IMPROVED RELIABILITY OF SWEDISH RESIDENTIAL HEAT PUMP SYSTEMS

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Abstract: This paper describes a study of the most common failures of residential heat pumps in Sweden, with the aim of suggesting what measures could be taken to reduce the number of failures. Methods used were analysis of public failure statistics and interviews with installers, service technicians, manufacturers, sales agents and claims adjusters at insurance companies. Based on answers given in the interviews and analysis of the statistics, the aim was to categorise the most common failures by whether they;

- could have been prevented by better operation and maintenance
- were caused by poor installation work quality
- could have been prevented if certain parameters had been measured, recorded and followed up
- were due to poor quality of components or systems.

The results showed that many of the common failures fall into several different categories, and that different types of measures must be taken to improve the reliability further. The interviews showed that failures are probably often caused by poor installation, neglected maintenance and surveillance, and/or poor quality of standard components or use of components outside their declared operating range.

Key Words: heat pump, failure, operation, maintenance, reliability

1 INTRODUCTION

Today, heat pump heating systems are common in Swedish single-family houses for space heating and domestic hot water production. Most owners are pleased with their installation, but statistics show that a certain number of heat pumps break down every year, resulting in high costs for both insurance companies and owners (Folksam, 2012). On behalf of Länsförsäkringsbolagens Forskningsfond[1], SP Technical Research Institute of Sweden has studied the causes of the most common failures for residential heat pumps in Sweden (Haglund et. al, 2012). The objective of the study was to suggest what measures could be taken to reduce the number of failures, i.e. further improving the reliability of heat pumps. The target group of the study was mainly insurance companies and owners of heat pumps.

[1] Länsförsäkringsbolagens Research Fund. Länsförsäkringar is a Swedish bank and insurance company.

The heat pump market is mature in Sweden. During the last ten years, half of Swedish house owners have bought a heat pump (SVEP, 2011). Figure 1 shows the number of heat pumps sold in Sweden over the last 30 years. The number of air-to-air heat pumps is an approximation, since no full compilation of sales of this type of heat pump exists. The number of air-to-air heat pumps sold has increased rapidly during the 2000s and air-to-water heat pumps starting to become common again in 2003.

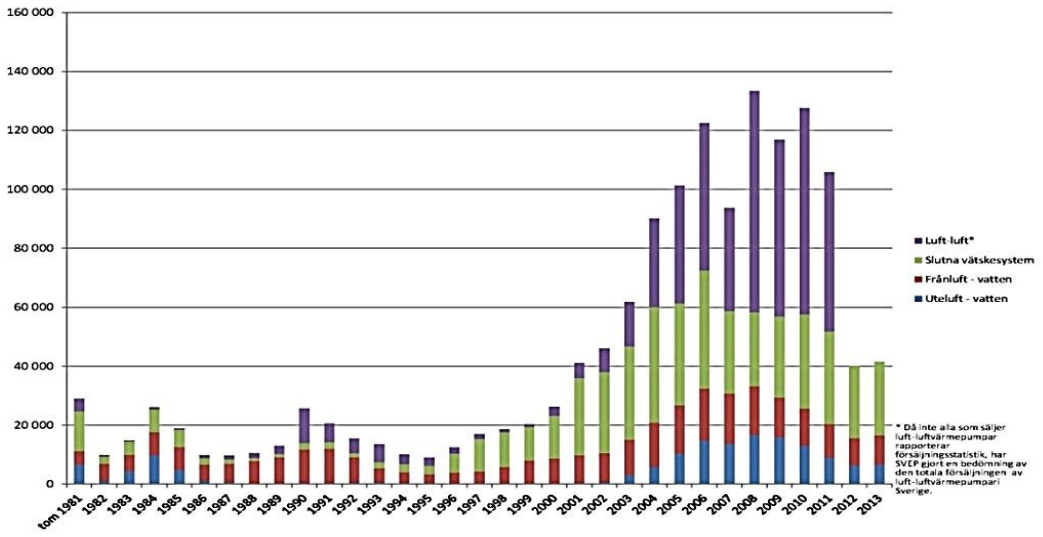

Figure 1: Number of heat pumps sold between 1981 and 2013 in Sweden (SVEP, 2013). The columns represent air-to-air (lilac), closed brine system (green), exhaust air (red) and air-to-water (blue) heat pumps. Figures for air-to-air heat pumps are approximations, since not all heat pumps that are sold are reported to SVEP, and not included at all for the two last years (due to high uncertainty).

2 METHOD

The scope of the study was to analyse why heat pumps in single-family houses fail in operation or break down, and what could be done to prevent the failures. The methods used were;

1. Analysis of failure statistics to identify the most common types of failures of air-to-air, air-to-water, exhaust air and brine-to-water (i.e. ground source) heat pumps.

2. Interviews with heat pump installers, service technicians, manufacturers, sales agents and claims adjusters at the insurance company Länsförsäkringar. The interviews were aimed at examining different stakeholders' opinions regarding reasons for heat pump failures and what can be done to prevent the failures. The interviews were used to categorise the common failures in four groups;
    - Could the failure have been prevented by better operation and maintenance of the heat pump?
    - Was the failure caused by poor quality of installation work?
    - Could the failure have been prevented if certain parameters had been measured, recorded and followed up?
    - Was the failure due to poor quality of components or systems?

The categorisation was used to permit suggestion of measures to reduce the number of heat pump failures. The interviews also included general questions about installation and service procedures, manuals, maintenance and the owners' interests and knowledge of their heat pump installations.

The study was based on a total of 38 interviews. Even though the number of interviews was limited, the study indicates the reason why a certain number of heat pumps fail in operation.

3 FAILURE STATISTICS

Swedish heat pump failure statistics were analysed and used as a basis for the questions in the interviews. Public statistics for failures reported to the Swedish insurance company Folksam were used to identify common failures of air-to-air, air-to-water, exhaust air and ground source heat pump types (Folksam, 2012). Annual statistics of failures were available for the years 2006 to 2010, and the figures were assumed to be representative for all failures reported to Swedish insurance companies. The statistics were used to see both numbers of failures and trends of the failures. The statistics included heat pumps that were two years old or older, since failures that arise during the first two years after installation are covered by warranty. Figure 2 shows the age of the different heat pump types when failures were reported to the insurance companies. The diagram shows that most of the heat pumps were two to five years old when a failure was reported. One reason why quite recently installed heat pumps are so common in the statistics is that the possible amount of payment from insurance companies decreases yearly. One can assume that failures for some of the older heat pumps were corrected without involvement of insurance companies.

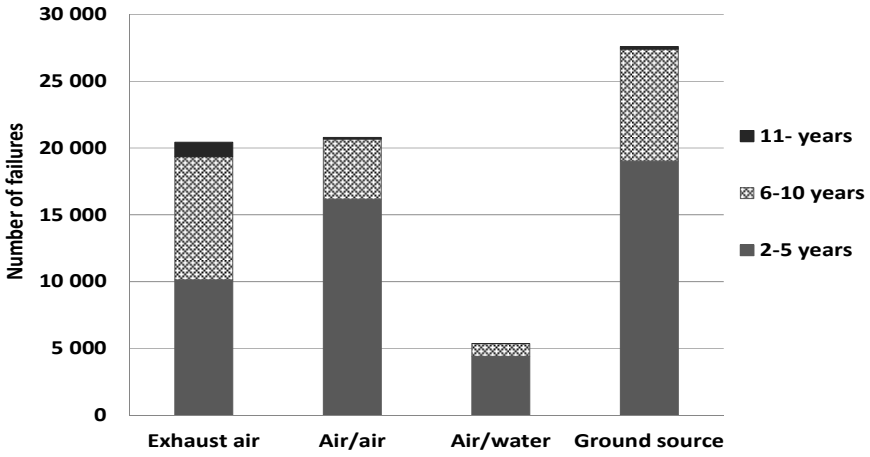

Figure 2: Age of heat pumps at failure reported to Swedish insurance companies, between 1999 and 2010.

3.1 Failures of Air-to-Air, Air-to-Water, Exhaust Air and Ground source Heat Pumps

The different failure categories in Folksam's statistics for air-to-air, air-to-water, exhaust air and ground source heat pumps are shown in Figure 3 to Figure 6 (Folksam, 2012). The two largest failure categories of air-to-air heat pumps were "compressor" and "fan", as shown in Figure 3. The statistics do not indicate whether it is the indoor or the outdoor fan that suffers the most failures, and this was one of the questions for the interviews.

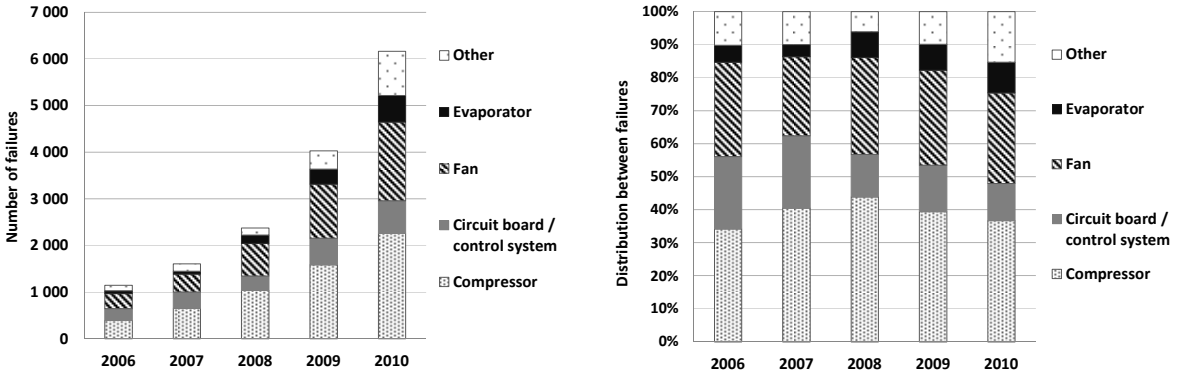

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Figure 3: Failures of air-to-air heat pumps reported to insurance companies between 2006 and 2010, (a) in total numbers and (b) as percentages.

Figure 4 shows that the two largest failure categories for air-to-water heat pumps were "other" and "compressor". "4-way valve" became a category in 2009, in which year "direction control valve" was no longer listed as a specific failure category. "Evaporator leakage" became a category first in 2010.

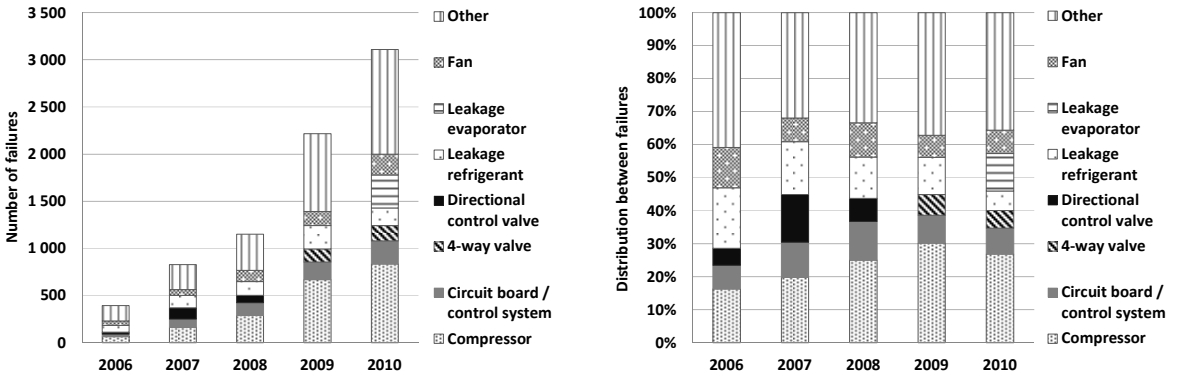

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Figure 4: Failures of air-to-water heat pumps reported to insurance companies between 2006 and 2010, (a) in total numbers and (b) as percentages.

Of all failures reported, the fraction of compressor failures has declined for exhaust air heat pumps, but was the largest failure category all years between 2006 and 2010, see Figure **5**. The category which has increased the most is "circuit board/control system". "Shunt valve" became a failure category in 2008.

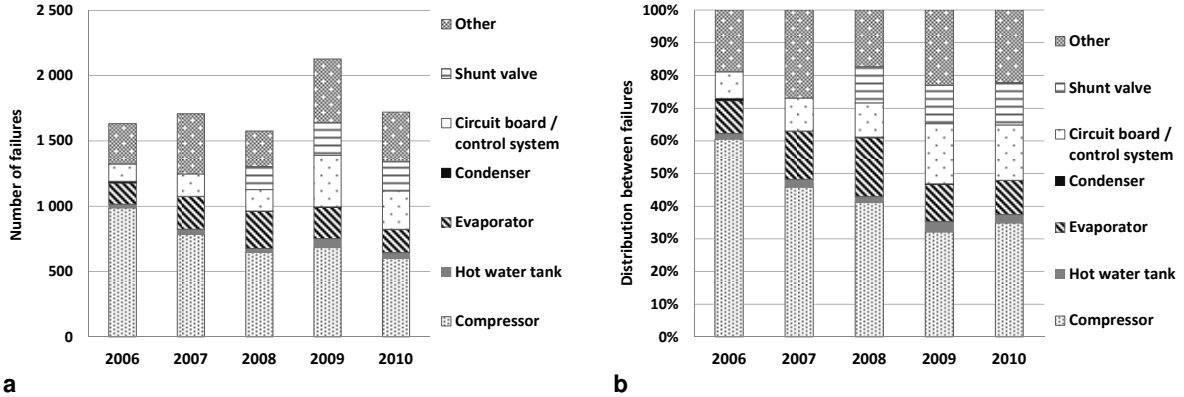

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Figure 5: Failures of exhaust air heat pumps reported to insurance companies between 2006 and 2010, (a) in total numbers and (b) as percentages.

Figure 6 shows that the largest failure categories for ground source heat pumps were “directional control valve”, “other” and “compressor”.

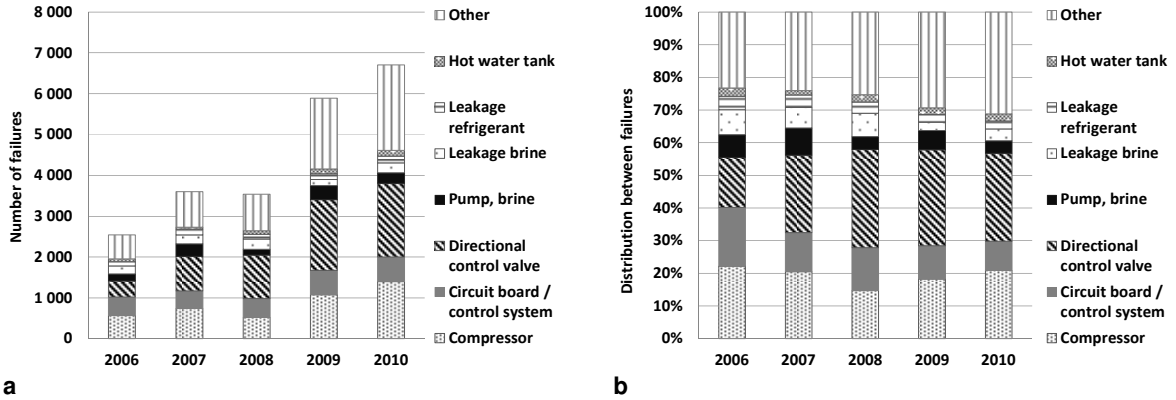

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Figure 6: Failures of ground source (brine-to-water) heat pumps reported to insurance companies between 2006 and 2010, (a) in total numbers and (b) as percentages.

For each heat pump type, a questionnaire was produced covering the cause of the most common failures stated above and what could be done to reduce the number of the failures. All the heat pump types had a failure category named “other”, which turned out to be a large category, particularly for air-to-water and ground source heat pumps. One question for the interviews was what the “other” category could include; if the interviewees missed a failure category in the statistic.

4 INTERVIEWS WITH STAKEHOLDERS IN THE HEAT PUMP INDUSTRY

Installers, service technicians, manufacturers, sales agents and claims adjusters were interviewed concerning their opinion about failures of heat pumps and what could be done to reduce the number of failures. The questions asked were based on common failures for each heat pump type described in the statistics, see Section 3. The questions also concerned installation and service procedures, trouble-shooting, heat pump manuals and the owners’ interest in their heat pumps. In total, 38 interviews were held between December 2011 and February 2012, mainly by telephone. The basis for the selection of interviewees was to cover different regions in Sweden, since the mean outdoor temperature varies between about -2 ºC in the north and +10 ºC in the south of the country. In addition, the amount of snowfall and the distance from the sea differs between the regions, and these factors may affect the heat pump components. All larger heat pump brands in Sweden were represented among the installers and service technicians.

4.1 Interviews with Installers and Service Technicians

This section describes the interviews with heat pump installers and service technicians, who work with heat pumps in the owners’ homes. The questions to these two groups were similar. Eleven interviews were conducted with installers representing different companies. On average, the installation companies had four employees working with heat pump installations and an installation rate of about 10-30 heat pumps per year and person. The number of service technicians whom were interviewed was sixteen, all representing different companies. On average, the service companies had seven employees working with heat pump service. Only three of the interviewed service companies employed more than ten service technicians.

To summarise, the installers' and service technicians' general opinion about the annual number of failures presented in the failure statistics was;

- Heat pump owners are satisfied with their installations.
- Not many heat pumps break down in comparison with the number of installed heat pumps in Swedish households.
- The heat pumps that break down are mainly old ones, ones installed by the owner or "cheaper" heat pumps not designed for the Nordic climate.
- There have been problems with some models of air-to-air heat pumps, which were actually air conditioners designed for the Mediterranean climate that have been sold as heat pumps on the Swedish market. But the number of this type of heat pumps sold has decreased on the Swedish market.
- There have been problems with some models of air-to-water heat pumps with insufficient compressor capacity, not suited for the Nordic climate. Nowadays, air-to-water heat pumps are generally equipped with compressors that can deliver the pressure rise needed to heat domestic hot water during the winter.
- Failures usually occur on heat pumps in the age range of 5-7 years, and are generally caused by poor installation, improper operation, lack of maintenance or because some of the components have shorter lifetimes than the bulk of the heat pump system itself.
- Production defects do occur, but for the heat pump brands that the interviewees install and service, the manufacturers take responsibility for their products and try to solve the problems that arise. The installers and service technicians would not work with brands and manufacturer they do not trust.

4.1.1 Heat pump installations

The service technicians emphasised that the quality of installation is critical for the operation and function of the heat pump. Location of the outdoor units, pipe fitting, refrigerant charge, adjustment of heat transfer medium flows and control settings are some examples of factors that affect the operation of the heat pump. Many heat pumps are delivered with an installation protocol that should be filled in by the installer at installation. The protocol is in general requested by the manufacturer as a warranty condition. According to the interviewees, such installation protocols are completed for about half of the installations. The reasons given why the protocols were neglected, were that they are time-consuming to fill in and no one asks for them: not the owner, not the manufacturer and not the claims adjuster. However, according to 20 of 27 interviewees, a filled-in protocol could be seen as a quality assurance of a properly performed installation and be used later to check the installation procedure and control settings.

The service technicians wanted the installers to know more about the heat pumps in detailed depth. Many heat pumps in Sweden, excluding air-to-air types, are monobloc units and are often installed by people without, or with only limited, training in refrigeration systems. All the service technicians were of the opinion that, in general, the installers' knowledge of heat pump operation is poor. The service technicians, who were trained and certified for refrigeration work, also said that the time for trouble-shooting heat pump failures would be reduced if understanding of heat pumps improved.

4.1.2 Owners' interest in their heat pumps and heat pump manuals

Most of the interviewees, 18 of 27 interviewees, felt that the manuals are user-friendly, useful and have improved over the last few years. On the other hand, the manuals should not be too wide-ranging, since it makes it hard to find specific information in them. The parts requested to be included in manuals were;

- A good description of the control menu
- An explanation of alarms and error codes
- Trouble-shooting tables

For trouble-shooting, all the service technicians said that the manufacturers' support centres are also helpful. As far as owners' manuals are concerned, the main problem according to the interviewees was that the owners do not read the manuals. The reasons given were both lack of interest and that the manuals include too much information.

According to the interviewees, half of the owners show interest in their heat pumps and the other half do not want to touch their heat pumps at all because they are afraid of the technology, are not interested, or do not have time. One piece of advice given was that there should be a short form operation and maintenance manual, about A4 paper in size and with the most important information for the owner. At installation, the information in this version should be read by the owner together with the installer.

Some interviewees mentioned that most of the owners focus on energy efficiency when buying a heat pump. Aspects such as quality, warranty and service organisation are neglected. An aware buyer should also ask questions concerning expected service life and maintenance, according to the interviewees.

4.1.3 Maintenance and regular heat pump inspections

The perception of heat pump maintenance has changed in the last few years, according to the interviewees. Historically, a selling argument in favour of electrically-driven heat pumps was that they are almost maintenance-free compared to other non-electrical heating systems, and require no fuel management. All the interviewed service technicians empathised that maintenance of the heat pump system is important. Some also recommended that the function and operation of the heat pump should be checked regularly by a refrigeration-trained service technician. At such a regular inspection, incorrect control settings, operation outside the heat pump's operating range or close to its limits could be discovered, and worn components could be replaced before they cause any damage. Half of the service technicians said that regular inspections can prevent failures, while the other half said that failures of components with design faults cannot be prevented by regular inspections.

4.1.4 Quality of components

The service technicians objected to the numbers of failed compressors in the statistics. According to their experience, compressor failures are rare nowadays. Compressor failures are more likely a result of improper operation, i.e. compressor operation outside or close to its operating limits, rather than poor quality of the compressor.

Regarding standard components such as temperature sensors, directional control valves and circulation pumps, the general experience among those interviewed was that the quality of these products has declined because cheaper components are used. Broken circulation pumps were mentioned as a common failure when the interviewees were asked if they needed another failure category in the statistics. Circulation pumps could fail also as a result of water dripping upon them from, for example leaking hot water tanks. Corrosion causes failures of hot water tanks and one of the service technicians stated that the quality of tanks has declined, since most of the focus of manufacturing and development is on the refrigerant circuit. According to the interviewees, circuit board failures are mainly caused by thunderstorms, since they are sensitive to high voltage and it is hard to protect the heat pump from these failures. The interviewees also mentioned temperature sensors as a

component that often fail, and which were not represented in the failure statistics. Temperature sensors often fail because of damp. In the opinion of the interviewees, it is not a question of if the sensors will fail, but simply of when they will fail, depending on their quality and their surrounding medium.

4.1.5 Heat pump systems with outdoor or indoor air as the heat transfer medium

The most common cause of failures of outdoor units for heat pumps with air as the heat source was snow and ice, according to the interviewees. Fans and evaporators can fail because ice and/or condensate from defrosting cannot be drained and freezes the outdoor unit. It is more common for fans in indoor units to fail than fans in outdoor units, according to the interviewees. Bearing and motor failures were mentioned as two reasons why indoor fans break down. But according to the service technicians, poor cleaning or failure to change filters were the most common reasons why fans fail on indoor units of air-to-air heat pumps and evaporator and fans on exhaust air heat pumps. Evaporator failures on exhaust air heat pumps can also be caused by corrosion and improper solder, and resulting in refrigerant leakage.

4.1.6 Heat pump systems with brine or water as the heat transfer medium

The quality of the liquid in heat transfer systems is important for the operation of heat pumps with water or brine as the heat transfer medium, according to the service technicians. In older houses with metal piping, deposits and dirt in the systems were a common cause of failures. Dirt in the system clogged valves, circulation pumps, heat exchangers and filters. Both the flow rate and the heat transfer are affected by clogging. Directional control valves have been a common failure category. The reason was said to be a design failure in combination with dirt in the water system that clogged the valves and made them fail. All the service technicians said this failure had decreased.

4.2 Manufacturers and Sales Agents

Four heat pump manufacturers and sales agents were interviewed. All of the interviewed companies had procedures for returning components that break during the warranty time to the manufacturer in order to investigate the cause of the failure, but often not after this period. Two of the interviewees applied approval procedures for installers and service technicians allowed to work on their heat pumps during the warranty period, and recommended regular inspections of the heat pump performance and operation performed by certified service technicians.

4.3 Claims Adjusters

Seven claims adjusters were interviewed, all working for the Länsförsäkringar insurance company in Sweden. Both city regions and countryside regions were represented. All the interviewed claims adjusters noted that there are many failures of heat pumps, but could not tell whether the failure rate has increased or not. They wanted to compare the number of failures to sales figures to be able to follow and analyse failure trends. The insurance company had no statistics of the number of heat pumps installed in customers' houses and could not tell how many of the heat pumps that fail yearly. The claim adjusters' general opinion was that the manufacturers need to be better in holding spare parts and correcting manufacturing and design defects.

The claims adjusters believed that some service companies replace perfectly good components in heat pumps just to make money. None of the claims adjusters had a procedure for inspecting items replaced by service companies in order to check that replaced components really were defective. Instead, they work with service companies that they

trusted. The claims adjusters in the larger city regions were more keen to be able to decide what service company that is hired for repair and service work, since they experienced more trouble with companies they did not trusted. But none of the regions had a list of authorised installers and service companies approved for performing heat pump work paid for by insurance. All of the claims adjusters thought that a regular heat pump inspection of performance and operation, performed by certified service technicians could improve the reliability of heat pumps.

5 MEASURES TO PREVENT FAILURES

One of the results from the interviews was that it was hard to distinguish the cause of a failure and categorise the failure cause according to the summary list in Section 2. Often at least three different causes were given, when the cause of a particular failure was requested in the interviews. Some failures can be covered by all of the categories presented in Section 2, while the main reason for the failure cannot be stated. It shows that different measures are needed in order to prevent failures and improve the reliability of heat pumps further. Suggested measures to prevent heat pump failures given in the interviews are described in the following section.

5.1 Compressors

According to the service technicians, the most common cause of compressor failures was unfavourable or severe operating conditions that impose an abnormal load on the compressor. Failure caused by poor quality of the compressor should appear during the first year in service, i.e. during the warranty period, and should therefore not be represented in failures statistics of insurance companies, said the technicians. Their experience was that compressors in air-to-water heat pumps have the hardest working conditions, because the necessary rise in pressure to be delivered by the compressor is high during the winter.

5.1.1 Installation

To provide good operating conditions for the compressor, some important aspects at installation are;

- Provision of the correct amount of refrigerant charge to prevent compressor wear and tear or, in the worst case, break down.
- The number of radiators affects the heat exchange area in the house. Too small an area requires a higher outlet temperature from the heat pump and increases the load on the compressor.
- Adjustment of circulation pumps to provide the recommended heat transfer medium flow, i.e. proper heat exchange at evaporators and condensers to ensure that the compressor is working in its operating range.
- Adequate piping size to provide sufficient flow of the heat transfer medium.
- Dirt in liquid heat transfer system clogs components and reduces the heat transfer medium flow and the capacity of heat exchangers, and may increase the load on the compressor. The installer should take a liquid sample to check the liquid quality, and filters should be installed.
- Bleed air from liquid heat transfer systems to minimise corrosion and maintain heat exchange capacity of evaporators and condensers.
- Wrong choice of heating curve could make the compressor work harder to reach a higher condensing temperature than needed to heat the building.
- Too low a volume of heat transfer medium in liquid systems could make an on/off-controlled compressor start and stop too frequently, which does not do it any good. A storage tank may be needed.

5.1.2 Maintenance

Maintenance should be performed to maintain as good operating conditions as possible for the compressor, by ensuring sufficient heat transfer medium flow;

- Replace or clean dirty filters in air and liquid heat transfer systems to maintain the flow and heat exchange capacity.
- Keep the outdoor unit of air-to-air and air-to-water heat pumps free from ice and snow to maintain required air flow through the evaporator.
- Regular checking of performance and operating conditions, carried out by certified service technicians to maintain as good operation as possible.

5.1.3 Monitoring of performance parameters

Some parameters could regularly be checked in order to discover departures from normal or correct values, which can cause failures;

- A decrease of COP (coefficient of performance) with unchanged heating load and ambient climate could be a sign of lack of refrigerant.
- A change in temperature difference between the outlet and inlet of the heat transfer medium could be a sign of a flow change, for which the reason should be determined in order to prevent failures. If the temperature difference deviates by more than a given value, there is something wrong with the heat transfer flow or the heat exchanger. For a ground source heat pump, this may indicate insufficient capacity of the borehole, but this is difficult to correct.
- The temperature of the warm heat transfer medium flow after the directional control valve indicates if the valve is in the right position. The valve shall alternate between domestic hot water production and space heating, and shall not deliver heating water to both systems at the same time. Leakage of the heating water may increase the load on the compressor.
- Increased electricity consumption with similar heating load and ambient climate could be a sign of a fall-off in compressor performance or improper operating conditions.

5.2 Outdoor units

For outdoor units, ice and snow are the most common reasons for fan and evaporator failures. The condensate from defrosting has to be drained so that it does not cover the fan or evaporator with ice and cause breakdowns. The defrost procedure must be designed to prevent water droplets from freezing on the fan blades and causing imbalance. The owner should inspect the outdoor unit when the weather is cold, damp and/or snowy to see if the defrost function is working properly and that condensate is drained. The owner should also remove snow and ice if necessary. Snow and ice must be removed in accordance with the manufacturer's recommendation.

5.3 Directional Control Calves, Circulation Pumps and Temperature Sensors

Directional control valves are a common failure category for ground source heat pumps and could be a component design problem, a result of poor quality of the heat transfer medium, or most likely a combination of the two. At times of the year when there is no space heating demand, valves stand in the same position and some circulations pumps are not in operation, with the result that components could be clogged and then fail when they are taken into service again. Regularly starting and running these components for a short time when they not in normal service can prevent them from failing.

Temperature sensors are important since they control the operation of the whole heat pump system and fail often as a result of poor quality or improper surrounding medium. Improvement of the quality and specifications of the environmental conditions for which the sensors are designed would improve the sensor reliability and so improve the performance of the heating system. The owner should check that the sensors are working by seeing whether they indicate a realistic temperature.

5.4 Maintenance Manuals and Installation Protocols

The owner needs information in order to be able to perform required maintenance, which means that information on what, why, how often and by whom maintenance activities should be performed should be stated in the manuals. The owner should be recommended to be present during installation to learn about the heat pump system and what maintenance that should be performed. The owner should also request that the installer fills in the installation protocol, which should include at least;

- the installation date
- the product model name and serial number
- the name of owner and installer, with contact information
- the version of software
- a checklist of the installation process
- table(s) of adjustments and control settings at commissioning
- indication that the installer and the owner have gone through the general operation and maintenance instructions for the heat pump.

The installer should revisit the installation after a suitable time, to check that the heat pump is operating properly, and to make and adjustments that may be needed. This is most important if the installation was made when there was no space heating demand, i.e. during the summer season.

6 CONCLUSION

Statistics show that a certain number of heat pumps fail every year. However, the installer and service technicians whom were interviewed were generally of the opinion that the owners were pleased with their heat pumps, and that the number of heat pumps with problems is small in comparison with the total number of such systems installed in Swedish single-family houses. The claims adjusters experienced many failures on heat pumps, but requested that failure statistics should be compared with sales figures for a better overall picture of the failure trend for installed heat pumps.

The interviewees stated that heat pump failures are often caused by;

- poor installation
- neglected maintenance and surveillance
- poor quality of standard components
- the use of components outside their declared operating range.

The result showed that many of the common failures can be caused by several of the categories above, and different types of measures must be taken to improve the reliability of heat pumps further. The quality of the installations could be improved by increasing installers' knowledge of heat pumps and by requesting that an installation protocol should be filled in. By requesting completed installation protocols, the risk decreases that steps in the installations are forgotten. It is also important that the owner of the heat pump performs the maintenance recommended by the manufacturer. Another example that can improve reliability is that a certified heat pump service technician should regularly check the heat

pump system and its performance and operation. Poor quality components can include, for example, temperature sensors, valves and circulations pumps. Failures due to such components can be reduced by requesting higher quality components that are better suited to the operating and environmental conditions. Compressors often fail because the heat pump is being operated outside, or too close to, its operating limits, and not necessarily due to poor quality of the compressor itself. By monitoring and following up relevant parameters, such as temperatures of heat transfer media and electricity use, improper operation can be detected and compressor failure avoided.

7 DISCUSSION

In order to improve the reliability of heat pumps and reduce the costs for the insurance companies and heat pump owners, there must be incentives for purchasers not only to choose a product with good quality but also to engage the best installers and service technicians, since some failures and costs are due to poor installation and service. Insurance companies could, for example, reduce the cost of insurance for customers who employ a certified heat pump installer and/or choose a heat pump marked with a quality label that requests components of a certain quality and an efficient service organisation. Most of the current focus is on the energy efficiency of heat pumps and questions regarding lifetime and reliability tend to be neglected in purchasing. In addition, heat pump owners must understand the importance of looking after the heat pump to ensure that it operates as efficiently as possible. Communication and cooperation between stakeholders in the heat pump industry is needed in order to achieve these incentives.

8 ACKNOWLEDGEMENTS

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