.

The scheme originally ran to the end of 2019, but as it took longer than anticipated to develop the business cases and to engage with potential customers. The period of the scheme was, therefore, extended to the end of 2020.

1,900 heat pumps are not many compared to the needed 200-300,000 heat pumps before 2030. However, the idea with the support scheme was not to support heat pump installations but to support the development of durable business cases with the ability to overcome the obstacles for the homeowners, making it easier and safer to switch to heat pumps. The homeowner should not have to deal with questions like:

- What type of heat pump is most appropriate for my house?
- How do I finance the heat pump, and can I borrow the money?
- Which size of heat pump should I choose?
- Where do I find a good installer?
- Can I be sure that the heat pump is as efficient as proclaimed?
- How should a heat pump be maintained?
- What happens at the end of the lifetime of the heat pump?
- How do I get rid of my existing installations?

2.1 Heat pumps and heat pump efficiency

Installed heat pumps are assumed to have a high efficiency. The SCOP label (Seasonal Coefficient of Performance – see chapter 5) for a heat pump typically states this. However, many things may go wrong when installing a heat pump in a house as described in chapter 5. A Danish survey concluded based on measurement from 200 heat pumps in single-family houses that only 15 % of these could be considered as good heat pump installations with a sufficient high efficiency [7].

The survey concluded further that the main reasons for malfunctioning heat pump installations are faults in the installation and lack of service and maintenance of the heat pumps. By the introduction of the concept of HaaS, it was the expectation that the efficiency of heat pump installations would increase, as the energy service companies have an interest in well-running heat pumps, as this will increase their profit.

When installing many heat pumps the companies and their installers:

- Gain major insight and experience in how to install heat pumps, that are adequate for the actual houses
- Gain insights in what can go wrong during installation and knowledge of how to avoid this
- Perform professional quality assurance

- May due to measurements for billing purposes monitor the performance of the heat pump and early detect arising problems
- Perform regular service on the heat pump in order to avoid problems

2.2 The companies involved in the scheme

The four companies selected for the scheme had a very different background, which enabled an evaluation on which type of background knowledge and existing networks that are of importance for HaaS.

Company 1: The company is part of a development company with roots in the power utility area. The company had during several years carried out research and development projects on heat pumps in private households.

Company 2: The company was originally part of a wholesale company that, among other things, imports heat pumps. The company has a network of heat pump installers, who are continuously informed about new products and optimal ways of installation and maintenance. The company, however, did not have any experience in sales to private customers. The company, therefore, teamed up with a power utility.

Company 3: The company had during many years delivered oil to private households with boilers and also power to private households. The company had thus direct access to the target group of the scheme. Furthermore, the company had already experience in sale and leasing of heat pumps.

Company 4: The company is an investment fund that invests in projects on energy renovation of larger buildings and renewable energy. The company had no experience in marketing towards private customers, so they teamed up with two utility companies: one dealing with both power and district heating, and one with district heating.

2.3 Contract terms for the consumer

In the scheme the four companies own the heat pumps and are responsible for the installation, operation and maintenance. The house owner pays a sign-on fee at the installation of the heat pump, a price for the heat supplied, and a monthly fee for the subscription. However, there are some differences in the contract details of the four different companies as shown in table 2.1. The values in table 2.1 is from [1] and were collected in early 2019. In [1] it is assumed that a house owner can buy a heat pump (installed) at the price of approx. DKK 100,000 (€13,600) incl. VAT.

Table 2.1 only states some of the terms needed to be in the contract between the energy service company and the house owner. Other important terms in the contract are:

Table 2.1. Some of the contractual terms for the four companies [1].

	Cost in DKK incl. VAT	Cost in € incl. VAT
Sign-on fee	20,000-25,000	2,700-3,400
Annual subscription fee	5,000-7,236	680-985
Price for heat per kWh measured from the heat pump to the house	Three companies: 0.85 One company: dependent on heat demand. Example: 1.08[1]	Three companies: 0.12 One company: dependent on heat demand. Example: 0.15[1]
Lowest heating bill	One company: none Two companies: 13,500 or 14,000 kWh One company: smaller customers pays more per kWh	
Who pays for the power	One company pays the power utility directly Three companies measure the power demand and refund the customer	
Duration of contract	The companies guarantees 10 years delivery of heat	

[1] this kWh price is for a house with a typical heat consumption for Danish single-family houses.

- Who owns and maintains the heat pump?
- Who dismantles and removes the old boiler and who pays for this?
- Who pays for the repair of the building when the old boiler is dismantled, and the heat pump is installed?
- Who will be responsible for the installation (the installer should be certified)?
- Whether the energy service company screens the building before installation to detect if anything should be modified on the building or on the existing heating system in order to make the heat pump installation more efficient?
- Who pays for the above modification to the building and heating system?
- Who ensures that the installation is legal and in accordance with any restrictions in the municipality's local plans?
- Where is the interface between the indoor heating system owned by the customer and the outside air-to-water heat pump owned by the energy service company – see figure 2.1?
- Is there a minimum demand that the customer needs to pay even if using less heat?
- What happens if the house owner changes the layout of the house or the heat distribution system?
- How should the heat pump be insured?
- Who owns the heat and power meter on the heat pump?

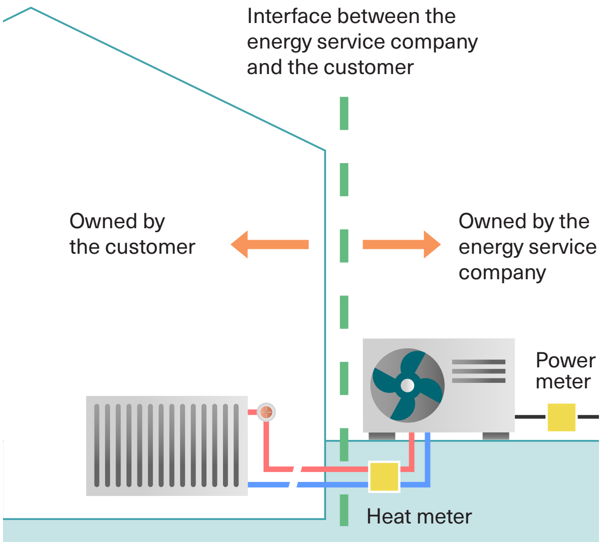

Figure 2.1. The figure illustrates which components belong to the house owner and which to the energy service company.

- Who should supply the power to the heat pump: a utility appointed by the energy service company or by the customer?
- If power is not directly paid for by the energy service company, how and at what price does the energy service company refund the electricity for the heat pump purchased by the house owner?
- How is the energy service company able to change conditions in case of e.g., rising prices of electricity, changed VAT, changes in legislation, etc.?
- Where can the house owner complain if something seems to be wrong?
- How can the customer terminate the contract?
- What happens if the house owner sells the house?

The measured data should be protected according to the EU General Data Protection Regulation (GDPR).

In order to have a clear distinction between what is owned by the energy service company and by the house owner, and because air-to-water heat pumps are cheaper and easier to install and maintain, all four companies only use air-to-water heat pumps. Furthermore, this makes it easier if the energy service company has to remove the heat pump in case of replacement due to a breakdown or in case of an early termination of a contract.

The four companies have different terms when a house owner wants to terminate a contract before time [2]. For two of the companies, the customer can terminate the contract after 11 months with one month's notice. One of these two companies has a withdrawal fee of DKK 18,000 (€2.250), while the other have no fee. For some of the companies, the customer can redeem the heat pump, but an evaluation of the residual value of the heat pump needs to be carried out in each individual case.

2.4 Economy for HaaS vs house owned heat pump

The traditional way to obtain a heat pump is that the house owner buys the heat pump and hire an installer to install it. HaaS is an alternative for house owners who perhaps otherwise do not have the possibility for investing in a new heat pump. There are several differences in the two ways of obtaining a heat pump; one of them is the economy. The energy service company needs a profit but may be able to get a discount on the heat pumps due to a larger number of purchased units. The energy service company, on the other hand, needs to install a heat meter which is not necessary for the house owner (by law a power meter needs always to be installed with a heat pump. However, this meter do not need to be remotely readable). The combination of large-scale procurement and professional maintenance is expected to lead to more efficient heat pumps. However, there are many uncertainties in an economical comparison between HaaS and a self-owned heat pump.

In [1] from 2019 there is an example of a comparison of the economy for HaaS and a self-owned heat pump. In the calculation, the following assumptions have been used:

- Cost of the heat pump for the house owner: DKK 100,000 incl. VAT
- Cost for the energy service company is the same but includes the electricity and the heat meter
- The annual heat demand of the considered house is 18,600 kWh (average size of houses: 140 m^2)
- Sign-on fee is DKK 20,000
- The subsidy in the scheme is DKK 20,000 to the energy service company of which DKK 10,000 is used to reduce the sign-on fee for the house owner
- The heat price for the customer is 0.85 DKK/kWh (approx. 0.12 €/kWh)
- Electricity price for both the energy service company and the house owner: 1.53 €/kWh DKK/kWh (approx. 0.21 €/kWh)[1]
- The efficiency of the heat pump in HaaS is 15-20 % higher than for the self-owned heat pump. A SPF of 3 has been used for the HaaS case, which in section 5.1 is stated to be a good heat pump installation. In section 5.1, the mean efficiency of installed air-to-water heat pumps is estimated to be 2.5
- The annual fee for HaaS is DKK 6,600
- The costs for maintenance for the house-owned heat pump is DKK 3,000 annually
- The profit for the energy service company is annually 7 %
- The house owner needs to take out a loan with an interest rate of 5 % annually
- The calculations are performed for a 10-year period

Table 2.2 gives the results of the calculations.

Table 2.2. Mean annual heating cost with the three different forms of having a heat pump [1].

	Mean annual cost	Difference
House owned heat pump	DKK 25,071	-
HaaS with subsidy	DKK 26,835	7,0 %
Haas without subsidy	DKK 27,402	9.3 %

Table 2.2 shows that in this specific case there is a small economic advantage in owning the heat pump compared to HaaS. In addition, the table shows that there is not a big difference whether the HaaS installation is subsidized by DKK 10,000 or not.

However, maybe more importantly for many potential customers: the sign-on fee is here only DKK 20,000 compared to the price of a new heat pump of DKK 100,000, which may be too expensive for some house owners.

The calculations are of course with some uncertainties, but it seems that Haas could be a rather cheap way of getting rid of all the worries listed in the start of the chapter.

1. If a house was heated by a heat pump, the house owner received a discount on the electricity tax of 0.64 DKK/kWh equal to approx. 0.09 €/kWh in 2019 for electricity use above 4,000 kWh/a. In 2021, this discount has increased to 0.89 DKK/kWh or approx. 0.125 €/kWh.

3.0 Evaluation of the HaaS concept

Photo: EWII Varmepumper

The subsidy scheme for new business concepts for heat pumps originally ran until the end of 2019, but as it took longer than anticipated to develop the business cases and to engage with potential customers, the period of the scheme was extended to the end of 2020.

By October 2018, 527 heat pumps were installed, while this number was increased to 670 by the beginning of March 2019 [1]. By the end of the scheme in December 2020, 885 heat pumps were installed. This mean that less than half of the expected 1,900 heat pump were installed. This number, however, hides important knowledge about the success of the four involved companies. Figure 3.1 shows the number of heat pumps installed by the four companies.

Installed no. of heat pumps

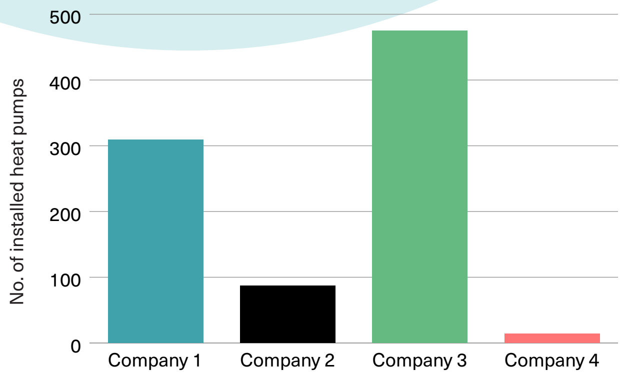

Figure 3.1. Number of heat pumps installed by the four companies by the end of 2020.

From figure 3.1, it can be seen that Company 3 reached the goal of installing 475 heat pumps, while Company 1 had installed 65 % (309 heat pumps) of the goal. The two other companies installed respectively 3 and 18 % of the expected 475 units.

The reason why Company 1 did not reach the goal is twofold. After the installation of 200 heat pumps, the subsidy was only half of the subsidy for the first 100 installations. This made it a bit more difficult to attract new customers. Halfway through the scheme, the company started to focus on larger installations for commercial and public customers.

Company 2 did not have any potential customers in their portfolio from the beginning, and marketing is very expensive. The company was taken over by a power utility in September 2020.

Company 3 did reach the goal as they already were in contact with house owners who could be potential customers.

Company 4 also suffered from the fact that they did not have any potential customers in their portfolio from the beginning. As a small company, it was further a problem that the subsidies were only released after a contract was signed. There were no upfront subsidies for a proper marketing campaign. The company will in the new scheme, team up with a nation-wide heat pump installer (see Chapter 4).

Figure 3.2 shows the number of installations throughout the four-year duration of the scheme. In figure 3.2, it is anticipated that no heat pumps were installed because of the scheme by the beginning of 2017. The graph only contains two other points: October 2018 and end 2020. Figure 3.2 shows that Company 1 and 2 have a constant installation rate, while Company 4 has no installations in 2019 and 2020. Company 3's installation rate decreased a bit after October 2020. Company 3 explains that the higher installation rate during the first period of the scheme is probably due to the great media attention that the scheme received when it was announced. The scheme was mentioned in radio, TV and newspapers. The customers therefore approached the company themselves in the beginning, while the company later had to reach out to potential customers

No. of installed heat pumps

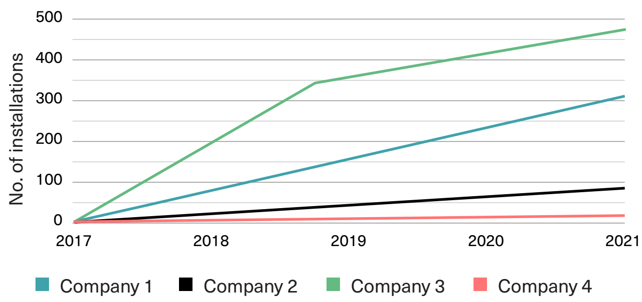

Figure 3.2. The number of installations for the four companies throughout the subsidy scheme.

An initial evaluation of the scheme was carried out in the period from October 2018 to March 2019 i.e., midway in the scheme [1]. The evaluation was based on interviews with the four companies and with 18 house owners. In May/June 2021 after the finalization of the scheme, the four companies were interviewed again.

3.1 Results from the interviews with the four companies

All companies state that the funding of the scheme was necessary in order to develop their business case or to secure a larger rollout. In spite of the difference in number of installed heat pumps, all companies are interested in the follow-up scheme which started in October 2020 – see next chapter. Three of the companies have already been pre-qualified, and the fourth is getting ready to be pre-qualified (May 2021).

The answers from the companies are in the following grouped in themes.

3.1.1 Houses and existing boilers

The companies state that they replaced an existing oil boiler in 83 % to 100 % of the cases. Two companies state that they replaced an existing gas boiler in 5 % and 15 % of the cases. One company even replaced 90 wood pellet boilers.

All companies assessed whether the house was suitable for being heated by a heat pump before entering into a contract. The assessments are based on an analysis of the historical energy consumption for heating of the building in relation to the heated area and the age of the house. A visit to the house has also been a part of the assessments in order to evaluate the insulation level and the existing heating system.

During the inspection of the house, the companies would inform the house owner if they had noticed anything with the house and the heating system that could be changed in order to improve the performance of the heat pump. However, it is up to the house owner if they want to do this.

Based on the assessment, the companies decide whether they want to include the house in their portfolio or not. Some houses are not suited for heat pumps. Especially if they need a very high forward temperature to the heating system in order to keep the house warm. One company, however, states that they accept some of these houses as they use a heat pump which can run at a higher forward temperature than other heat pumps.

Two companies include the dismantling and removal of the old boiler in the sign-on fee. The two other companies consider dismantling/ removal of the old boiler as an extra service that the house owner needs to pay.

3.1.2 Heat pumps and installations

All companies use air-to-water heat pumps, as they are cheaper, easier accessible for service and easy to remove in case of e.g., an early termination of the contract.

The companies use heat pumps in different sizes ranging from 7 to 20 kW. If a larger heat input is required, a cascade solution is used. Most of the heat pumps are capacity controlled, while only a few are on/off controlled.

Some companies use local installers, others always use the same external installers or have their own installers. All the companies state that they have always used skilled installers and that they now only use certified heat pump installers (see Chapter 6). All companies perform a quality check of the final installations.

3.1.3 Measuring of energy consumption and calculation of efficiency

All companies both have an electricity meter and a heat meter on their heat pumps. Three of the companies have installed their own electricity meters while the fourth uses electricity meters installed by the local power utility. This means that for the three companies, the house owners pay the utility for the electricity to the heat pumps, and the energy service companies then reimburse the house owner for the used electricity based on readings from the companies' electricity meter. The fourth company pays the power utility directly for the used electricity. In the new scheme for HaaS, the electricity meter must be a utility meter, so that the energy service company always pays directly for the electricity for the heat pumps.

The heat meter is used for billing the house owner for the delivered heat.

Based on readings from the power and heat meter, the companies calculate the instantaneous efficiency (COP) of the heat pump installations and are after a year able to determine the annual mean efficiency (SPF) see chapter 5. Based on the latter, the companies can make decisions on adequate adjustments to the heat pump if necessary. Until now, no degeneration of the SPF has been seen. Two companies state that due to their continuous check of the SPF, they can optimize their installations over time. The companies have a clear interest in optimizing their heat pump installations, since whenever the efficiency of the heat pump can be improved; it improves the business case of the company.

Two of the companies did not wish to share information about the SPF of their installations due to business considerations. The actual SPF of an installation is further very much dependent on the actual house, the heating system of the building and the behavior of the owner of the house.

However, there seems to be a large spread of SPFs ranging from 2.4 to above 3 (as high as 3.8 has been seen for a single installation).

A well-defined process and a resilient control and data setup is important to avoid problems in collecting the energy data and to keep track of the efficiency of the installations. This worked well for all companies, however, for one company only after switching to another technology.

Three companies state that they do not have many calls from their customers. Monitoring the installations is not that labor intensive. Most labor resources are spent on the mandatory annual service inspection of the heat pumps.

3.1.4 Encountered problems

As already mentioned, it took longer than anticipated (especially for two of the companies) to develop the business case. The engagement with the customers was likewise slower than anticipated, as this way of buying heat was very new.

The company using electricity meters installed by local power utilities found in the beginning that it often took a long time to get the power meters installed. It could take up to 7 weeks, which has resulted in loss of potential customers and additional expenses for the company. Many utilities had difficulties in handling this type of meter installations in their system. This has gotten better with time and all utilities now have internal procedures for handling this type of meter installations.

3.1.5 Changes in the contracts with the customers

During the pilot project, the energy service companies have both gained experience in how to physically run a HaaS as well as insights into the economy of such a scheme. Some changes have been made in the new scheme for HaaS (next chapter), one being a currently fixed subsidy of DKK 25.000 per installed heat pump.

Including the new subsidy of DKK 25,000 DKK per installation[2]:

- One company has not changed the economic terms in their contract
- One company has now no sign-on fee, but has increased the annual subscription fee by DKK 400 (11 %), however, the zero sign-on fee has led to an increase in the heat price from 0.85 to 1.2 DKK/kWh for an annual consumption of approx. 18,100 kWh
- One company has increased the sign-on fee by DKK 5-10,000 (25-50 %), and the annual subscription fee by DKK 995 (20 %) but decreased the heat price from 0.85 to 0.79 DKK/kWh
- One company has decreased the sign-on fee by DKK 10,000 (50 %), decreased the annual subscription fee with 0-17 % depending on the

2. The following conditions were from first half of 2021, before the energy prises started to increase rapidly.

size of the house and furthermore decreased the heat price from 1.08 to 0.90 DKK/kWh for an annual consumption of 18,000 kWh

Some changes have thus been made. With the four above conditions (incl. sign-on fee) and without any changes in subscription fee and heat price over time, the simple mean annual price in a 10-year period for a house with an annual heating demand of 18,000 kWh will be between DKK 22,800 and DKK 27,600 (average price of DKK 24,300). This means that the difference is not as big as could have been expected from the above four sets of terms.

In table 2.1, the annual simple mean costs were between DKK 22,800 and DKK 28,700 with an average of DKK 24,200 DKK. Thus, the average price is the same while the range has decreased a bit. However, it needs to be considered that the subsidy per heat pump has been increased in the new scheme – from DKK 20-10,000 to DKK 25,000, which means that the simple mean annual price in fact has increased with around DKK 1,000 DKK or about 4 %.

However, there may be other expenses, which need to be considered e.g., what are the costs of dismantling and removal of the old boiler and what is the cost of terminating the contract before time? The company with no sign-on fee does not dismantle/remove the old boiler for free, while the company that has reduced the sign-on fee by DKK 10,000 to now DKK 10,000 includes dismantling/removal of the old boiler in the sign-on fee.

3.2 Results from interviews with 18 house owners

As a part of the midterm evaluation of the subsidy scheme in [1], 18 house owners were selected and interviewed about their motivation for choosing HaaS as their heat supply.

Most of the interviewed house owners stated that the main reasons for choosing HaaS were:

- Lower sign-on fee compared to buying a heat pump directly
- Easy and convenient
- No risk regarding the lifetime of the heat pump

Also, but less important were:

- Lower heating bill
- Climate friendly heating system (less CO_2 emission)
- Good dialogue with the energy service company

From the interviews with the 18 homeowners, it seems that HaaS fulfills its goal of making the choice of a heat pump easier for the customers.

Statements from the four companies supports that the low sign-on fee is the main reason for choosing HaaS. Some of the customers could otherwise not afford a heat pump. However, there are also customers who would have bought a heat pump even if HaaS did not exist.

3.3 Conclusion

It took longer than anticipated for the companies to get started, to develop the business cases and to engage with potential customers. Therefore, the period of the scheme was extended to the end of 2020. However, in spite of the extension, only 885 out of the expected 1,900 heat pumps were installed as part of the scheme, but, as mentioned earlier, the aim of the project was to get companies to develop business models and not to install a large number of heat pumps.

Although only one company managed to achieve the goal of 475 installed heat pumps, all companies did manage to develop a business model that they are so confident about that they will continue in the new scheme of HaaS for heat pumps.

Three of the four energy service companies have changed their economic terms of their contract for new customers. However, it is mainly redistribution between the three economical items: sign-on fee, annual fee and cost of delivered heat. For a typical Danish household, the simple annual cost remains the same. Furthermore, although the terms for the companies seems very different, the annual costs for the customers are not that different. However, in this comparison, different costs for demolition and removal of the old boiler have not been considered.

The interviewed customers are satisfied with the concept and especially with the low sign-on fee. They are happy that HaaS is easy and convenient and that they do not have to worry about the maintenance of the heat pump.

It is the impression among the companies that several customers would not have been able to afford a heat pump if it had not been for the HaaS scheme. This means that HaaS has the potential to get more heat pumps installed than would otherwise have been installed. In addition, it shows that there is also a social aspect to this type of heat supply.

Concerning the efficiency of the heat pumps: based on the sparse information from the four companies, it is not possible to draw a firm conclusion on whether HaaS leads to more efficient heat pump installations than otherwise seen in Denmark. However, as all companies now only use certified heat pump installers (which is also a demand in the new scheme) and since the companies benefit economically from well-running heat pump installations with high efficiencies, it is believed that HaaS – at least for new installations – will lead to more efficient heat pumps.

It is too early to determine whether HaaS for heat pumps will lead to the necessary number of installed heat pumps for achieving the ambitious Danish climate goals. However, the Danish Parliament has decided to start a new more permanent scheme on heat pumps on subscription. This scheme is described in the following chapter.

4.0 The new HaaS scheme

Photo: OK a.m.b.a., Ole Hartmann

Subsidy schemes for the replacement of individual oil boilers are not something new in Denmark. The first scheme for scrapping oil boilers was launched on 1 March 2010 with a budget of 400 mil. DKK. The scheme lasted until 30 June 2011.

In the scheme, the house owner could apply for:

DKK 10,000 when replacing the oil boiler with a district heating unit
DKK 15,000 when replacing the oil boiler with an air-to-water heat pump
DKK 20,000 when replacing the oil boiler with a ground source heat pump

In total, nearly 22,000 house owners applied for this funding, of which nearly 20,000 were granted. Mainly conversion to district heating received funding. However, also 5,854 ground source heat pumps and 2,784 air-to-water heat pumps received grants [3].

4.1 New scheme for HaaS

With the Danish Climate Agreement for Energy and Industry signed by most parties in the Danish Parliament in June 2020, a more lasting scheme was established. This scheme entails conversion of oil boilers as well as natural gas boilers for space heating. At the same time, the total budget of Government financial support was increased in order to ensure cheaper conversions for more Danish households.

Different from the above-described earlier scheme, this scheme is based on experience from the pilot project described in chapter 3. The subsidy is given to the energy service company as in the pilot project. However, house owners can instead still apply for a subsidy to replace an oil boiler themselves, but this is under a more general scheme where various forms of energy efficiency measures in buildings can be applied for.

Subsidies are only given to replace oil and gas boilers outside district or local heating network areas or areas that are not planned for district heating. The installed heat pumps should be air-to-water heat pumps. The electricity consumption for the heat pumps needs to be measured by a utility meter.

In order to encourage as many energy service companies as possible to participate in the scheme and offer heat pumps on subscription, no companies have been pre-awarded subsidy pledges. The scheme is now based on a model where all energy service companies can apply for admission to the scheme through a pre-qualification process run by the Danish Energy Agency.

The pre-qualified energy service companies apply for subsidies on a continuous basis, and the final number of grants depends on how many subscriptions the energy service company registers throughout the life of the scheme. It is expected that this will ensure competition and thereby better and cheaper subscription solutions for house owners.

The pre-qualification phase has been designed to objectively ensure that the energy service companies have an adequate administration and sales setup as well as financial capacity to operate the scheme. The energy service companies must have existing knowledge on how to install and maintain heat pumps as well as the financial ability to install at least 100 heat pumps. The energy service companies further need to have a setup for continuous optimization of their installed heat pumps. Energy service companies can apply for pre-qualification throughout the entire life of the scheme under supervision by the Danish Energy Agency. When the scheme expires, the market should have reached a level where it will be attractive for energy service companies to continue to provide solutions to existing and potential customers in the future.

In order to ensure a geographically dispersed scheme, smaller parts of the funding for the scheme have been reserved for the five Danish regions (local government areas). Specifically, 5 % of the funding has been reserved for each region, amounting to 25 % of the funding in total.

The remaining 75 % of the funding can be spent in all regions. The scheme has been set up in this way to prevent only regional service providers or utility companies from applying. The pilot project indicated that this could happen.

The market for heat pumps on subscription is still under development in Denmark, but experience so far indicates that a fixed level of grants corresponding to approximately one-quarter of the price of a privately purchased heat pump results in the highest amount of potential further conversions through the scheme. In situations where a heat pump is small and thus cheaper, the amount of the subsidy will be reduced equally, as maximum grant size corresponds to 45 % of the eligible costs according to the EU state aid legislation. The maximum subsidy per heat pump is DKK 25,000.

In May 2021, five companies had been pre-qualified. Of the four companies in the pilot project, three have been pre-qualified while the fourth is getting ready to be pre-qualified. This means that despite problems in the pilot project, none of the four companies has been scared away from the concept which is a good sign for the survival of HaaS.

A new company based on a power utility company has in May 2021, 550 customers spread all over Denmark. This number was in October 2021 inceased to 800 customers.

4.1.1 District heating companies

The Danish District Heating Association published in October 2019 a document [4] in which they argue that district heating companies can also provide HaaS via individual heat pumps, as they already are used to handling customers buying heat on subscription. The concept of district heating is well known also by house owners outside heating districts. This may give HaaS a certain credibility which private company may not have.

At least one district heating company has taken up the challenge, however, more in the form of user-owned heat pumps. The customer buys the heat pump through the district heating company which may also help obtaining a loan for financing the heat pump. The price is DKK 75,000. The customer becomes a member (part owner) of the company which is a traditional way for Danish district heating companies and pays a quarterly annually fee for maintenance and for saving up for a new heat pump. The customer pays for the electricity consumption directly to the power utility.

5.0 Danish heat pump installations by 2016

Photo: Sustain, Klaus Gadeberg

Heat pumps are expected to play a major role in the transition of the Danish energy system to become climate neutral. Both in the form of large heat pumps connected to district heating and as small heat pumps in houses situated outside the district heating networks. This makes good sense as heat pumps can be powered by electricity from wind turbines and PV. Heat pumps are furthermore very efficient, producing more kWh heat than kWh electricity being consumed. However, in order to decrease the number of wind turbines and the area of PV fields it is important that the efficiency of the installed heat pumps is as high as possible.

The efficiency of a heat pump can be expressed in different ways:

- COP: Coefficient of Performance – typically used during test of a heat pump at specific test conditions
- SPF: Seasonal Performance Factor – the actual annual efficiency when installed in a house
- SCOP: Seasonal Coefficient of Performance – an annual weighted efficiency mainly for labeling purpose

COP (Coefficient of Performance) is a measure of efficiency. The efficiency of any machine or system can be calculated as the ratio of amount of work done by the machine to the amount of work given to the machine. In the case of a heat pump, its efficiency is the ratio of useful heat energy produced to electrical energy consumption. A COP of 3 means that the heat pump supplies 3 times as much heat energy to the system as it consumes in electrical energy. COP for heat pumps are typically measured at specific conditions defined in CEN/EN 14825.

SPF (Seasonal Performance Factor): Where COP gives the efficiency of a heat pump at a given time, SPF gives the same but for annual performance of the heat pump. Air source heat pumps use heat energy from the outside air and ground source heat pumps use heat energy from the ground. The heat pump needs to raise the temperature of the outside source to the temperature needed by the heating system.

The outside temperature is obviously lower in winter and higher in summer and this affects the amount of work the heat pump needs to do. At lower outside temperatures the heat pump will need more electrical energy to produce a given heat output, meaning that the system is less efficient. As a result, the COP will be different through the seasons and SPF encompasses this by considering the annual performance of the system. SPF includes both space heating demand and hot water production

SCOP (Seasonal Coefficient of Performance) describes the heat pump's average annual efficiency performance. SCOP is, therefore, an expression for how efficient a specific heat pump will be for a given heating demand profile. The SCOP calculation method consists in dividing the heating season into a number of hours with different temperatures (called bins), which together reflect the variations of the forward temperature and source temperature (ground or air) over a heating season. Furthermore, a heating-demand curve is determined that states the heating demand that the heat pump needs to meet for each set of ambient temperatures. A COP value for each of the bins is found, and together these form the basis for calculating the average COP, i.e. the SCOP[3].

SCOP do not include hot water production.

SCOP is the parameter forming the basis for European minimum requirements and energy labelling for heat pumps. Since the climate varies across Europe, SCOP can be calculated for three different climate zones (climate conditions).

These are:

- Average corresponding to Strasbourg
- Warmer corresponding to Athens
- Colder corresponding to Helsinki

3. For information on how to calculate SCOP please refer to: https://www.varmepumpsforum.com/vpforum/index.php?action=dlattach;ts=1505933467;topic=65119.0;attach=49952

In European energy labelling, SCOP for the Average climate profile is mandatory, whereas the other two profiles are voluntary. The minimum requirement is, thus, the SCOP for Strasbourg.

Heat pumps on the market in Denmark are listed on Varmepumpelisten [4] (List of heat pumps). The heat pumps are here sorted with the heat pumps having the highest SCOP being listed first. Table 5.1 show the highest SCOPs from the Varmepumpeliste for the two types of heat pumps:

- Ground source heat pumps here called Liquid to water
- Air-to-water heat pumps

The SCOP for a heat pump is listed for two different heating systems: underfloor heating and radiators. The reason for this is that radiators typically need a higher forward temperature from the heat pump. A higher forward temperature decreased the efficiency of a heat pump. In general, the efficiency of a heat pump is reduced by 2-3 % for each degree increase in the forward temperature.

Table 5.1. The highest SCOPs found on the Heat Pump List (Varmepumpeliste) in April 2021.

SCOP	Heating system	
Type of heat pump	Underfloor heating	Radiators
Liquid to water	5.55	4.25
Air-to-water	5.2	3.9

It should be mentioned that there is only a small difference of less than 10 % in the SCOP among the 20 highest listed heat pumps. Thus, most heat pumps are today generally very efficient.

The SCOP for air-to-water heat pumps is a bit lower than for ground source heat pumps. The reason for this is twofold:

- The heat uptake from the ground is more efficient than the heat uptake from the air. Moreover, the fan in an air-to-water heat pump uses more electricity than the circulation pump in the external circuit of a gound source heat pump
- During cold humid periods, water condenses on the surface of the evaporator (the outdoor part of the heat pump) of an air-to-water heat pump and may freeze to ice. The ice reduces the heat transfer and must be removed by deicing which means that the heat pump is reversed, and electricity is used to heat up the evaporator.

4. https://sparenergi.dk/forbruger/vaerktoejer/varmepumpelisten

The SCOPs given on the Heat Pump List is for the average climate which does not exactly represent Danish conditions. SCOP further does not include hot water production, while SPF does. Due to comparison between SCOPs and SPFs for Danish conditions, the following relations between SCOP and Danish SPF has been developed:

- Ground source heat pumps: SPF = SCOP * 0.9
- Air-to-water heat pumps: SPF = SCOP * 0.85

This leads to the SPFs for Danish conditions in table 5.2.

Table 5.2. The highest expected SPFs based on SCOPs found on the Heat Pump List in April 2021.

	Heating system		Average of underfloor heating and radiators
Type of heat pump	Underfloor heating	Radiators	
Liquid to water	5.0	3.8	4.4
Air-to-water	4.4	3.3	3.85

Table 5.2 also indicates the mean value of SPFs for heat pumps in underfloor heating systems and radiator systems, as this is a convenient figure as shown later. These mean value states that the difference in SPF between ground source heat pumps and air-to-water heat pumps is around 0.5.

Table 5.2 shows that the efficiency of heat pump installations is quite high. This, however, are theoretical efficiencies. What are the actual efficiencies in real physical installations?

5.1 The actual efficiency of Danish heat pump installations

The actual efficiency depends on a lot of things like correct installation without faulty connections, the right setting of the heat pump etc. The real efficiency is often much lower than the theoretical value.

In order to obtain an impression of the efficiency of Danish heat pump installations, the Danish Energy Agency in 2015 asked the Danish Technological Institute to conduct a study of the actual efficiencies of Danish heat pump installations.

The efficiency of heat pump installations in private households is typically not recorded, although some heat pumps do calculate the COP minute by minute. However, some projects have been carried out where data for the heat pump installation were available, including collected measurements of electricity consumption and heat produced. The vast number of measurements were historical date from 2011-2012 [5], while in 2016 ongoing but fewer measurements were from [6]. The investigated heat pumps were thus installed before the HaaS scheme described in chapters 2-3 was implemented.

At the time of the study, the SPF for a 'good installation' and a 'really good installation', respectively, was assumed to be as shown in table 5.3. These values are a bit lower than shown in figure 5.2. The reason for this is that existing buildings and heating systems are typically not ideal for heat pump operation. Furthermore, most heat pumps at that time were on/off controlled heat pumps, while the SPFs given in table 5.2 are for capacity-controlled heat pumps that have a 10-15 % higher performance than on/off controlled heat pumps [7].

Table 5.3. SPFs for heat pump installations considered as "good" or "really good".

Type of heat pump	Good installation	Really good installation
Liquid to water	3.5	4.0
Air-to-water	3.0	3.5

The results and a full description of the survey can be found in the report 'The Good Installation of Heat Pumps' [7]. The following is a short description of the findings from [7].

In 2015, the main part of installed heat pumps was of the type ground source heat pumps. Only few air-to-water heat pumps were installed at that time. This picture is opposite in 2021, where the majority of the installed heat pumps are air-to-water heat pumps (80 % in 2020). As only a minor part of the measurements in [5] and [6] are for air-to-water heat pumps, the following described investigations are for ground source heat pumps. However, these findings are also applicable for air-to-water heat pumps.

Reference [5] had historical data for 170 ground source heat pumps. The measured SPFs for these heat pumps are shown in figure 5.1 where the heat pumps are sorted according to the SPF. Figure 5.1 show that only 15 % of the 170 heat pump installations could be stated as "good installations", while only 6 % could be stated as "really good installations". One installation has a SPF as low as 1.7. The mean value of the SPFs shown in figure 5.1 is 3 which is 0.5 lower than for a good installation.

Measured SPFs for Danish ground source heat pump installations

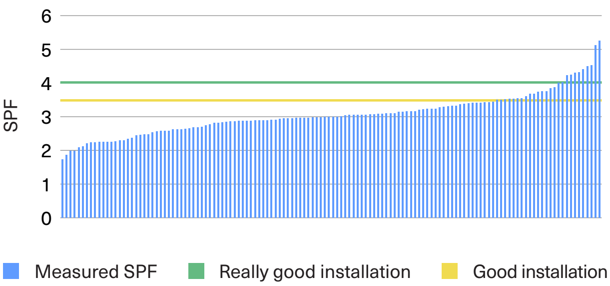

Figure 5.1. The measured SPF for 170 Danish ground source heat pumps measured during 2012 [7].

Why was the efficiency for the main part of heat pumps in figure 5.1 lower than expected?

Table 5.2 shows that there is a rather large difference between the SPFs for underfloor heating systems and for radiator systems. Can this be the reason that radiator systems are the worst performing systems in figure 5.1? Figure 5.2 shows otherwise. Figure 5.2 is identical to figure 5.1 besides the coloring:

- Yellow: Heat pump installations with only radiators
- Red: Heat pump installations with only underfloor heating
- Blue: Heat pump installations with both underfloor heating and radiators – e.g., underfloor heating in the bathroom(s) and radiators in the rest of the house

The three heating systems are more or less evenly distributed in figure 5.2. This evenly distribution shows that the mean SPF value from table 5.2 is a good assumption. However, the "really good" systems (having a SPF above 5) are in houses with underfloor heating. This is most probably because these installations do not contain errors.

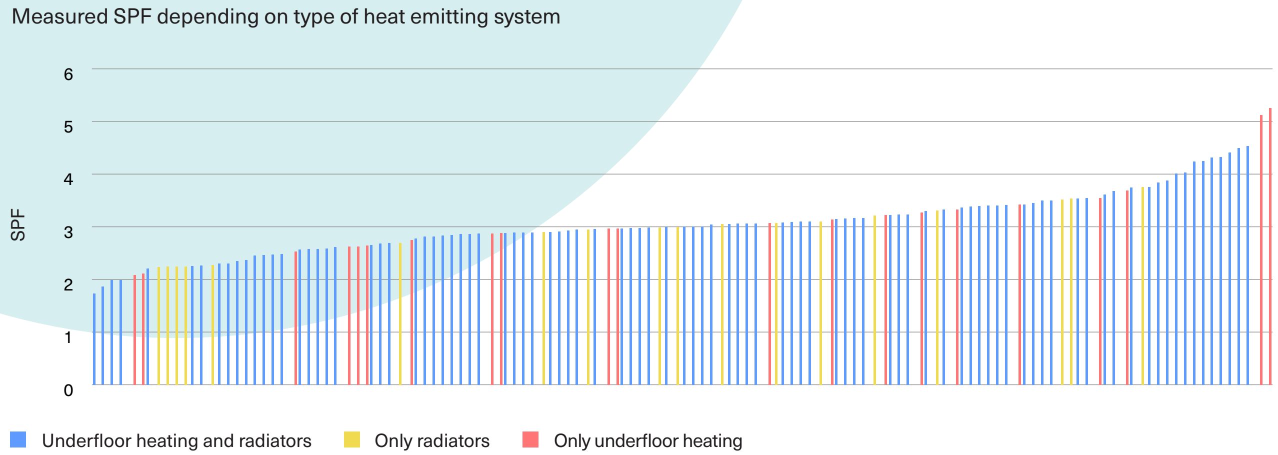

Figure 5.2. Identical to figure 5.1 except that the three possible heating systems are indicated by colors.

Figure 5.3 indicates that it is not poor heat pumps that are causing the low SPF. Figure 5.3 is identical to figure 5.1 and 5.2, but here the coloring indicates different heat pumps in the form of different manufactures. There are five main manufactures plus a group of manufactures who supplied only one or two of the heat pumps. Again, as in figure 5.2, there is a fairly even distribution indicating that it is not the heat pumps that are causing the differences in SPF.

So, what can then cause the often rather low performance of the heat pump installations? The main factor responsible for the SPF is the temperature difference between the temperature of the cold outside (ground or air) delivering

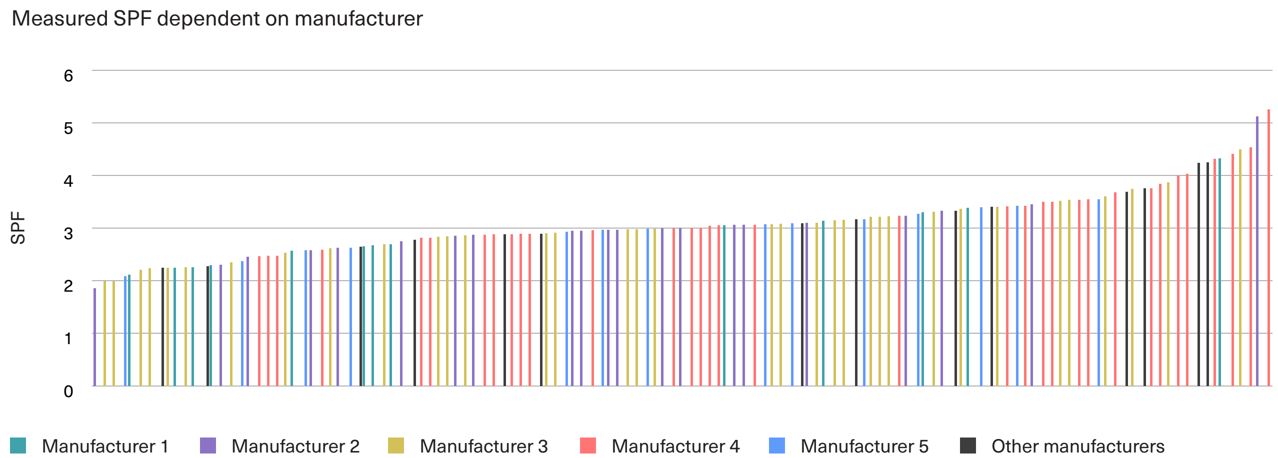

Figure 5.3. Identical to figure 5.1 except that the different manufacturers of the heat pumps are indicated by colors.

heat to the heat pump and the required forward temperature from the heat pump to the building to maintain the preferred indoor air temperature and the temperature of domestic hot water. A large difference between these two temperatures gives a low SPF. As stated previously: An increase of this temperature difference of one-degree Celsius leads to a decrease in the SPF of 2-3 %.

In order to examine what goes wrong, the heat pumps having continuous measurements at that time [6] were included. In this population, there were only 32 ground source heat pumps with sufficient high-quality measurements. SPF from [6] showed the same result as in figure 5.1 [7]. The good thing about these heat pump installations was that they were accessible. Ten of the 32 heat pump installations were selected for physical inspection. The owners were contacted, and a team of heat pump experts visited the houses.

Based on this and on already existing knowledge among the members of the visiting crew, the following areas of typical issues leading to poor SPFs has been identified:

- Errors and problems in the installation
- Missing or wrong setting of the heat-emitting system
- Missing or wrong setting of the heat pump

5.1.1 Errors and problems in the installation

The heating system of the house needs to be suitable for a heat pump. In existing houses with a gas or oil boiler, the heating system (radiators) is typically designed for a high forward temperature from the boiler. This forward temperature is typically too high for a heat pump. A heat pump can normally deliver up to about 50°C, however, with decreasing COP. Above this, an electrical heating element in the heat pump will deliver the remaining heating, however, at a very low efficiency with a COP of 1 which equals direct electrical heating. This will often drastically reduce the overall SPF of the heat pump.

In houses that have been energy renovated with new windows, additional insolation in the ceiling, additional wall insulation and/or a mechanical ventilation system with heat recovery, the existing radiators may in fact have become oversized and, thus, appropriate for heat pump operation. In other cases, the radiators may need to be replaced with larger ones.

Some heating systems include a shunt where hot water from the boiler is mixed with cooler return water from the heat-emitters (radiators or underfloor heating circuits) in order to reduce the forward temperature to the radiators. With a shunt, the heat pump must thus deliver a higher temperature than necessary. Therefore, the shunt needs to be removed. However, in combined radiator/underfloor heating systems, a shunt may still be necessary on the underfloor heating side, as the forward temperature required for the radiators may be too high for underfloor heating.

The higher the flow in the heat distributing system, the lower is the needed temperature difference across the heat pump. Therefore, components in the heating system with a high-pressure loss must be replaced. This can be pipes with a too small diameter, bad functioning valves, filters etc.

The heat pump must be installed as described by the manufacture. For air-to-water heat pumps, it is very important that the pipes from the external part and into the house are well insulated. For this type of heat pump, it is also very important to ensure that the evaporator can get rid of the condensing water so that it does not pile up in the external heat exchanger.

5.1.2 Missing or wrong setting of the heat-emitting system

It is very important that there is the correct flow through all heat-emitters in the house (radiators or underfloor heating circuits). If one heat-emitter has a too large flow, there is less flow to the other heat-emitters. The rooms with these heat-emitters then need a too high forward temperature from the heat pump in order to receive sufficient heat as the emitted heat is proportional with $\dot{m} * \Delta T$, where $\dot{m}$ is the flow rate and ΔT is the forward temperature minus the return temperature from the heat-emitter. Therefore, a wrongly balanced heat-emitting system leads to a poor SPF for the system.

It is also important not to set the thermostat of the domestic hot water tank too high, as a temperature level above 50°C will start the electrical heating element and thus reduce the SPF.

5.1.3 Missing or wrong setting of the heat pump
The forward temperature of a heat pump is given by a heating-curve (the correlation between the outdoor temperature and the forward temperature from the heat pump) programmed in the heat pump. If it is very cold outside and the house need much heat, the heat pump will produce a higher forward temperature than when the outside temperature is higher. Therefore, the setting of the heating-curve has an influence on the SPF. The default heating-curve set by the manufacturer is seldom correct for the actual installation and needs to be adjusted according to the actual house. Setting it too high will lower the SPF. However, adjusting the heating-curve, requires not only skills in the physically installation of the heat pump, but also skills in defining the need of the actual house.

In two of the houses from the survey [7], the heating-curve of the heat pump was adjusted during the visit and a saving of 7-8 % was immediately seen without any loss in heating comfort. In a third house, the heating comfort was poor. The house was situated in a rather windy location leading to an often too low room temperature. The heating-curve was adjusted and the problems with heating comfort disappeared without any reduction of the SPF.

Some installers may deliberately set the heating-curve too high so that they do not receive complaints about lack of heat. As the owner of the heat pump cannot compare a new higher electricity bill with a former gas or oil bill, the owner does not know that the SPF of the heat pump is too low. The owner is therefore not aware of whether the heat pump actually performs as expected.

However, the owner of the heat pump may also be the causes of a low SPF. If the owner e.g., during a cold period would like the room temperature to be somewhat higher than the heating-curve in the heat pump allows, he or she will raise the heating-curve which may be fine if the heating-curve is subsequently lowered again. This does not always happen which thus leads to a lower SPF.

5.1.4 The result of the study on Danish heat pump installations
The study concluded that a large share of the heat pump installations did not have the expected high efficiency. Only 15 % of the 200 representative heat pump installations could be considered as “good installations”.

The problem does not arise from the heat pumps themselves. Today’s heat pumps are very efficient. The problem lies in the installation and the operation of the heat pumps and some of the reasons are:

- The heat distribution/heat-emitting system is not suited for heat pump operation. A high forward temperature is needed to meet the heating demand of the house
- The heating system is wrongly balanced leading to a too low flow in some radiators or underfloor heating circuits, which again causes the need of a too high forward temperature
- The heating curve is incorrectly adapted to the house which is either caused by the installer or the owner of the heat pump
- Installing a heat pump requires skills other than connecting a heat pump to a heating system. It requires skills in:
    - Evaluation on whether the existing heating system is suitable for heat pump operation, and if not how to fix it
    - Balancing the heating system in order to obtain the correct flow in all radiators or underfloor heating circuits
    - Evaluation and adjustment of the correct heating-curve for the actual house
    - Instruction to the house owner on ‘dos and don’ts’
    - Many installers only install one or two heat pumps a year and will therefore hardly obtain the above-mentioned skills

The survey was conducted on ground source heat pumps, but as the defined problems relate to the heating system in the house as well as the installer and the owner, the above conclusions are also valid for air-to-water heat pumps. As the main value of the shown SPFs in figure 5.1 is 3.0 for ground source heat pumps, it is assumed that the mean SPF for air-to-water heat pumps based on table 5.2 was 2.5 at that time.

The study shows that there is still a large potential for increasing the performance of Danish heat pumps. Based on the survey, it is proposed to reduce the problems in heat pump installations by:

- Improving the training of installers
- Improving the quality insurance of the installations
- Inspecting the installations regularly

Improved training: Most suppliers have courses for their installers, and there are two certified educations for heat pump installers in Denmark. Since 2020, it has become mandatory to use certified installers in order to receive subsidies for installation of heat pumps as explained in Chapter 4.

Improved quality insurance: As part of the mandatory training, the certification should only be maintained if a number of installations per year are inspected by independent persons. Persons with the right to penalize if an installation has faults.

Regular inspections: Danish heat pumps must be inspected annually, but only for checking of the filling and pressure of the refrigerant. The study recommend that this annual inspection shall be combined with an energy inspection by a certified heat pump installer in order to discover any faults. This could e.g., be in the adjustment of the heating-curve, too much dirt on the external heat exchanger of an air-to-water heat pump or important changes in the heating system.

The above points will be investigated in the next chapter.

5.2 The economy of Danish heat pump installations

Like in [1] (section 2.4), economic calculations have also been carried out in [7]. Here the economy of private owned heat pumps is compared to oil, gas and wood pellet boilers.

Figure 5.4 shows the results of these calculations, where the economy is shown in the form of Present Values [5] (including all costs in the form of the installation cost of the heat pump/boilers, maintenance costs and energy costs for power, oil, gas or wood pellets). The Present Value is shown dependent on the actual annual energy demand for space heating and domestic hot water (DHW).

Only air-to-water (A/W) heat pumps are shown, as the majority of today's installations are air-to-water heat pumps. The economy of air-to-water and ground source heat pumps (L/W) is compared in figure 5.5. The calculations are of course subject to some uncertainty due to the chosen conditions for the calculations. A detailed description of the calculation conditions can be found in [7]. However, it is believed that figure 5.4 and 5.5 provides a reasonable picture of the economy – at least for 2016, when the calculations were carried out.

Figure 5.4 shows for this case that a gas boiler performs better compared to air-to-waters pumps in houses with a low annual heat demand – until 17 MWh/a compared to a heat pump with a SPF of 3.5 and until 25 MWh/a compared to a heat pump with a SPF of 3.0. A wood pellet boiler is as good as a heat pump with a SPF of 3.5 until 22 MWh/a, after which the heat pump outperforms the boiler. The wood pellet boiler is always a bit better than a heat pump with a SPF of 3.0. All heat pumps, except the poorest with a SPF of 2.0, outperform the oil boiler.

Figure 5.5 shows that for this case the economy of air-to-water heat pumps are better than for ground source heat pumps with identical SPF. However, the SPF of a good installation is different for the two types of heat pumps: 3.0 for air-to-water heat pumps but 3.5 for ground source heat pumps – see table 5.3. For this case, the economy is identical, but the ground source heat pump will use less electricity: (1-3.0/3.5)*100 = 14 % less electricity.

The advantage of using air-to-water heat pumps is that they are cheaper and easier to install

5. Present value is the current value of a future sum of money or stream of cash flows given a specified rate of return. Future cash flows are discounted at a given discount rate.

because they are installed outside the house and no pipes need to be buried in the ground. Due to this, the majority (80 % in 2020) of heat pumps being installed in Denmark today are air-to-water heat pumps. However, air-to-water heat pumps have some drawbacks: They are more visible than ground source heat pumps and they are noisier. Air-to-water heat pumps should be located close to the house in order to reduce the heat loss from the pipes to and from the house, however, in such a way that the noise from especially the fan does not disturb the neighborhood or the people in the house.

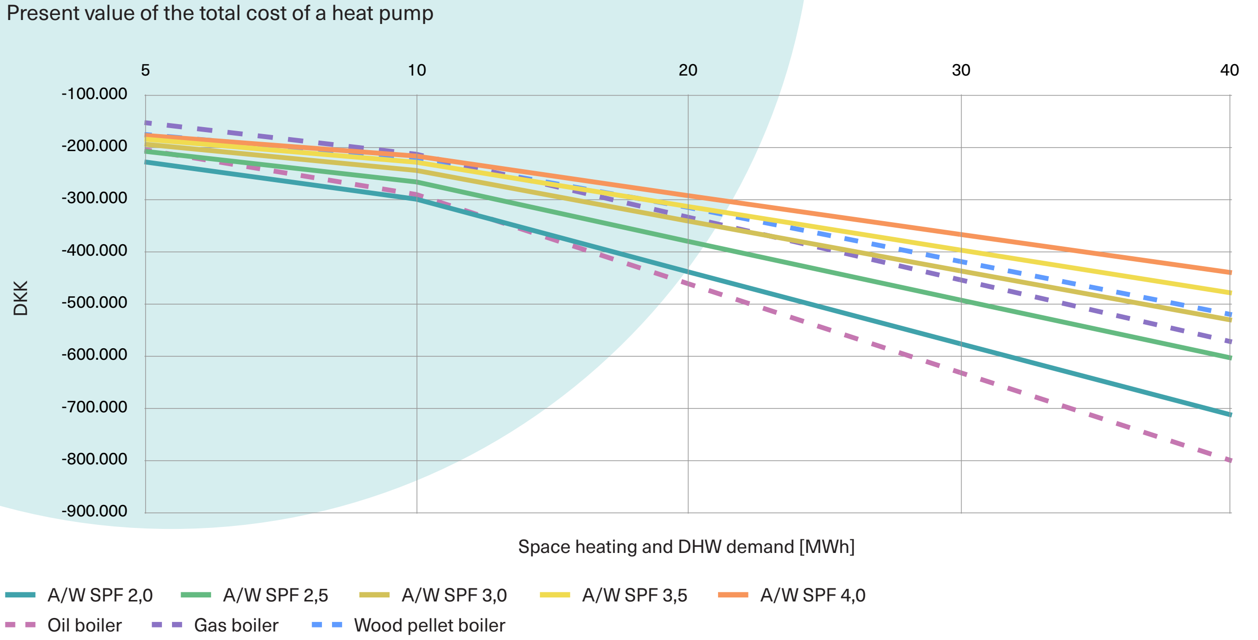

Figure 5.4. The economy of air-to-water heat pumps with different SPFs compared to the economy of oil, gas and wood pellet boilers.

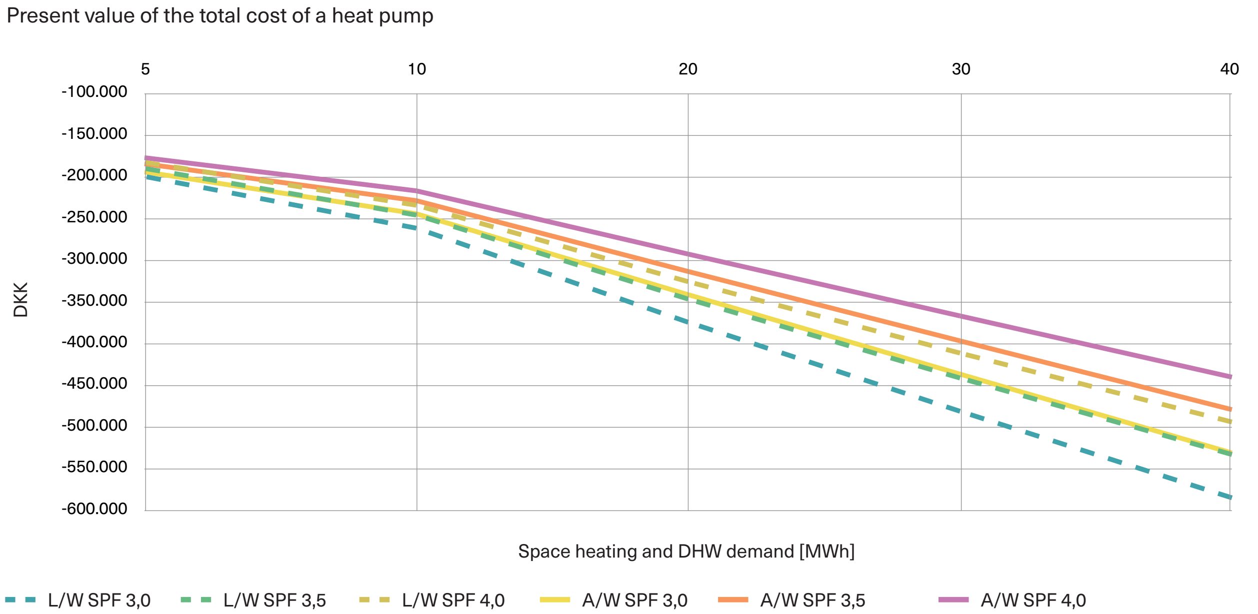

Figure 5.5. The economy of air-to-water and ground source heat pumps.

6.0 Danish heat pump installations by 2021

Photo: OK a.m.b.a., Ole Hartmann

In the previous chapter, it was proposed to reduce the problems in heat pump installations by:

1) Improving the training of installers
2) Improving the quality insurance of the installations
3) Inspecting the installations regularly

6.1 Certification scheme for RE installers

By Executive Order on an approval scheme for companies that install small renewable energy plants (hereafter called the RE approval scheme) from 2013, an education scheme for installers of small heat pumps, PV, solar thermal, biomass boiler and biomass stoves was established. The RE approval scheme is voluntary, but in later subsidy schemes it has been made mandatory for obtaining subsidies that RE systems are installed by RE certified installers. This has resulted in an increase in the number or RE certified installers. In 2016, there were 71 RE certified installers/companies, half of which were certified in installation of heat pumps, while in June 2021 there are close to 1,000 RE certified installers.

A RE certified company needs, in addition to having at least one RE certified installer, to have an approved quality management system.

A certified RE installer has been educated, passed an exam and is skilled in all aspects of installing a RE system. For heat pumps, this means knowledge and skills in:

- Relevant legislation
- Environment, safety and noise issues
- Function of heat pumps and related components
- Providing advice to the customer
- Determination of the energy demand for space heating and domestic hot water in order to be able to correctly dimensioning a heat pump
- Correctly connect to the heating system of the house, including dimensioning of pipes and pipe insulation
- Evaluating whether changes to the heat-emitting system is necessary
- Correctly adjust the controllers of the heat pump and the heat-emitting system
- Installing safety equipment

RE certified installers/companies should thus be able to deal with all three issues in the above list of how to reduce problems in heat pump installations.

In order to examine whether RE certified installers can solve the problems described in the previous chapter, the Danish Knowledge Centre for Energy Savings in Buildings[6] conducted a study during the first half year of 2021 [8] on behalf of the Danish Energy Agency with the aim to:

1) Investigate the quality of at least 24 heat pump installations and provide realistic SPF values for a representative sample of Danish households with heat pumps
2) Determine whether RE certified heat pump installations are more efficient than non-RE certified heat pump installations
3) Examine the potential of expanding the existing mandatory service inspection for heat pumps with an energy inspection

It was a prerequisite that the investigated heat pump installations should be representative for Danish conditions regarding the construction year of the house (range of selected samples: 1848-2020), the size of the house (range of selected samples: between 72 and 380 m^2), heating system (both underfloor heating and radiators), both ground source and air-to-water heat pumps as well as houses from all five regions in Denmark. The selected heat pumps were installed during the period 2015-2021, of which 44 % (11 units) were installed in 2020, while between two and four units were installed annually in the other years. During this period, there were not many RE certified installers, meaning only 29 % of the investigated heat pump installations were carried out by certified RE installers.

Different from the previous chapter, the main part of heat pumps were air-to-water heat pumps. Only 16 % were ground source heat pumps, which, however, quite well represents the present situation in Denmark. In 38 % of the houses, the space heating system was underfloor heating, while the rest only had radiators or a combination

6. https://byggeriogenergi.dk/

of radiators and underfloor heating (the latter configuration acts like a pure radiator system, as it is the radiators that determine the forward temperature from the heat pump).

The investigations were carried out in two ways:

- Measurements
- Visual inspection including correction of some problems in the installations

6.1.1 Measurements
Two measuring periods of 14 days were performed. For both periods, values from the energy meters (power to the heat pump and heat from the heat pump) were read at both the beginning and end of the period. The measured energy demand was then used to calculate the annual SPF based on a method of dividing between produced space heating and domestic hot water (DHW) as well as degree days for a reference year [8].

The meters were either external meters or internal meters in the heat pumps. In some cases, both external and internal meters were available, enabling a calibration of the internal meters. The result was that the quality of the internal meters was sufficiently high for the purpose of the investigation.

The **first test period** was to determine the efficiency of the heat pumps installed by the RE or non-RE certified installers in order to detect whether RE certified installations have a higher performance.

The **second test period** was performed after the visual inspection where some of the observed errors in the installations had been corrected. The aim of this test period was to determine whether a mandatory energy inspection would lead to better performing heat pump installations.

6.1.2 Visual inspection
The visual inspection was based on a set of predefined parameters, which were given points from 1 to 5 by the expert who performed the inspection of the heat pump. The parameters were grouped in three of different importance ranging from 1 to 3:

Most important (3):
Correct dimensioning and adjustment of the heat pump and heating system as well as customer satisfaction
Middle important (2):
Correct piping to and from the heat pump, correct insulation, correct adjustment of the DHW temperature and location of the heat pump (noise – only for air-to-water heat pumps)
Lowest importance (1):
Distance from the heat pump to the house (only for air-to-water heat pumps), drainage from the external heat exchanger (only for air-to-water heat pumps) and external energy meters

The max obtainable points were 100.

Based on the visual inspection, possible errors or inconveniences that were easy to change were corrected and the second test period was started.

6.2 Result of the study
The result of the study cannot be directly compared with the results from the study in Chapter 5 due to differences in the methodology. In Chapter 5, the SPFs were measured as actual annual efficiencies based on a full year of measurements, while the SPFs in Chapter 6 are calculated based on only 14 days of measurements during a cold period. However, the trend found in the following can be used with caution in conjunction with the results from Chapter 5.

Different from the 200 samples in Chapter 5, the conclusions of Chapter 6 are based on only 25 samples, making the results somewhat uncertain. However, the relative trends are considered to be realistic while the absolute figures are more uncertain.

6.2.1 Results from the first test period
Table 6.1 shows the calculated SPFs for the installed heat pumps. In order to minimize the influence of more extreme measurements, the two highest and two lowest values have been omitted.

Table 6.1. Calculated SPFs for heat pump installations installed by RE and non-RE certified installers. The SPFs are shown as an interval in order to illustrate the uncertainty and that the SPF is dependent on the actual installation.

	Installed by RE certified installers	Installed by non-RE certified installers
Number of installations	6	15
Calculated SPF	3.2-3.5	2.7-3.0
Part with underfloor heating only	50 %	38 %

Table 6.1 shows that the SPF of RE certified installations is 0.5 higher than the SPF for non-certified RE installations. The higher SPF for RE certified installers may be because their installations had more underfloor heating which may lead to a higher SPF for these installers. Table 6.2 shows the difference in SPF for underfloor heating systems compared to radiator systems.

Table 6.2 indicates a difference of 0.6 between the SPF for underfloor heating systems and radiators, which is comparable to the 0.5 postulated in Chapter 5. Based on this, it can be calculated that if 50 % of the non-RE certified systems had been underfloor heating system in table 6.1, it would have only led to an increase in the SPF of less than 0.1 for the non-RE certified installations. Figure 5.2 similarly shows that the type of heating system is not the main reason for differences between the obtained SPF.

Table 6.2. Calculated SPFs for heat pump installations with underfloor heating compared to installations with radiators. Again, all installations minus the two highest and two lowest values.

	Underfloor heating	Radiators
Number of installations	8	13
Calculated SPF	3.1-3.4	2.7-3.0
Part with underfloor heating only	50 %	38 %

Table 6.1 thus indicates that a RE certificate is a good way to improve the efficiency of heat pump installations.

6.2.2 Results from the visual inspection

The 25 heat pump installations were visited by an expert who gave the installations points as described in section 6.1.2. In [8], a score of 80 in the visual inspection was defined as a “good installation”.

The inspections revealed that 75 % of the installations scored above 80, making them good installations. This is as opposed to the 15 % good installations found in the previous study, as described in Chapter 5. So, have the quality of heat pump installations increased considerably during the past few years?

The number of good installations in Chapter 5 and 6 cannot be compared. In Chapter 5, the conclusion was based on real measurements while the 75 % in this chapter is based on a visual inspection. Therefore, the assessment method is far too different to allow a comparison. The results from the visual inspection are described in more detail in [8]. However, the mean SPF found in figure 5.1 was 3.0 for ground source heat pumps leading to a possible mean SPF for air-to-water heat pumps of 2.5. The SPF for non-RE certified installations in table 6.1 is 2.95 with only a small part of ground source heat pumps. It thus seems that the quality of non-RE certified installations has increased. However, part of the increase in SPF may be due to more efficient capacity-controlled heat pumps.

The visual inspections lead to a mean score for the RE certified installations of 91 (all RE certified installations were above 80); while the non-RE certified scored a mean of 81.5 with 39 % of the installations were below 80. The mean scores for the RE certified installations were thus 12 % higher than for non-RE certified installations. When compared to the SPFs from section 6.2.1, the mean SPF for the RE certified installations was 18 % higher than for the non-RE certified installations.

The preformed measurements and the visual inspections thus indicate a rather similar conclusion: The RE certified installations are of a higher quality.

6.2.3 Results from the second test period

Based on the visual inspection and a set of "energy elements" proposed to form the basis of a mandatory energy inspection, possible areas for correction of a heat pump installation were carried out and a new test period was initiated.

The "energy elements" are described in Appendix 2 of [8] but are closely related to the list of parameters for the visual inspection in section 6.1.2. One of the main points in an energy inspection is to determine whether the heating-curve of the heat pump is correctly adjusted as it is often set too high.

Table 6.3 shows how the corrections affected the calculated SPFs for the installations.

Table 6.3. Calculated SPFs for heat pump installations installed by RE and non-RE certified installers for test period 2: after corrections have been applied to the installations.

	Installed by RE certified installers	Installed by non-RE certified installers
Number of installations	7	14
Calculated SPF	3.3-3.6	3.1-3.4
Part with under-floor heating only	57 %	36 %

When comparing table 6.3 with table 6.1, it shows that the visual inspection with following correction of possible errors led to an increase in the SPF for RE certified installers of 0.1 (3 % increase) and for non-RE certified installers 0.4 (12 % increase). From this, it could be stated that a mandatory energy inspection only needs to be carried out for non-RE certified installations. However, it is often seen that the users of heat pumps themselves change the settings of the heat pumps (the heating-curve) which often decreases the SPF.

Furthermore, for air-to-water heat pumps, which have become the most installed heat pumps in Denmark, there is a need to ensure that the external heat exchanger is kept clean. Additionally, it is proposed that the company carrying out the energy inspection keeps a record of the readings from the meters (power to and heat from the heat pumps). In this way, it is possible to detect whether the SPF is starting to deteriorate, and a more thorough examination of the installation is needed. Several things can cause decrease in the SPF: Wear and tear of the heat pump, changes in the heating system, changed usage patterns, etc. An energy inspection of heat pump installations therefore requires skills in not only heat pumps but also in heating systems and how to interact with the users of the heat pump.

Table 5.2 shows a SPF based on the SCOP for new air-to-water heat pumps of 4.4 for underfloor heating and 3.3 for radiators. With 57 % underfloor heating systems and 43 % radiators, as is the case for RE certified installers in table 6.3, this gives a mean SPF of 3.9. This is in the same order of magnitude as for RE certified installers in table 6.3, especially when considering that only 7 installations are included in table 6.3. No information is available for the houses in this study. Therefore, it is not known whether e.g., high SPFs are difficult to be obtained in these houses.

Another reason for the slightly lower SPF for RE certified installations in table 6.3 compared to table 5.2 may be due to the age of the houses. In accordance with table 6.3, 57 % of the installations were solely underfloor heating. Underfloor heating started to be popular in the late 1980's. Therefore, several of the houses with RE certified installations in table 6.3 may have a lower space heating demand than the mean space heating demand for Danish households. With a low space heating demand, the DHW demand becomes dominant. The DHW temperature is typically in the range of 50-55°C, which means that the COP for DHW generation is lower than for space heating. Therefore, a high fraction of DHW will reduce the possible obtainable SPF. If the fraction of DHW is higher than considered in the factors for going from SCOP to SPF, as shown in relation to table 5.2, the values in table 5.2 will be lower.

Based on this, it seems that RE certification in general lead to heat pump installations with a sufficiently high efficiency.

Conclusion

The conclusions in [8] are as mentioned based on a relative low sample of heat pump installations – measurements from 25 installations, so the obtained results are not absolutely certain. However, the survey indicates that the use of RE certified installers will decrease most of the problems described in chapter 5 and [7] and lead to better performing heat pump installations.

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Photo: Danish Energy Agency

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