

Annex 37

Demonstration of Field Measurements of Heat Pump Systems in Buildings

Good Examples with Modern Technology

Final Report

Operating Agent: Sweden

Published by

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This project was carried out within the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) which is an Implementing agreement within the International Energy Agency, IEA.

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TABLE OF CONTENTS

1	ACRONYMS.....	4
2	LIST OF FIGURES.....	5
3	LIST OF TABLES.....	7
4	INTRODUCTION.....	13
4.1	BACKGROUND	13
4.2	HEAT PUMP SYSTEM INCLUDED IN THE ANNEX.....	15
4.3	WHAT IS A GOOD HEAT PUMP SYSTEM?	15
4.4	OBJECTIVES AND SCOPE OF THE PROJECT	15
4.5	EXPECTED RESULTS:	16
4.6	DELIMITATIONS.....	16
4.7	PROJECT PARTICIPANTS.....	16
4.8	ANNEX EXECUTION	16
5	CRITERIA FOR GOOD QUALITY OF FIELD MEASUREMENTS AND HEAT PUMP INSTALLATIONS	18
5.1	BOUNDARY SYSTEM FOR EVALUATION.....	18
5.2	MONITORING	21
5.2.1	<i>Definition of the measurement process.....</i>	<i>21</i>
5.2.2	<i>Criteria for monitoring.....</i>	<i>23</i>
5.2.3	<i>Monitoring equipment.....</i>	<i>24</i>
5.3	DATA QUALITY	24
5.4	PERFORMANCE REQUIREMENTS ACCORDING TO THEORETICAL PRINCIPLES.....	25
5.5	PERFORMANCE REQUIREMENTS ACCORDING TO REGULATIONS AND STANDARDS	27
5.6	PERFORMANCE CRITERIA FOR GOOD HEAT PUMP SYSTEMS	29
6	EVALUATION OF FIELD MEASUREMENTS	30
6.1	SYSTEM SOLUTIONS COVERED BY THE STUDY	30
6.2	SWEDEN.....	31
6.2.1	<i>Description of the HP sites included (Effsys project).....</i>	<i>31</i>
6.2.2	<i>Examples of results from site 4.....</i>	<i>33</i>
6.2.3	<i>Examples of results from site 5.....</i>	<i>36</i>
6.3	UK.....	40
6.3.1	<i>Description of the HP sites included (EST study).....</i>	<i>40</i>
6.3.2	<i>Experimental set-up.....</i>	<i>41</i>
6.3.3	<i>Summary of results</i>	<i>42</i>
6.3.4	<i>Examples of best practices.....</i>	<i>43</i>
6.3.5	<i>Carbon savings.....</i>	<i>43</i>
6.3.6	<i>Case: Site 492.....</i>	<i>49</i>
6.4	SWITZERLAND.....	53
6.4.1	<i>Description of the HP sites included (FAWA study).....</i>	<i>53</i>
6.5	OTHER FIELD MEASUREMENT PROJECTS	57
6.5.1	<i>Germany</i>	<i>57</i>
6.5.2	<i>Denmark</i>	<i>61</i>
7	ANALYSIS OF RESULTS FROM MEASUREMENTS	66
7.1	DETERMINED SPF VALUES FOR THE HP SYSTEMS	66
7.2	YEARLY COST SAVINGS BY USING HEAT PUMPS	66
7.3	CO ₂ SAVINGS BY USING HEAT PUMPS	66
8	CONCLUSIONS AND RECOMMENDATIONS.....	69
9	COMMUNICATION TO STAKEHOLDERS	70

10	SUGGESTIONS FOR FURTHER WORK	72
11	REFERENCES.....	73
12	APPENDICES.....	76
12.1	SITE INFORMATION SHEETS.....	76

1 ACRONYMS

ASHP	Air Source Heat Pump
COP	Coefficient of Performance
DECC	Department of Energy and Climate Change
DHW	Domestic Hot Water
Ecodesign	Ecodesign regulation, http://ec.europa.eu/growth/industry/sustainability/ecodesign/index_en.htm
Effsys	Resource efficient cooling- and heating systems, Swedish research programme
EST	Energy Saving Trust
ExCo	Executive committee of IEA HPT
FAWA	Field measurements of small heat pumps (Swiss heat pump monitoring project)
GSHP	Ground Source Heat Pump
HP	Heat Pump
HPT	Heat Pumping Technologies Technology Collaboration Programme
IEA	International Energy Agency
IEE QAISt	Intelligent Energy Europe project - Quality assurance in solar thermal heating and cooling technology
JAZ	Jahr ArbeitsZahl (Annual performance Factor (German))
LT	Low Temperature
MT	Medium Temperature
RES-Directive	Directive of Renewable Energy Sources
SCOP	Seasonal COP
SEPEMO	Intelligent Energy Europe project - Seasonal Performance Monitoring in Buildings
SH	Space Heating
SPF _{H3}	Seasonal Performance Factor, index refers to system boundary H (for heating) and boundary i (i = 1 to 4)

2 LIST OF FIGURES

Figure 1. Histogram of heat pump performance factors (SPF_{H3}).	9
Figure 2. Average annual CO_2 savings using a heat pump as compared to oil or gas boilers for the evaluated heat pump sites.	10
Figure 3. Cost savings versus annual heat delivered based on 2012 figures.	10
Figure 4. Daily average COP for space heating (blue) and DHW production (green) vs. average outdoor temperature for an air source heat pump in the UK, monitored at the SPF_{H3} level.	11
Figure 5. System boundaries for electrically driven heat pump systems applied in this Annex.	19
Figure 6. Choice of boundary condition for evaluation.	19
Figure 7. Monthly averaged values of COP for a heat pump system according to the four system boundaries defined in SEPEMO project [7].....	21
Figure 8. Placement of measurement points for data collection for a heat pump system.	23
Figure 9. Carnot COP vs. temperature lift with a heat source at zero degrees C.	26
Figure 10. Carnot COP as a function of source temperature vs. temperature lift.	27
Figure 11. COP of brine-to-water heat pumps according to EN 14511 and EN255 in lab tests for 0/35 test condition [12].	27
Figure 12. Pictures illustrating installed monitoring equipment in one of the Swedish sites.	33
Figure 13. Scheme over system and monitoring positions, site 4, SE.	34
Figure 14. Space heating demand vs outdoor temperature for site 4 (SE).	35
Figure 15. Used heat or space heating and DHW heating per month for site 4.....	35
Figure 16. SPF_{H1} - SPF_{H4} calculated from measured data, site 4 (SE).	36
Figure 17. Scheme over system and monitoring positions, site 5, SE.	37
Figure 18. Space heating demand vs outdoor temperature, site 5 (SE).	37
Figure 19. Used heat or space heating and DHW heating per month for site 5. Blue bars represent amount of energy for DHW preparation, red bars represent Space heating demand.	38
Figure 20. SPF_{H1} - SPF_{H4} values for site 5 (SE) where the heat pump is assisted by solar heating.	39
Figure 21. Heat pump system SPF (equivalent to SEPEMO SPF_{H4}) for the ground source heat pumps in the field trial [27].	42
Figure 22. Heating system SPF for the air source heat pumps in the field trial. (The heating system SPF is similar to SEPEMO SPF_{H4}) [27].....	43
Figure 23. Estimated CO_2 emissions from using a heat pump as a function of the estimated emissions from electric storage heating (using the 2008 grid carbon factor, $0.52 \text{ kgCO}_2/\text{kWh}$).	45
Figure 24. Estimated CO_2 emissions from using a heat pump as a function of the estimated emissions from a standard oil condensing boiler (using the 2008 grid carbon factor, $0.52 \text{ kgCO}_2/\text{kWh}$).	46
Figure 25. Estimated CO_2 emissions from using a heat pump as a function of the estimated emissions from a standard gas condensing boiler (using the 2008 grid carbon factor, $0.52 \text{ kgCO}_2/\text{kWh}$).	47
Figure 26. Average and return temperatures of the heat distribution system, site 492 (UK).	49
Figure 27. System efficiency (SPF_{H4}) as a function of condenser and evaporator temperature, site 492 (UK)	50

Figure 28. Burst operation. The figure show heat output versus electric back-up use.	51
Figure 29. Hourly SPF_{H3} vs outdoor temperature.....	51
Figure 30. Delivered heat vs outdoor temperature.....	52
Figure 31. System boundaries in the Swiss FAWA-project.	54
Figure 32. ASHP SPF_{H3} for some selected sites (CH).....	56
Figure 33. GSHP SPF_{H3} for borehole units using brine (CH).....	56
Figure 34. Mean SPF_{H3} for different categories of heat pumps in Switzerland.	57
Figure 35. Structure of the Fraunhofer ISE monitoring project(s).	58
Figure 36. Fraunhofer ISE monitoring positions.	58
Figure 37. Heat distribution systems by type (DE).....	59
Figure 38. Heat sources by type (DE).....	59
Figure 39. System boundary description for the Fraunhofer Project WP Efficientz. ...	60
Figure 40. Average monthly SPF 's for GSHP's in the study.	60
Figure 41. SPF degradation in the Fraunhofer project.....	61
Figure 42. SPF 3 values for the GSHPs monitored by Fraunhofer GSHP	61
Figure 43. Classification of heat pump types included the Danish field study.....	62
Figure 44. Classification according to heat distribution system.	63
Figure 45. SPF H3 boundary in the Danish study.	64
Figure 46. Calculated SPF 3 for GSHPs (DK).	65
Figure 47. Calculated SPF_{H3} for ASHPs (DK).....	65
Figure 48. CO_2 emissions from different heating alternatives. The electricity used for heating is assumed to be produced from a Swedish grid mix and an EU grid mix. The oil boiler is assumed to have an efficiency of 82%.	67
Figure 49. CO_2 emissions from different heating alternatives. The electricity used by the heat pump is assumed to be produced from a Swiss grid mix and an EU grid mix. The oil boiler is assumed to have an efficiency of 82%.	67
Figure 50. CO_2 emissions from different heating alternatives. The electricity used by the heat pump is assumed to be produced from a UK grid mix and an EU grid mix. The gas boiler is assumed to have an efficiency of 85%.	67
Figure 51. Carbon-intensity of UK electricity generation under 80 % and 90 % emissions targets for 2050 (Markal).	68

3 LIST OF TABLES

Table 1. Description of evaluated heat pump systems.....	8
Table 2. Threshold values to be regarded as a good system.....	11
Table 3. Buffer tank placement and guide of when to include buffer tank losses into space heating.....	20
Table 4. Ecodesign requirements, η_s	28
Table 5. SPF _{H3} to be classified as a good example.....	29
Table 6. Annex 37 requirements for heat pump system to be regarded as a good performing systems.....	29
Table 7. Heat pump sites included in the study. The heat produced by the heat pump is used for space heating (SH) and domestic hot water (DHW).....	30
Table 8. SPF _{H3} -values for monitored Ground Source Heat Pumps.	31
Table 9. SPF _{H3} -values for monitored Air Source Heat Pumps.	31
Table 10. Description of 5 monitored sites in Sweden	32
Table 11. Estimated expanded measurement uncertainty for the monitored parameters.	32
Table 12. CO ₂ reduction from using heat pump compared to electric radiators or oil boiler.	39
Table 13. Heat demand (expressed in degree days) for a typical UK house.	44
Table 14. Predicted average and marginal carbon factors for electricity at the point of generation and at the point of use (i.e. after correction for transmission and distribution). – UK figures	47
Table 15. Comparison of different heating systems and corresponding CO ₂ emissions using 2008 electricity carbon factor (0.49 kgCO ₂ /kWh).....	52
Table 16. Switzerland's proposal for good performing heat pump systems.....	53
Table 17. Selected FAWA monitoring objects.....	55
Table 18. SPF _{H3} values for different heat pump systems to be considered good performing systems.....	66

EXECUTIVE SUMMARY

The aim of this project was to present examples of domestic heat pump systems with good performance, and to give guidance on what could be considered good performance. Data from 12 installations in domestic properties was analysed in detail to illustrate the principles of design and installation that ensure good performance.

As the term modern systems are used in the annex title, we clarify that we by modern in this Annex refer to systems installed in the years 2008-2012.

The heat pumps were located in Switzerland (5 heat pumps), the United Kingdom (UK) (4) and Sweden (3). A range of configurations was covered, as illustrated in Table 1 below:

Table 1. Description of evaluated heat pump systems.

Heat source	Heat sink	Domestic hot water provision	Heating capacity	Annual heat load (space + water)
6 ground source, 6 air-source	Underfloor, underfloor + radiators and radiators	9 out of 12 systems	5–14 kW (average 7.6 kW)	12,400-25,100 kWh (average 17,500 kWh)

In addition, comparisons were made to fulfilled field monitorin projects across Europe.

Background and Objectives

There are many published examples of field measurement data from domestic heat pump systems. The aim of this project was to carry out detailed analysis of monitoring data from a selection of heat pump sites with good performance.

Methodology

For each site, the analysis included:

- Calculation of the seasonal performance factor as SPF_{H3} . This factor describes the seasonal (annual) efficiency of the heat pump, taking into account the electricity used by the inlet fan or ground loop pump, the electricity used by the Heat Pump (Compressor, crank case heaters, control system, ...) and any back up electricity used for space heating or domestic hot water production.
- Calculation of the CO₂ emissions relative to a gas or oil boiler. CO₂ emissions have been calculated using the EU average CO₂ coefficient of electricity generation and the appropriate national coefficient.
- Calculation of the cost of running the heat pump, as compared to the cost of a gas or oil boiler or the cost of electric heating by a hydronic system.

More detailed analysis was carried out on a selection of sites, including:

- Calculation of SPF_{H1-H4} for each month of the monitoring period
- Calculation of SPF_{H3} for each year of the monitoring period, for those sites with long monitoring periods.
- Daily average seasonal performance factor (SPF_{H3}) as a function of external temperature
- Separate calculation of space heating and water heating efficiencies (as SPF_{H3})

Results and Conclusions

Figure 1 shows the annual seasonal performance factors, presented as SEPEMO-Build (SEPEMO onwards) SPF_{H3} , for the 12 sites examined. The average performance of the air-source systems is 3.2, while the average performance of the ground-source systems is 4.1.

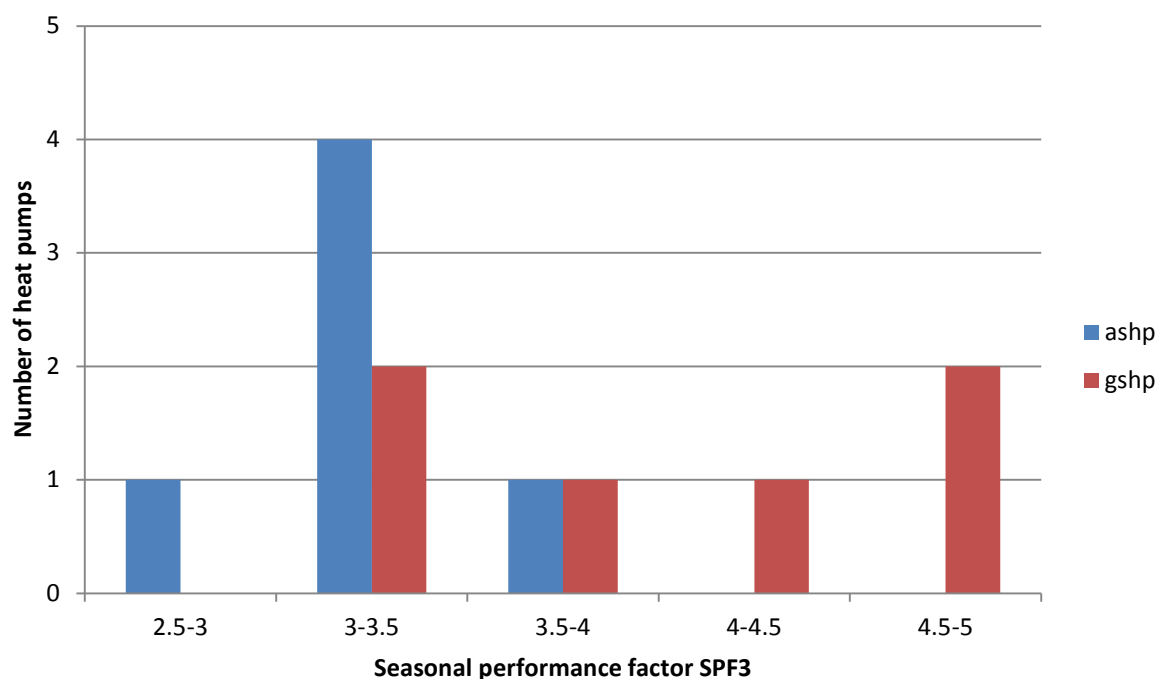


Figure 1. Histogram of heat pump performance factors (SPF_{H3}).

Heat pumps can reduce CO₂ emissions. In Sweden and Switzerland, where the carbon content of electricity is low (0.04 kgCO₂/kWh, 2009 figures), using a heat pump resulted in average CO₂ savings of more than 5 tonnes as compared to an oil boiler for the evaluated sites. In the UK, the default fuel is gas and the carbon content of electricity is considerably higher (0.49 kgCO₂/kWh), but the average saving was still 1.25 tonnes CO₂/year, Figure 2.

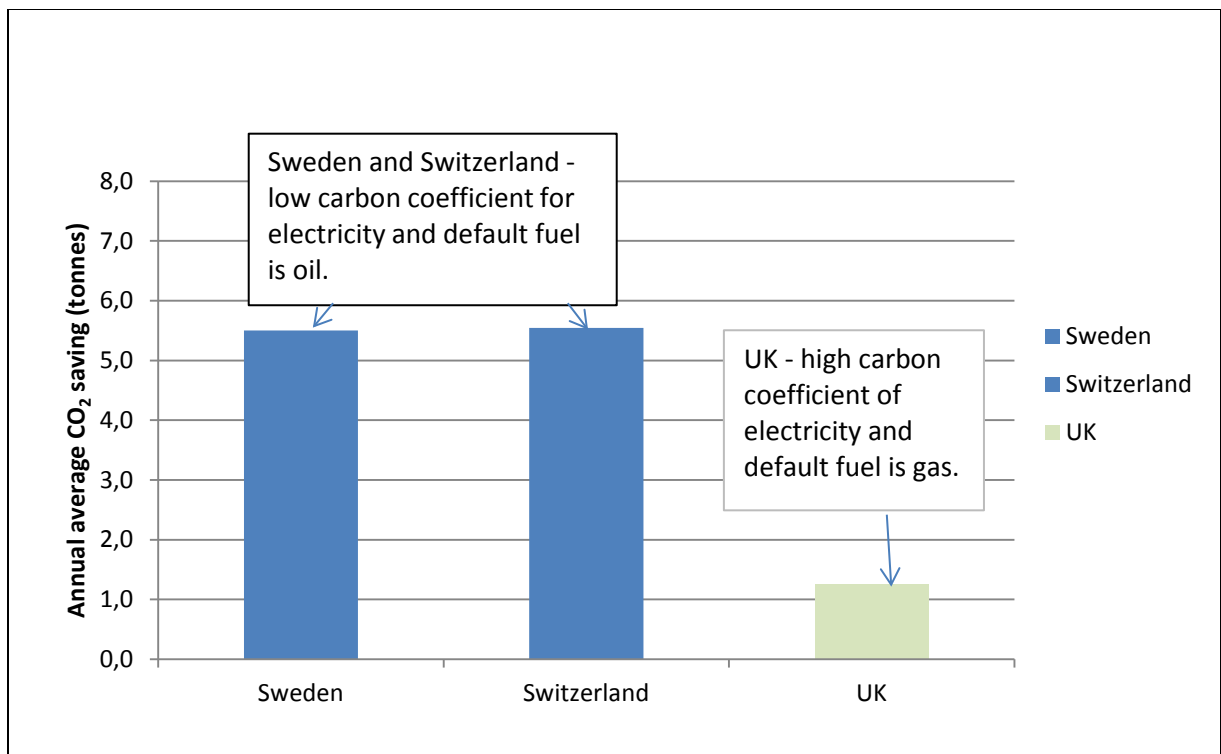


Figure 2. Average annual CO₂ savings using a heat pump as compared to oil or gas boilers for the evaluated heat pump sites.

Substantial cost savings can be made with heat pumps, depending on the heat pump efficiency and the relative prices of electricity and alternative fuels, Figure 3. Annual cost savings were the highest in Sweden (which has cheap electricity and expensive oil) and the lowest in the UK (which has expensive electricity and relatively cheap gas).

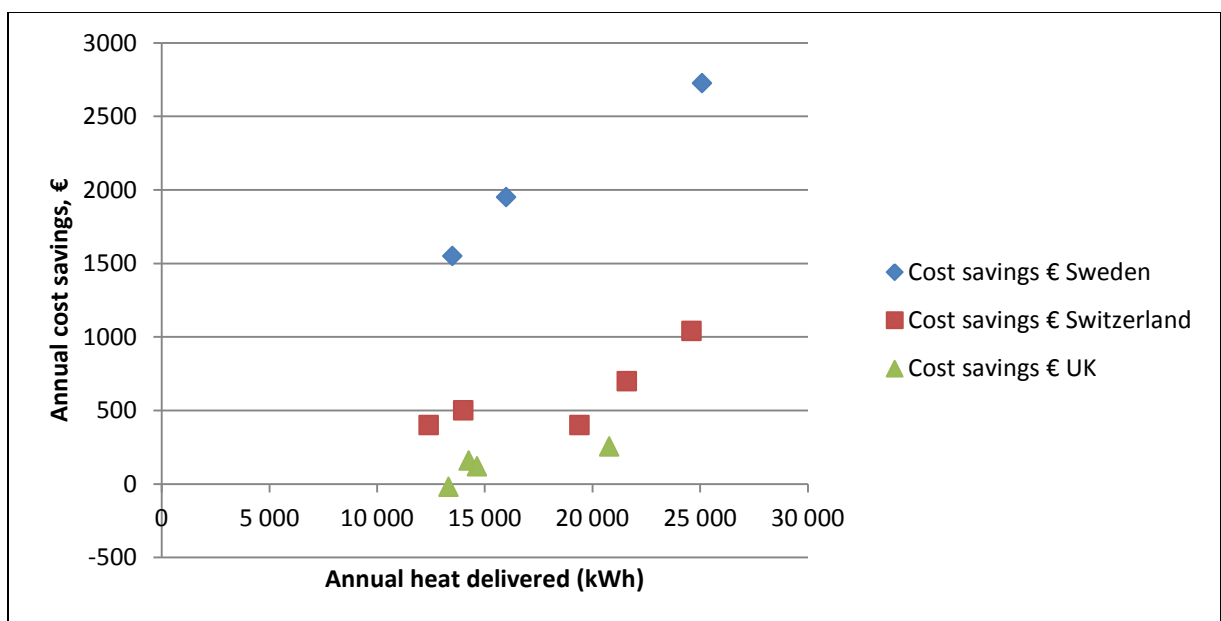


Figure 3. Cost savings versus annual heat delivered based on 2012 figures.

Space heating can be performed more efficiently than water heating, but good water heating efficiencies (>2.5) were found for some of the sites, Figure 4.

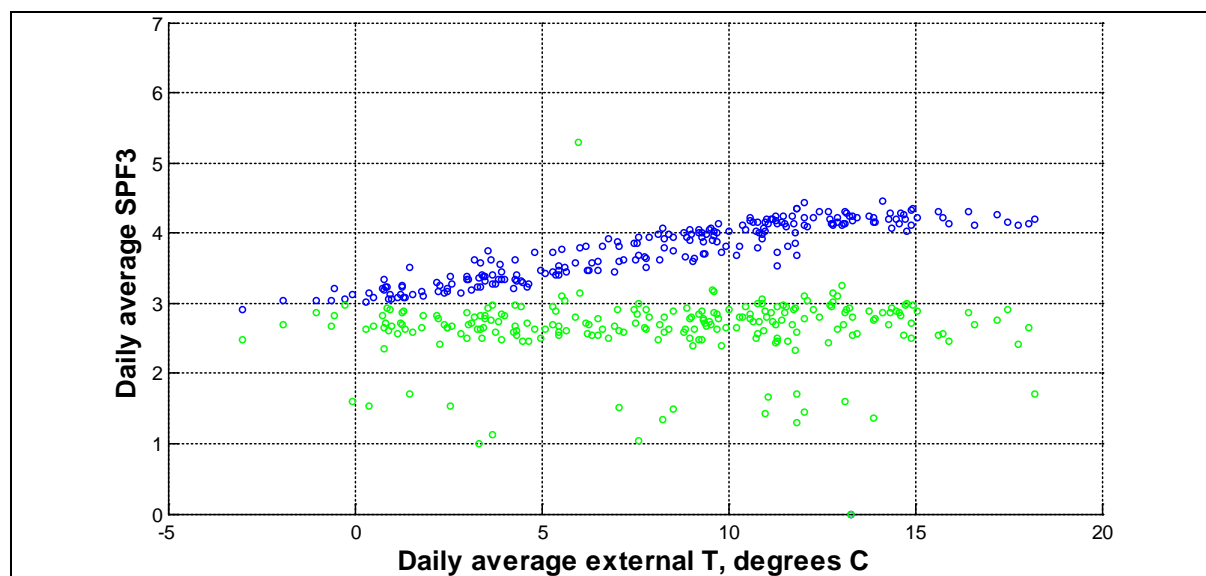


Figure 4. Daily average COP¹ for space heating (blue) and DHW production (green) vs. average outdoor temperature for an air source heat pump in the UK, monitored at the SPF_{H3} level.

Considering legal requirements from e.g. energy label and the Ecodesign regulations in Europe, theoretical achievable levels and the positive effects on energy cost, CO₂ abatement and primary energy reduction, according the conclusions from this project, air-source systems should be considered as good systems if they have a SPF_{H3} value of 2,8-3,2 and above and a ground source system having an SPF3 of 3,3-3,9 and above should be considered as well performing heat pump systems. When floor heating in heat pump systems for new houses is assumed and radiators heating for retrofit installations are assumed, the figures below represent good performance, see Table 2 below. These values concern DHW + space heating. Supply temperatures for new systems can be regarded as those required for underfloor heating (35 °C), and temperatures for retrofit systems can be regarded as those required for radiator heating (55 °C).

Table 2. Threshold values to be regarded as a good system.

	ASHP, new	ASHP, retrofit	GSHP, new	GSHP, retrofit
SPF _{H3}	3.2	2.8	3.9	3.3

¹ SPF is generally a value achieved over a longer period of time (**Seasonal** Performance Factor) of monitoring. In this report, we have used the term COP when we refer to shorter time monitoring results (instantaneous, hourly, weekly).

ABSTRACT

The aim of this project was to demonstrate and disseminate the economic, environmental and energy saving potential of heat pumping technology. The focus has been on available technology, and results from existing field measurements have been used to calculate energy savings and CO₂ reduction.

The heat pump systems included in this project are the best we have found in our field measurements. The SPF values for the studied heat pump systems range from 2.6 to 4.7. Four ground-source heat pumps and five air-source heat pumps ended up at SPF values above the limits we defined for systems to be regarded as good (2.8-3.2 for air-source heat pumps and 3.3-3.9 for ground-source heat pumps).

4 INTRODUCTION

4.1 Background

There is a need to be able to demonstrate the potential for energy savings and CO₂ reduction with heat pumping technology. There is also a need among the public for increased knowledge of the efficiency of heat pumps in real installations, especially concerning heat pump systems for combined operation including heating, cooling and domestic hot water production.

Field measurements of heat pump systems have been performed in previous years in different countries and by different institutes and companies. It was always a challenge, and sometimes impossible, to compare results from different field measurements with each other. Reasons for this has been the varying quality of the measurements, the system boundaries for the heat pump systems might be defined differently, and the uncertainty of measurement can be very high or not sufficiently well defined.

In order to increase the use of heat pumping technology it is important to be able to show a lot of very good examples of heat pump systems with really good energy efficiency. This can be done by gathering the results from a large amount of field measurements that have demonstrated high efficiency under the same or very similar monitoring conditions and system boundaries for the evaluation.

The quality of the measurements must be assured to be sufficiently good and locations of measuring points and system boundaries shall be communicated. It should be possible to compare data measured in different studies, in order to determine the potentials of different types of heat pump systems in real world installations.

There is also a need to be able to demonstrate the potential for energy savings and CO₂ reduction with heat pump technology. In addition, the knowledge of the efficiency of heat pumps in real installations should be increased, especially concerning heat pump systems for combined operation including heating, cooling and domestic hot water production.

Demonstration of heat pump systems would be an efficient way of communicating the potential of the technology, promoting top-of-the-line [state of the art] heat pump systems and also improving existing guidelines for selection, design and installation of systems. Demonstration of best available heat pump technology is a way to achieve further acceptance for the technology and, in that way, to increase take-up in new markets. It is important that information about different heat pump systems should be accessible, analysed and presented in a harmonised way. The on-going work with IEA Road Maps and Energy technology Perspectives studies [25, 26] has shown that there is a lack of such information on heat pumps from the IEA Heat Pumping Technologies Programme member countries.

The operational performance of heat pumps (COP) has up to now often been given as that measured under steady-state operating conditions and at full or rated capacity.

The efficiency measure used on the European Energy Label for space heaters, including heat pumps, is based on a seasonal COP (SCOP or SPF) which take varying outdoor and heating water temperatures into consideration. These conditions do not fully reflect the performance of heat pumps operating in real heating systems. The efficiency of a heat pump system is influenced by how the heat pump is connected to the system, by the system design and by the operating temperature of the heating system. In addition, user behaviour and habits are very important for how the heat pump system perform. This means that the design of the heat pump system, and the quality of the installation, will strongly influence the final efficiency of the heat pump system.

Field measurements of heat pump systems have been performed in previous years in different countries and by different institutes and companies. It is always a challenge, and sometimes impossible, to compare results from field measurements with each other. The quality of the measurements can vary, the system boundaries for the heat pump systems might be defined differently, and the uncertainty of measurement can be very high or not sufficiently well defined. It is most important that it should be possible for data measured in different studies to be compared, in order to determine the potentials of different types of heat pump systems in real world installations. In addition, there is a lack of a harmonised way to present the results, which should also be easy to understand by persons having only limited knowledge of heat pumps. A lot of these barriers for evaluating heat pumps systems in field measurements were tackled by the SEPEMO project [7], with which we have communicated and been inspired by a lot.

The aim of this project is to demonstrate and disseminate the economic, energy and environmental potentials of heat pumping technology. The focus will be on best available technology, and results from existing field measurements will be used to calculate energy and cost savings and CO₂ reduction. In order to draw the right conclusions, it is most important that the quality of the measurements is assured to be sufficiently good. The criteria for good and assured quality of both the heat pump performance and field measurement installation will be defined in the project.

The results from existing field measurements will also be used to calculate the electricity consumption and energy savings, compared to alternative ways of heating, for a given heat pump system. These figures can then be compared with predicted figures for such a system, based on input from laboratory tests, climatic data and heating demand.

Although operating conditions in real installations cannot be controlled in the same way as in a laboratory, there is still a need to verify that systems are running satisfactorily under realistic (real world) conditions. By better knowledge of real operating performance, it should be possible to predict the most suitable heat source and heat pump system for particular applications and good examples could help in such prediction.

The site information sheets that were developed in this project will be linked to the IEA Heat Pump Centre's website, and will be continuously updated with new examples after conclusion of the project. The overall idea is to make tailor-made, easy-to-understand information on heat pumps, with the aim of collecting good

examples from all IEA HPT member countries that can be used in the process to promote further deployment of the technology.

4.2 Heat pump system included in the Annex

Heat pump systems with the best available technology (with installation years 2008-2010) were studied in this Annex, of which the aim was to include as many system solutions as possible. It is important that all systems are reliable and efficient, but in other respects there is no limitation on the type or size of the systems.

The participants of this Annex decided which types of heat pumps that was to be included. It is worth commenting that at this time variable capacity heat pumps were still rather uncommon on the evaluated heat pump markets.

4.3 What is a good heat pump system?

A good heat pump system is a system that provides space heating and/or domestic hot water heating in an efficient and reliable way. It should provide high amounts of renewable energy, save CO₂ emissions compared to competing systems in the market, and it should be cost attractive from a life cycle cost (LCC) perspective. Well-designed systems should require low share of auxiliary heating. In addition, the system should be easy to operate by the house owner.

4.4 Objectives and scope of the project

The main objectives of Annex 37 were to

- Demonstrate/illustrate the **potential** with heat pumping technology for all types of domestic buildings from existing field measurements. The focus was on the best available technique. The electricity consumption and energy savings, compared to alternative ways of heating should be calculated.
- **Improve the understanding of key parameters** influencing the ~~reliability~~ **and** efficiency of heat pump systems.

Another goal in this project was to ensure good and similar quality of the performed field measurements in terms of such factors as system boundaries, measured parameters, sampling intervals, accuracy of measurements etc. An additional goal was to establish field monitoring information sheets connected to the Heat Pump Centre website where data from this and other field measurements can be presented. Such information has been requested by the programme's stakeholders in a survey performed by the Heat Pump Centre. The yearly statistics from the Heat Pump Centre website also indicate that the existing case studies are very popular, but they need to be updated. Measurements performed with a specified quality can be used to calculate a number of annual effects, such as energy savings and CO₂ reduction. Different heat pump systems can be compared to each other and with other heating systems.

4.5 Expected results:

- Good examples of “state of the art”, showing the potential for heat pump systems based on reliable data from field measurements
- Case studies to be used as input data for improved statistics on heat pump systems
- The outcome could be used to improve and extend existing guidelines, to include all types of heat pumps, for installation of energy-efficient and reliable heat pump systems, taking into account regional constraints as well as building standards.
- A set of information sheets, published on HPC website using a two page template from field measurements.

4.6 Delimitations

In the execution of the project, very few installations in multi-family buildings were identified, thus this project has come to focus on single family buildings. In this annex, none of the heat pumps studied were capacity controlled, even if in some cases, distribution pumps could have been capacity controlled.

4.7 Project participants

The participating countries in the annex were Sweden, Switzerland and the United Kingdom. Norway and Austria participated as observers. Denmark and Germany has provided valuable input from field monitoring projects in these countries for comparative analysis.

4.8 Annex execution

Annex 37 aimed to expand acceptance of heat pumping technology and to increase take-up in new markets. The intention was to demonstrate energy and environmental potentials of heat pumping technology, using existing field performance measurements, and with the emphasis on best available technology. It should be possible to envisage the most suitable heat source and heat pump system for particular applications and to be able to do so access to good examples are very helpful.

In order to ensure reliable results, it is most important that the quality of the measurements should be assured, and so the criteria for good and assured quality of the field measurements were defined in the Annex. As the results will also be used to compare the performance of given heat pump systems with alternative heating systems, it is important to define measuring conditions such as measuring points and system boundaries that influence energy savings and CO₂ reduction.

The work in the annex was completed through the following tasks:

Task 1

Make a common template of what should be communicated from the performed field measurements. The focus is on the template content. Cosmetics are not considered in this task.

Task 2

Define criteria for good quality of field measurements (e.g. boundaries of the measured systems, number of and placement of measuring points, measurement uncertainty, measurement time intervals etc.) and decide what parameters are important for assured good quality. In this Annex, system boundaries defined in SEPAMO [7] will be applied. The task of the Annex is to conclude which SPF boundary gives the best representation of a good working heat pump system.

Task 3

Collection and evaluation of current and concluded field measurements on heat pump systems. The focus is on the best available technique.

Task 4

Agree on how to recalculate the chosen annual performance measures, such as seasonal performance factor, energy savings and carbon footprints. Calculation of SPF, electricity consumption, energy savings and CO₂ reductions from the collected measurements. These parameters are to be compared with those for other heating systems.

Task 5

Establish a database connected to HPC website based on data from field measurements and the common template; the best examples will be documented. Due to decision from ExCo-meeting in May 2012 this task was cancelled. It was decided that data from field measurements can be presented in another way, e.g. through site information sheets.

Task 6

Information dissemination. Information to installer and manufacturers shall contain good examples but it could also contain bad examples with mistakes that are often made and should be avoided.

5 CRITERIA FOR GOOD QUALITY OF FIELD MEASUREMENTS AND HEAT PUMP INSTALLATIONS

In order to define good quality for field measurements, a number of parameters have to be set up, and minimum requirements on monitoring quality etc. have to be defined. It is also important to establish the boundary conditions under which the monitoring is taking place.

In order to establish threshold values based on SPF for a heat pump system to be regarded as good, we have looked upon theoretical limits and also on requirements according to different policies, e.g. the European energy label and eco-design regulations.

Some heat pumps operate in space heating mode only, others in combined space heating and domestic hot water (DHW) mode, and the mode of operation may have significant impact on the COP and thereby on the SPF. The SPFs have to be separated in diagrams or in any way marked out in different colours, since they should not be compared without commenting on these differences. In general, hot water production results in a lower efficiency and thereby on lower SPF value.

In the report, we think that a good example fulfils the criteria stated in section 5.6. However, the examples that we have measurements for in Sweden, Switzerland and United Kingdom are good ones, but not necessarily the best of all in the respective country. A particular heat pump could also be seen as a good example in terms of installation (pipe work, placement of unit, etc.) even if the performance does not achieve the set requirements of this annex.

In the project, selection of the sites was made by looking at general and technical factors. General factors include selection by building type, geographical site, energy use, etc. to represent common buildings. Technical factors include selection by method of measurement and obtained measurement accuracy.

5.1 Boundary system for evaluation

When declaring COP or SPF for a heat pump system it is of importance to communicate the system boundaries valid for the figures.

The definition of the system boundaries influences the results of the SPF due to the impact of the auxiliary drives. Therefore it is important to define the boundary systems and the SPF should be calculated according to different system boundaries. In this Annex the system boundaries defined in the Intelligent Energy Europe project SEPEMO [18] have been applied for electrically driven heat pumps.

SEPEMO defines four system boundaries and they are described as follows and are illustrated in [21] and Figure 5 and Figure 6:

SPF_{HI}:

This system contains only the heat pump unit. SPF_{H1} evaluate the performance of the refrigeration cycle. The system boundaries are similar to COP defined in EN 14511, except that the standard takes, in addition, a small part of the pump electricity consumption to overcome head losses, and both the source and the sink side, and all or part of fan electricity consumption (all for non-ducted units).

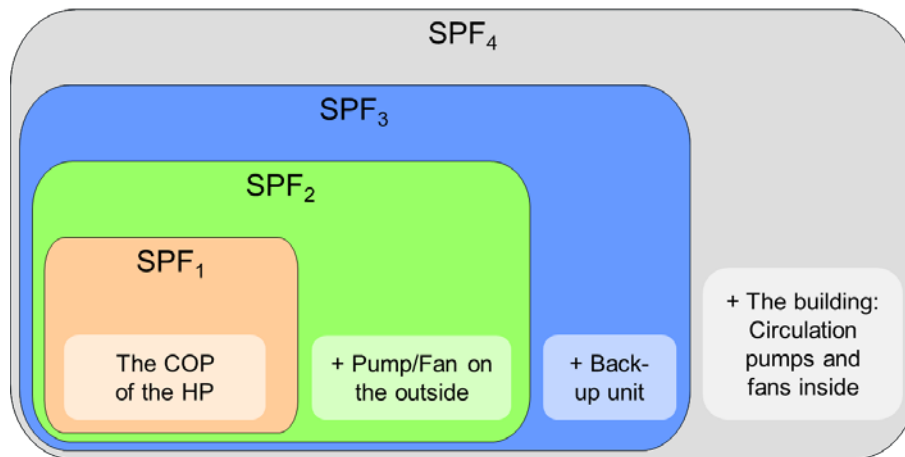


Figure 5. System boundaries for electrically driven heat pump systems applied in this Annex.

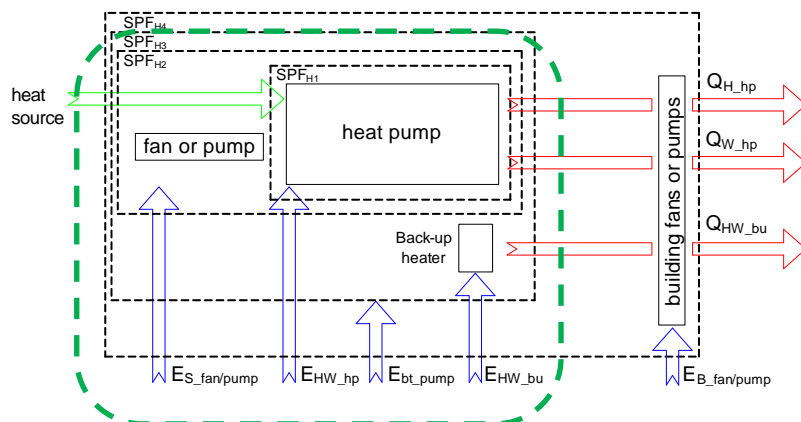


Figure 6. Choice of boundary condition for evaluation.

SPF_{H2} :

This system contains of the heat pump unit and the equipment to make the source energy available for the heat pump. SPF_{H2} evaluate the performance of the heat pump operation, and this level of system boundary responds to $SCOP_{net}$ in EN 14825 and the RES-Directive requirements. The difference is that no pump or fan electricity on the sink side and all pump or fan electricity on the source side is included in SPF_{H2} , while parts of to overcome head losses are included in $SCOP_{net}$ according to EN14825.

Note: The boundaries of COP in EN 14511 and $SCOP_{net}$ in EN 14825 are often more or less between SPF_{H1} and SPF_{H2}

SPF_{H3} :

This system contains of the heat pump unit, the equipment to make the source energy available and the backup heater. SPF_{H3} represents the heat pump system and thereby it can be used for comparison to conventional heating systems (e.g. oil, gas,...), Figure 6. This system boundary is similar to the SPF in VDI 4650 1, EN 15316-4-2 and the $SCOP_{on}$ in EN 14825 (besides that all pump and fan electricity is not included in $SCOP_{on}$ according to EN14825). Generally, this system boundary includes the *produced* domestic hot water by the heat pump and back-up heater.

SPF_{H4} :

This system contains of the heat pump unit, the equipment to make the source energy available, the backup heater and all auxiliary drives including the auxiliary of the heat sink system. SPF_{H4} represents the heat pump heating system including all auxiliary drives which are installed in the heating system. In this system boundary, space heating and *delivered* domestic hot water is included.

In this Annex, system boundary $SPFH3$ has been chosen. This means that all the heat produced from the heat pump system is included (except temperature rise from the heat distribution pumps). It should be noted that this gives an overestimation of the domestic hot water since buffer tank losses are included. For a better calculation of the real domestic hot water use, buffer tank losses should be estimated as a function of tank and room temperature, and subtracted from the monitored value. Similarly, for space heating, depending of the placement of the buffer tank, losses could add to the space heating. This must be examined for each site individually, since the physical placement of the buffer tank could be in different places, and only in some cases the losses are useful for the heating situation, see Table 3. The following table could be used as guidance for when to calculate buffer tank losses and add them to heat for space heating:

Table 3. Buffer tank placement and guide of when to include buffer tank losses into space heating.

Buffer tank placement	Winter (heat demand)	Summer (cooling demand)
Outside	Losses are not useful	Losses are not useful
Inside garage	Losses could be useful	Losses are not useful
Inside house	Losses are useful	Losses are not useful

In IEA HPT Annex 34 (Thermally Driven Heat Pumps for Heating and Cooling), system boundaries for the definition of the performance figures for thermally driven heat pumps have been proposed. Most of the boundaries are equal to the ones from Figure 5.

For heat pump systems in combination with solar thermal, a concept analogous to the definitions of the SEPOMO Project and Annex 34, taking into account the specific features of this combination, was developed within the IEE QAISt Project and SHC Task 44 / HPT Annex 38 [5].

Figure 7 shows the average coefficient of performance, COP, per month, for one site where field measurements were performed by SP Technical Research Institute of Sweden [16]. COP calculated according to the four different system boundaries defined in SEPOMO are shown. In this case it is clear that the auxiliaries of the heat

sink system decrease the COP values significantly. By calculating COP for different system boundaries it is possible to analyse how the performance of the different components affects the energy efficiency of the complete system. In order to obtain a high overall efficiency, it is important to use a good system solution, energy efficient components and a good installation.

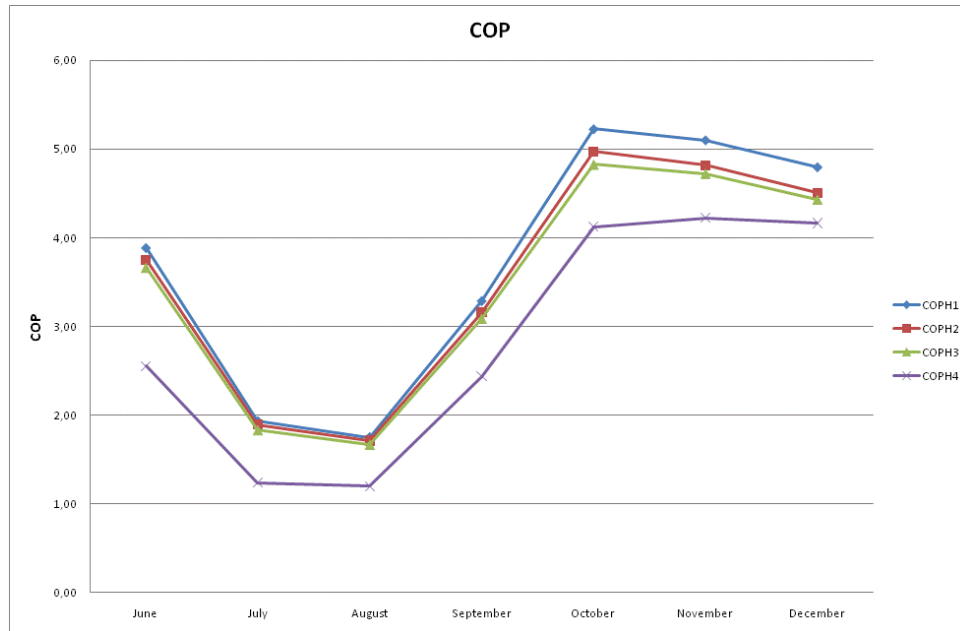


Figure 7. Monthly averaged values of COP for a heat pump system according to the four system boundaries defined in SEPOMO project [7].

5.2 Monitoring

Monitoring a heat pump over a time period of one year or more requires very thoughtful preparations. It is also important as already discussed to apply appropriate system boundaries for the purpose of the measurement. For replicability reasons and if the purpose is to follow up and make comparisons with lab testing, no prototypes should be included and labelled or certified products are desirable, but not a requirement.

5.2.1 Definition of the measurement process

First there is the need to define the following monitoring parameters:

- Number of measurement points
- Placement of measurement points
- Resolution
- Acceptable measurement uncertainty
- Sampling interval
- Duration of measurements

In this joint research project some definitions have been agreed on for the field measurement installation for a heat pump system to be referred to as a good example.

In order to compare the different results, measurements must be identical for all heat pump systems and therefore it must be defined how data should be collected. The definition for the measurement points are described in the following scheme. Each circle shown in Figure 8 corresponds to a measurement point for data collection as described below:

1: Measurement of heat produced by the heat pump and provided to the storage system (both for the space heating and domestic hot water where relevant). This measure should be achieved using a heat meter, composed of two temperature sensors and the measure of the volume flow rate. Device for measuring the volume flow rate have to be implemented on a straight pipe, in aim to assure fully developed flow to minimise measurement uncertainty. The output signal should be pulses with certain energy content per registered pulse.

2: Measurement of the electricity consumption of the heat pump. This point of measure has to be at the correct place in order to respect the boundary, as previously explained. Indeed, this measurement must include the electricity used by compressor and the operating system of the heat pump, electrical backup if needed, circulation pumps and fans (heat source side only). The output signal should be pulses with certain energy content per registered pulse.

3: Measurement of the running time of the heat pump and this data can be obtained by observing/tracking an appropriate component of the installation (compressor for example).

4: Measurement of the number of stops and starts of the heat pump system. As the previous one, this data can be obtained by observing/tracking an appropriate component.

5: Track and note problems related to the heat pump system.

6: Measurement of running time of the electrical backup if such is needed. This point of measure must be placed on the appropriate component.

Indoor or outdoor temperatures should be measured. Outdoor temperature should be measured in a place where sunlight does not affect the reading, normally on the north side of the house. When monitoring an ASHP, it is advisable to also monitor the temperature next to the heat pump outdoor unit, to check that the air flowing through the outdoor unit is not short circuited.

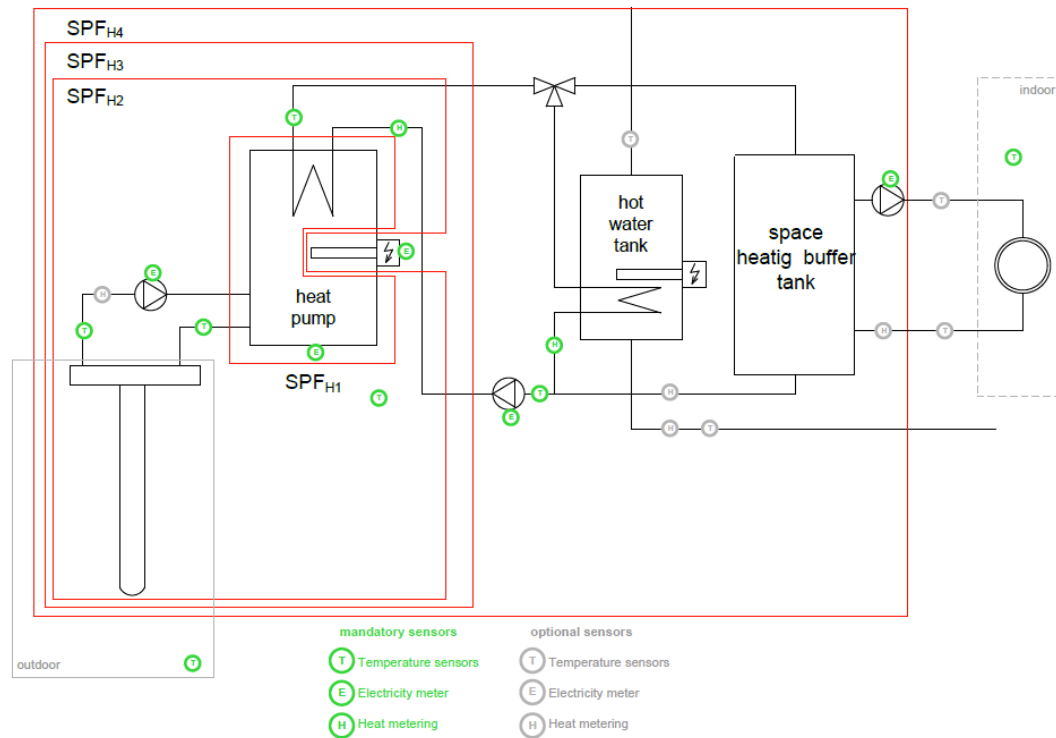


Figure 8. Placement of measurement points for data collection for a heat pump system.

5.2.2 Criteria for monitoring

Criteria for monitoring were set in this joint research project, based on the experiences made from analysing the monitoring campaigns already performed. These criteria should be used as basic requirements for performing new monitoring to achieve high quality monitoring results. The criteria were set as follows:

- Duration of measurement: at least one year
- Time step: maximum 1 week, monitoring pulses
- Accuracy of measurement should be SPF within +/- 10%
- Availability of the heat pump: over 99.0%
- Maximum cumulated time with faults: 20h per year²
- Maximum number of faults: 5 per year

² Heat pump systems could run with errors for long periods of time if not looked after. One typical error that occurs is that the heat pump is running with backup heating after a power outage. Such errors should be identified as soon as possible and adjusted for.

In the above set criteria, time step could be made much shorter if the purpose of the study is to look more into detail about heat pump operation. For outdoor units especially, sampling intervals need to be much shorter to enable correct calculation of COP at each time step. By applying time steps of one to five minutes, swift changes in temperature due to e.g. defrosting or clouds could be captured in the monitored results. However, if the purpose of the monitoring campaign is to look at one year performance, such small time steps will generate massive amounts of data to analyse.

Availability means here that the heat pump should be working in normal conditions for 99 % of the time. The heat pump system should be monitored all this time. Of course, if on-off modulation is a normal operating principle, or if householders have the habit to shut down the unit in the evening and burst heat in mornings, this should be accounted for as normal operation.

5.2.3 Monitoring equipment

In this project, field measurement data has been collected from field measurement installations for which the equipment has sufficiently low uncertainty to meet the study objective. A criterion when selecting the sites regarding measuring equipment was that the amounts of heat and amount of electrical energy had or should be measured by using pulses to ensure sufficiently low uncertainty of measurement obtained at variable flows. All measuring equipment had been checked before installation and compared to normal in a laboratory. The equipment had been installed with regard to the fact that the heating system should be restored to original condition after completion of measurements.

5.3 Data quality

The average heating capacity of the heat pump is calculated according to equation (1) and this calculation is performed by the heat meters that has been used at all sites. It results in the meter supplying a measured result in the form of heat, or the amount of heat per unit time.

$$\dot{Q} = q * \rho_{t,flow} * (t_{out} - t_{in}) * \frac{c_p(t_{out}) + c_p(t_{in})}{2} \quad (\text{Eq. 1})$$

The estimated value of the expanded uncertainty for the heating power depends on the uncertainty of the input parameters. Except for the temperatures, the different contributions can be regarded as independent of each other and therefore the simplified expanded uncertainty of the average heating power shall be calculated as follows:

$$\frac{\Delta \dot{Q}}{\dot{Q}} = \sqrt{\left(\frac{\Delta q}{q}\right)^2 + \left(\frac{\Delta p}{p}\right)^2 + \left(\frac{\Delta(t_{in} - t_{out})}{(t_{in} - t_{out})}\right)^2 + \left(\frac{\Delta c_p}{c_p}\right)^2} \quad (\text{Eq. 2})$$

The measured amount of heat used to heat hot water is relatively low compared to the total heat quantity for most installations in this study and when the heat pump is providing space heating the temperature difference between the supply and return of the heat pump is relatively small. The smaller temperature difference between supply and return, the higher the uncertainty of the temperature difference, because a small error of measurement of the temperature itself results in a large relative error of the distinction between them.

The pump to the heating system is running even when the heat pump does not produce heat, i.e. the compressor is not running, and during those periods it has been flow through the heating system's heat meters even when there was no heating demand. At these occasions the temperature difference should be close to 0 K. A small error of measurement of the temperature sensors can however provide a relatively large measurement error, as this operating mode occupies a large part of the year.

The expanded uncertainty of the measured values was estimated to be better than the following (with a 95% confidence interval) for the Swedish monitoring results:

Heat for domestic hot water (incl. idle consumption) $\pm 10\%$

Heating space heating $\pm 9\%$ but not more than 43 kWh / week

Indoor temperature $\pm 0.5\text{ }^{\circ}\text{C}$

Outdoor temperature $\pm 1.0\text{ }^{\circ}\text{C}$

Electric energy $\pm 2\%$

SPF $\pm 11\%$ ³

5.4 Performance requirements according to theoretical principles

Based on the Carnot principle, the Carnot COP for a zero degree heat source is illustrated in Figure 9. Due to the technical nature of different components in the heat pump, a real COP is normally 50-60 % of the corresponding Carnot COP.

³ As can be seen from this number, we set the criterion to be 10%, and in the Swedish monitoring project we assessed, an 11% uncertainty on SPF was achieved. We however see this as good enough to be included in the study.

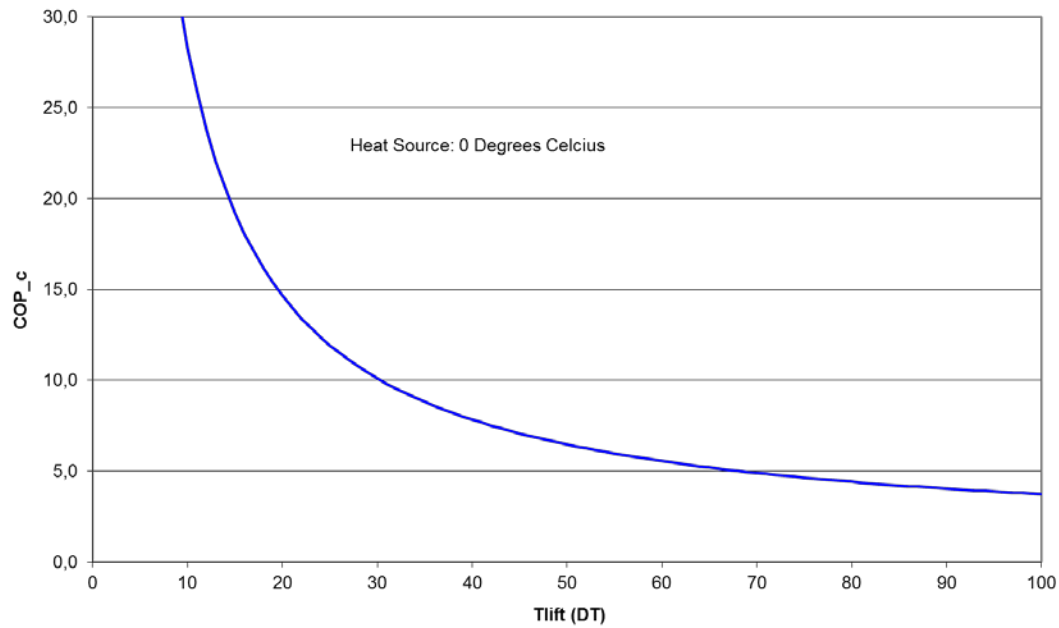


Figure 9. Carnot COP vs. temperature lift with a heat source at zero degrees C.

Given that ground heat sources could be around 0°C, and air source average temperature over the year is somewhat higher in most locations, and the fact that a temperature lift of between 30-50 K is required to produce space heating and DHW respectively, a seasonal COP, i.e. SPF of between 4 and 6 is reasonable (0 °C source temperature, Carnot efficiency 60 %). Higher source temperatures of course raise the level, as can be seen in Figure 10, and auxiliary heating lowers the level. Potential technical achievements may raise the Carnot efficiency, and a 10 %-point increase in Carnot efficiency raise the SPF to between 4.5 and 7.

It can also be noted that laboratory tests have shown efficiency increase by almost 30 % from 1995 to 2010, see Figure 11 [12].

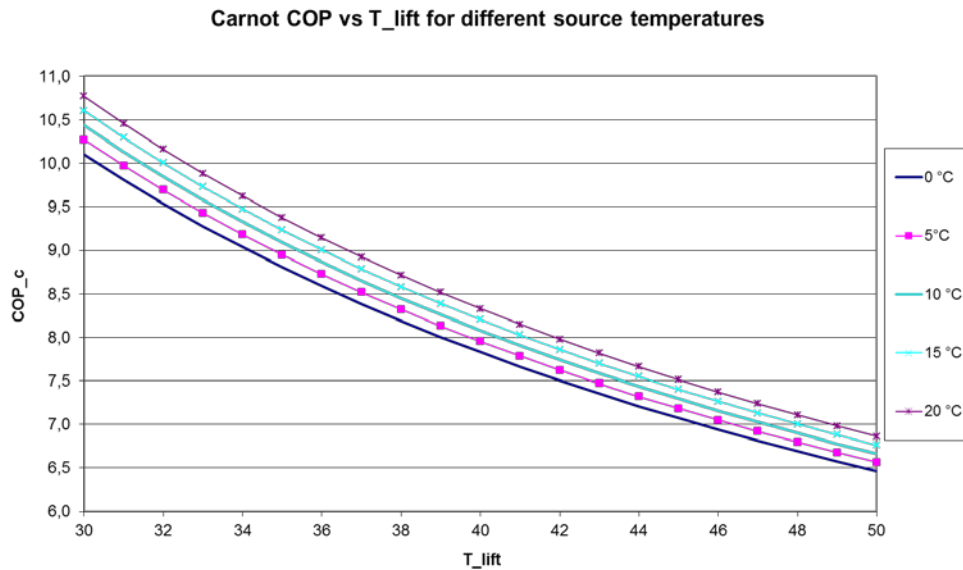


Figure 10. Carnot COP as a function of source temperature vs. temperature lift.

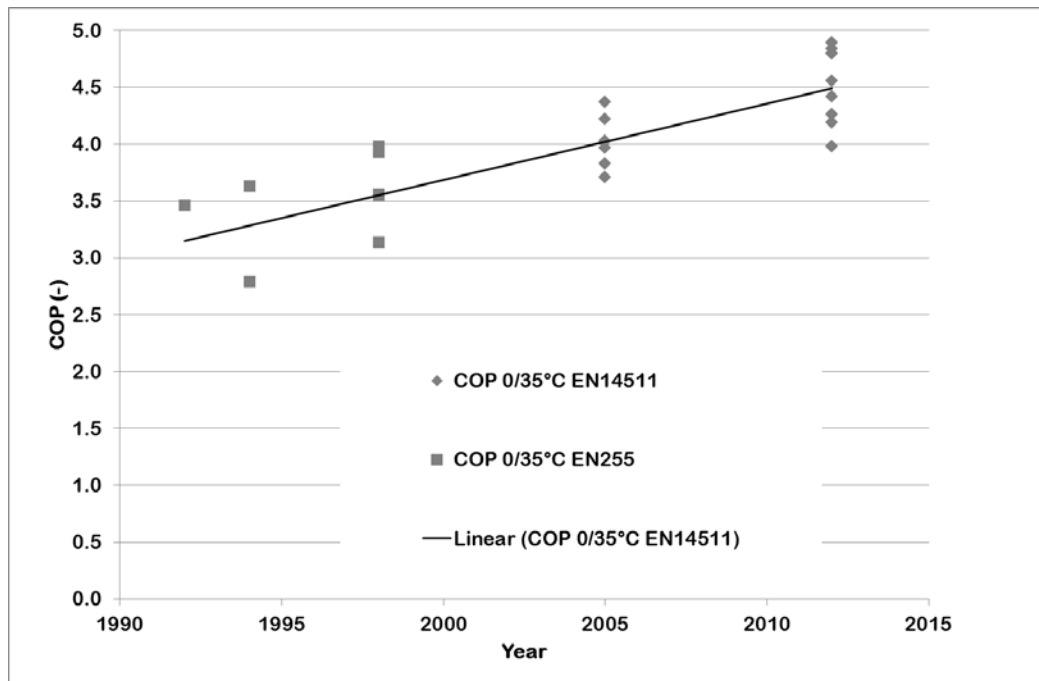


Figure 11. COP of brine-to-water heat pumps according to EN 14511 and EN255 in lab tests for 0/35 test condition [12].

5.5 Performance requirements according to regulations and standards

The future efficiencies of heat pumps that we may see in the market in Europe will be affected by the requirements of the Energy label and Ecodesign regulations for space heaters and water heaters [8, 9, 10, 11] and the Renewable Energy Directive [2]. In these European policies an emphasis has been put on introducing renewable energy in the energy system, to have more efficient products and processes, and to curb CO_2

emissions. Annex VII to the Renewable Energy Directive [2] (the Directive) establishes the basic method for calculating renewable energy supplied by heat pumps.

In accordance with Annex VII to the Directive, Member States shall ensure that only heat pumps with a SPF above $1,15 * 1/\eta$ are taken into account. With a power system efficiency (η) set at 45,5 % [12] it implies that the minimum SPF of electrically driven heat pumps ($SCOP_{net}$) to be considered as renewable energy under the Directive is 2,5, evaluated at the SPF_{H2} boundary.

For heat pumps that are driven by thermal energy (either directly, or through the combustion of fuels), the power system efficiency (η) is equal to 1. For such heat pumps the minimum SPF ($SPER_{net}$) is 1,15 for the purposes of being considered as renewable energy under the Directive [2].

In the Ecodesign and Energy label regulations [8, 9, 10, 11] , the efficiency for all space heaters for hydronic heating system are considered in parallel. This means that they are compared by the same measure according to the same scale. η_s is the seasonal energy efficiency which is the measure that is used as the benchmark in the Ecodesign and Energy label regulations. For heat pumps, the seasonal energy efficiency, η_s , is based on a SCOP values (seasonal COP) according to Eq. 3 and 4 below. The minimum efficiencies for products to be permitted to be placed on the European market have been defined and are shown in Table 4. LT represents low temperature systems, and can be interpreted as new built or deep-renovated buildings (e.g. floor heating), whereas MT systems can be seen as existing buildings applications radiator heating). In the table, it can also be seen that the requirements are sharpened in 2017.

Table 4. Ecodesign requirements, η_s

	Ecodesign requirements, η_s , %	
	LT	MT
2015	115	100
2017	125	110

LT : low temperature application (35°C)

MT: medium temperature application (55°C)

Based on these values, we have calculated the corresponding required SCOP values for GSHP and ASHP respectively, see Table 5. In these calculations, there are two correction factors that influence the calculation of η_s in relation to SCOP. Due to temperature regulation, 3% is deducted for all space heaters, including heat pumps. Due to the energy consumption of the brine or ground water pump, a further 5% is deducted for brine-to-water heat pumps alone. Therefore, the calculation of η_s is as follows (CC equals to the primary energy factor which is defined to be 2,5 in the regulations):

$$\text{Air-to-water heat pumps: } \eta_s = \frac{SCOP}{CC} - 3\% \quad (\text{Eq. 3})$$

$$\text{Brine-to-water heat pumps: } \eta_s = \frac{SCOP}{CC} - 3\% - 5\% \quad (\text{Eq. 4})$$

However, the SCOP calculated by Equation 3 & 4 is the SCOP resulting from tests according to EN14825, where only a fraction of the electric energy of the heat source pump is included; Eq. 3 & 4 should be used also when calculating a SCOP to be compared to SPF_{H3} .

Table 5. SPF_{H3} to be classified as a good example.

	GSHP		ASHP	
	LT	MT	LT	MT
2015	2,95	2,58	2,95	2,58
2017	3,20	2,83	3,20	2,83

To be among the top performing products, A+++ labelled products according the Energy label regulation, η_s values > 150% for 55°C heat emitter systems and an η_s values > 175% for 35°C heat emitter systems are required.

5.6 Performance criteria for good heat pump systems

As previously stated, the project has agreed on criteria that have to be met by the heat pump system to be considered good examples. First, the heat pump must have had an annual availability over 99.0%. Second, the maximum allowed accumulated time of faults has been set to 20 h per year with a maximum number of faults of 5 per year.

Moreover, the heat pump system must respect a minimum efficiency, at least at the same level as the European Ecodesign threshold values that will come into force in 2017 [10]. The minimum limit for SPF_{H3} has therefore been decided to be 2,8-3,2 for air-source heat pumps (retrofit/new) and 3.3-3.9 for ground-source heat pumps (retrofit/new).

Heat pump systems in buildings with a very large specific energy demand have not been accepted as good examples, even if the heat pump itself was performing well.

Considering both the new regulations and technological improvements, it was concluded from the project that reasonable requirements for heat pump system to be regarded as a good performing systems could be set to:

Table 6. Annex 37 requirements for heat pump system to be regarded as a good performing systems.

	ASHP, new	ASHP, retrofit	GSHP, new	GSHP, retrofit
SPF_{H3}	3,2	2,8	3,9	3,3

6 EVALUATION OF FIELD MEASUREMENTS

6.1 System solutions covered by the study

In total, 12 heat pump installations have been included in the project: three from Sweden (SE), five from Switzerland (CH) and four from the United Kingdom (UK). The main heat source types for the heat pumps are vertical borehole, horizontal loop or outside air. The Swedish heat pumps have additional heat sources by either the sun or exhaust air from inside the house. An overview of the details for the sites is presented in Table 7. Details about each site are presented in Appendix 1.

Table 7. Heat pump sites included in the study. The heat produced by the heat pump is used for space heating (SH) and domestic hot water (DHW).

Main heat source	Additional heat source	Use of heat (heat sink)	Outside temp (yearly average)	Location	Heated surface	Rated heat output
Vertical borehole	Exhaust air	SH + DHW	7.4°C	SE (Markaryd)	185 m ²	6.0 kW
Vertical borehole	Sun	SH + DHW	6.6°C	SE (Åkersberga)	200 m ²	8.0 kW
Outside air	Sun	SH + DHW	7.0°C	SE (Onsala)	280 m ²	14.0 kW
Vertical borehole		SH + DHW	9.3°C	CH (Tänikon)	300 m ²	7.5 kW
Vertical borehole		SH + DHW	9.0°C	CH (Tänikon)	132 m ²	6.0 kW
Outside air		SH	10.0°C	CH (Tänikon)	275 m ²	8.0 kW
Outside air		SH + DHW	9.5°C	CH (Neuchatel)	123 m ²	7.0 kW
Outside air		SH	9.3°C	CH (Schaffhausen)	160 m ²	9.6 kW
Horizontal loop		SH + DHW	8.1°C	UK (Glasgow)	226 m ²	5.0 kW
Outside air		SH	7.1°C	UK (Aberdeen)	251 m ²	7.0 kW
Vertical borehole		SH + DHW	7.1°C	UK (Aberdeen)	127 m ²	8.0 kW
Outside air		SH + DHW	7.1°C	UK (Aberdeen)	73 m ²	5.0 kW

The SPF values in this project have been calculated using system boundary SPF_{H3} from the project SEPOMO [7] (if nothing else is stated). This system boundary includes the heat pump, the heat source pump or fan and the backup heater, see Figure 5. System boundary 3 excludes the electricity consumption for operation of the heating system of the house, such as circulation pumps.

The back-up heaters are electric heaters or solar heating systems in the heat pump sites included in this project. This means that for the sites with solar heating as back-up, the SPF_{H3} values are normally higher than the SPF_{H2} values (for which do not include the back-up heaters, see Figure 5). In the heat pump systems with electricity as a backup, the SPF values normally decrease from system boundary 1 to 4: $SPF_{H1} \geq SPF_{H2} \geq SPF_{H3} \geq SPF_{H4}$.

Tables 8 and 9 present the calculated SPF_{H3} values from the evaluated sites.

Table 8. $SPFH_3$ -values for monitored Ground Source Heat Pumps.

Heat source	Use of heat (heat sink)	Outside temp (yearly average)	$SPFH_3$	Location
Vertical borehole	SH + DHW	9.3°C	4.7	CH (Tänikon)
Vertical borehole	SH + DHW	7.4°C	4.6	SE (Markaryd)
Vertical borehole + sun	SH + DHW	6.6°C	4.4	SE (Åkersberga)
Vertical borehole	SH + DHW	7.1°C	3.4	UK (Aberdeen)
Vertical borehole	SH + DHW	9.0°C	3.3	CH (Tänikon)
Horizontal ground loop	SH + DHW	8.1°C	3.9	UK (Glasgow)

Table 9. $SPFH_3$ -values for monitored Air Source Heat Pumps.

Heat source	Use of heat (heat sink)	Outside temp (yearly average)	$SPFH_3$	Location
Outside air	SH	7.1°C	3.7	UK (Aberdeen)
Outside air	SH + DHW	7.1°C	3.3	UK (Aberdeen)
Outside air	SH	10.0°C	3.2	CH (Tänikon)
Outside air + sun	SH + DHW	7.0°C	3.2	SE (Onsala)
Outside air	SH + DHW		3.1	CH (Neuchatel)
Outside air	SH	9.3°C	2.6	CH (Schaffhausen)

6.2 Sweden

6.2.1 Description of the HP sites included (Effsys project)

In Sweden five sites with electrically driven heat pumps have been monitored and evaluated. The heat pumps were selected by the manufactures as best practice. The measuring period lasted between 2010-06-01 and 2011-05-31. Table 10 summarizes information about the five sites in Sweden. Three of these, site 1, 4 and 5 have been included in this joint research project, since they reached acceptable SPF's for inclusion in the study. In the Swedish study, both emitted heat for space heating and domestic hot water are measured after the storage tanks. The amount of heat that the heat pump produces due to losses in the tanks were not measured. This affects the SPF value negatively. If meters were placed before the tanks the SPF would have been higher than in this study. In this Annex, no corrections have been made to the

Swedish monitoring results to include the tank losses as heat produced from the heat pump.

Table 10. Description of 5 monitored sites in Sweden

Site	1	2	3	4	5
Building: single-family house	1 level+garage 222 m ² +67m ²	2 levels 140 m ² +140 m ²	1 1/2 level 200 m ² +54 m ²	1 1/2 level 208 m ² +77 m ²	1 1/2 level 100 m ² +100 m ²
Construction year	2008	1991	2008	2009	2009
Installation year	2008	2010	2008	2009	2009
Type of system	Brine/water HP combined with solar heating	Air/water HP combined with solar heating	Brine/water	Brine/water	Brine/water HP combined with solar heating
HP capacity (kW)	6	14	9	6	8
Heat source system	Ground heat storage	Air-source-unit outdoor	Borehole heat exchanger	Borehole heat exchanger	Borehole heat exchanger
Distribution system	Floor	Floor	Floor level. 1 Radiators lev. 2	Floor level. 1 Radiators lev. 2	Floor level. 1 Radiators lev. 2

Monitored parameters included:

- Heat for space heating
- Heat for domestic hot water
- Heat from solar collectors
- Electric energy to compressor and control system
- Electric energy to electric back up heater
- Electric energy to all circulation pumps and fans
- Electric energy to the exhaust air fan
- In- and outdoor temperature
- Ambient relative humidity, RH

Sample interval was set to 30 s, and the resolution of the sampling was

Flow: 10 pulses/liter

Electric energy: 100 pulses/kWh

For the monitored parameters, the expanded measurement uncertainty was estimated to the values according to Table 11 below.

Table 11. Estimated expanded measurement uncertainty for the monitored parameters.

Flow, domestic hot water	±1,6%
Flow, water to space heating system	±1,2%

Flow, glycol (brine solar heat)	$\pm 2,0\%$
Water temperatures	$\pm 0,2^{\circ}\text{C}$
Indoor temperature	$\pm 0,5^{\circ}\text{C}$
Outdoor temperature	$\pm 1,5^{\circ}\text{C}$
Relative Humidity	$\pm 3,5\%$ -units
Electric energy	$\pm 2,0\%$
Heating energy, domestic hot water	$\pm 10\text{-}15\%$
Heating energy, space heating system	$\pm 7,1\%$

6.2.2 Examples of results from site 4

The heat pump system scheme and corresponding monitoring positions are shown in Figure 12 and Figure 13.

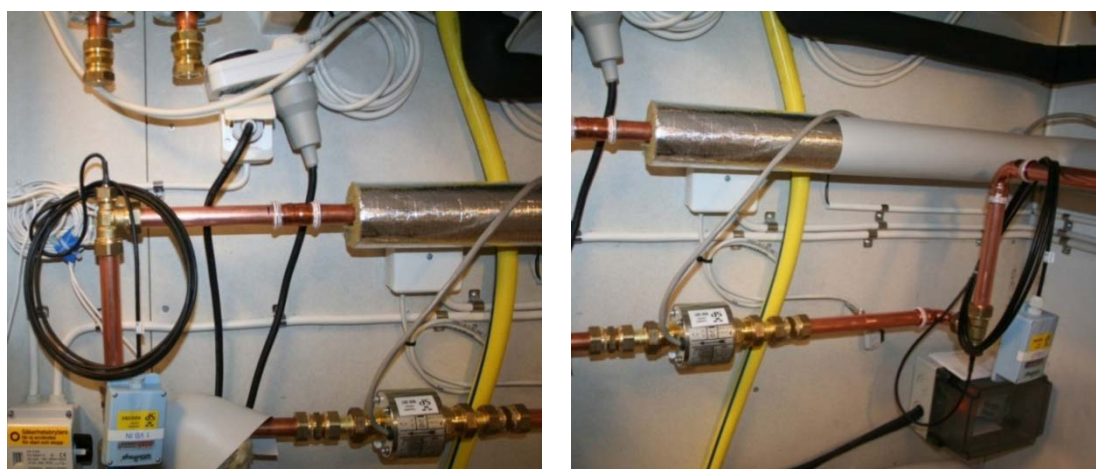


Figure 12. Pictures illustrating installed monitoring equipment in one of the Swedish sites.

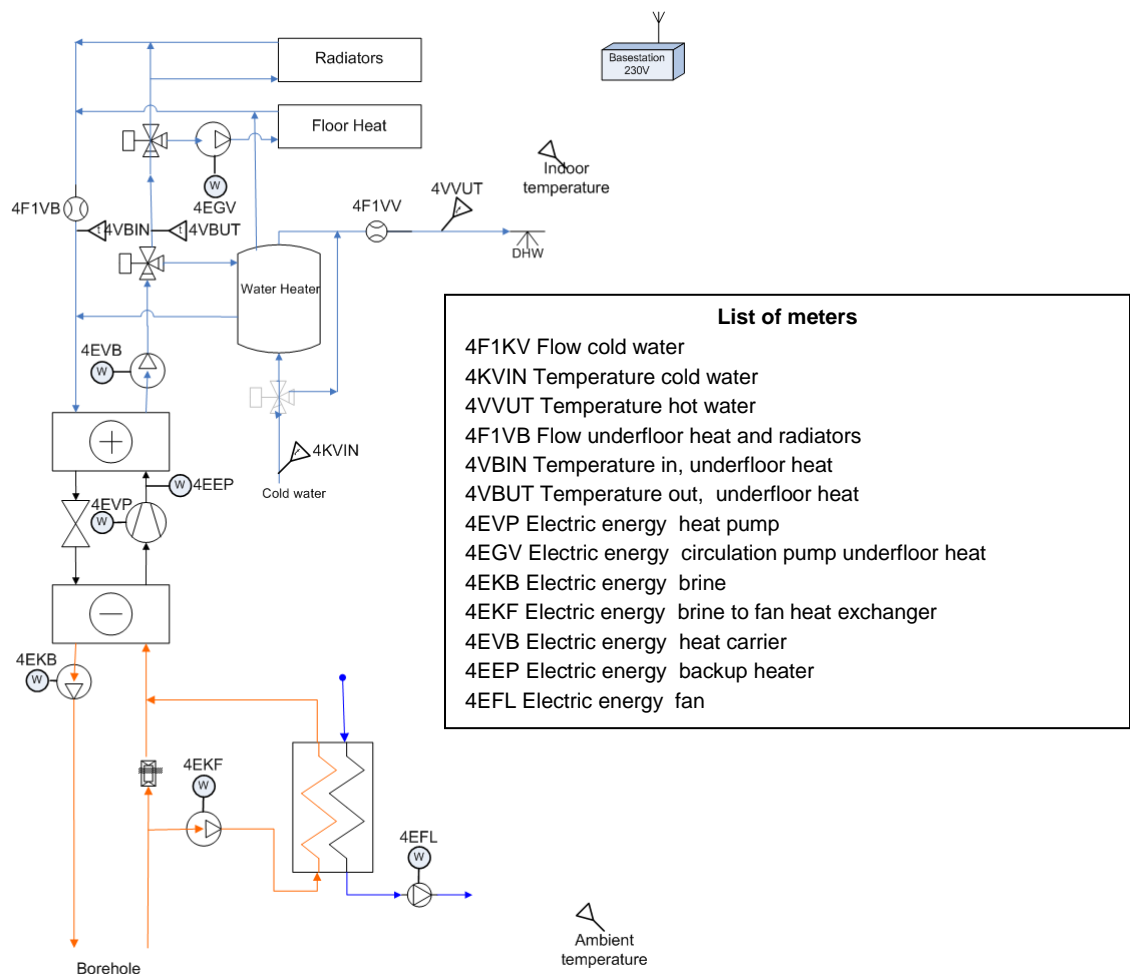


Figure 13. Scheme over system and monitoring positions, site 4, SE.

From the monitored data, several interesting graphs could be drawn. Figure 14 show the dependence of space heating vs outdoor temperature. It can be seen that this building has little or no space heating demand for outdoor temperatures over 12-15 °C. As expected, a linear relationship between space heating demand and outdoor temperature was found.

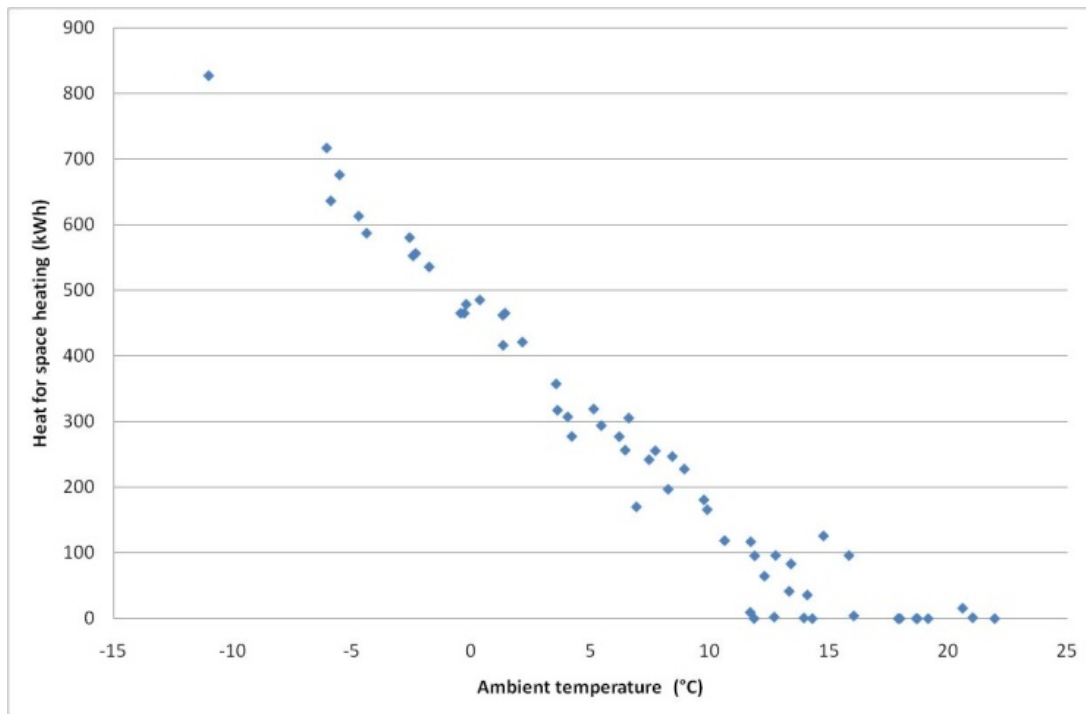


Figure 14. Space heating demand vs outdoor temperature for site 4 (SE).

From Figure 15, showing total amount of used heat, i.e. heating demand, per month, it can be seen that the DHW demand is rather constant over the year, while space heating dominates in cold periods as expected.

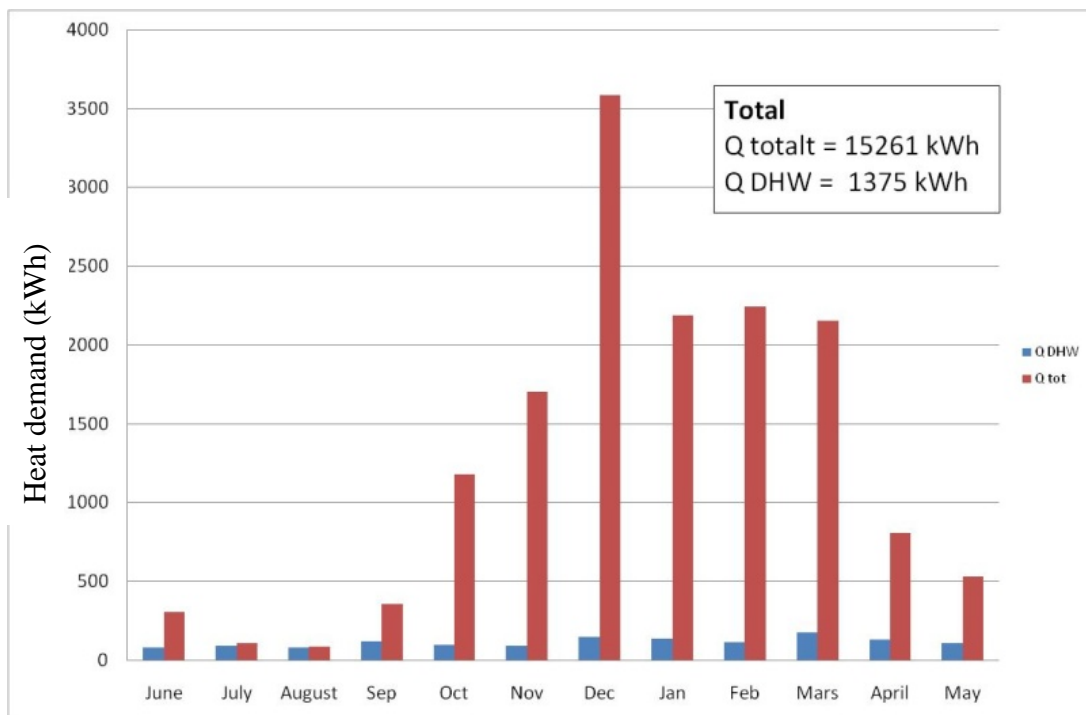


Figure 15. Used heat or space heating and DHW heating per month for site 4.

From Figure 16 it can be seen how the SPF degrades from SPF_{H1} to SPF_{H4} . In this particular site, we see that the borehole brine pump and circulator in the building consume quite some energy, since there is a clear difference between SPF_{H1} and SPF_{H2} and SPF_{H3} and SPF_{H4} . We can also notice that the difference between SPF_{H2} and SPF_{H3} is very small, suggesting that there has been little need for back-up heating. The SPF values are lower in summertime because the heat pump then only produces domestic hot water, which is heated to a higher temperature compared to when heating space heating water. However, we can conclude that in spite of this, a very good annual SPF is reached.

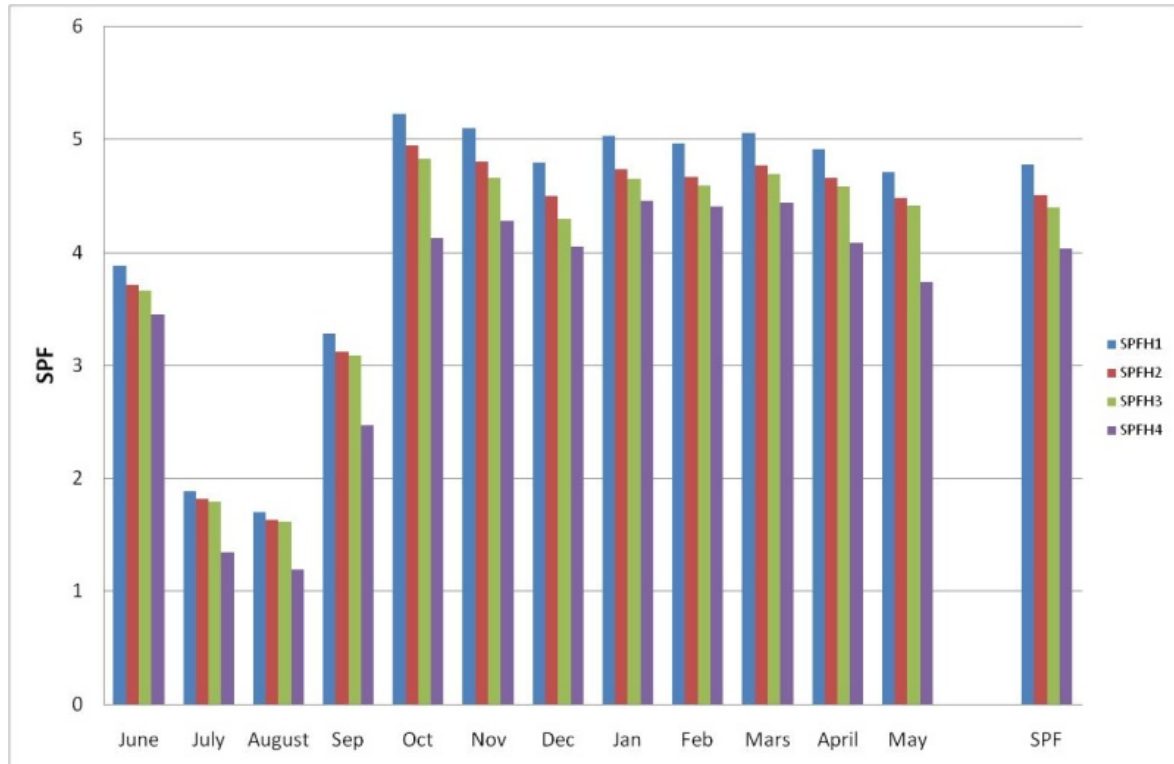
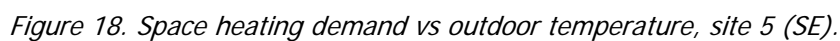


Figure 16. SPF_{H1} - SPF_{H4} calculated from measured data, site 4 (SE).

6.2.3 Examples of results from site 5

Site 5 represent a system with a GSHP (ground source heat pump) assisted by a solar heating system, Figure 17.



- 5F1KV Flow cold water
5KVIN Temperature cold water
5VVUT Temperature hot water
5F1VB Flow underfloor heat
5VBIN Temperature in underfloor heat
5VBUT Temperature out underfloor heat
5FSF Flow solar collector
5SF Temperature in solar collector
5SF Temperature out solar collector
5EVP Electric energy heat pump
5EGV Electric energy circulation pump underfloor heat
5ESF Electric energy circulation pump solar collector
5EKB Electric energy brine pump
5EEP Electric energy backup heat

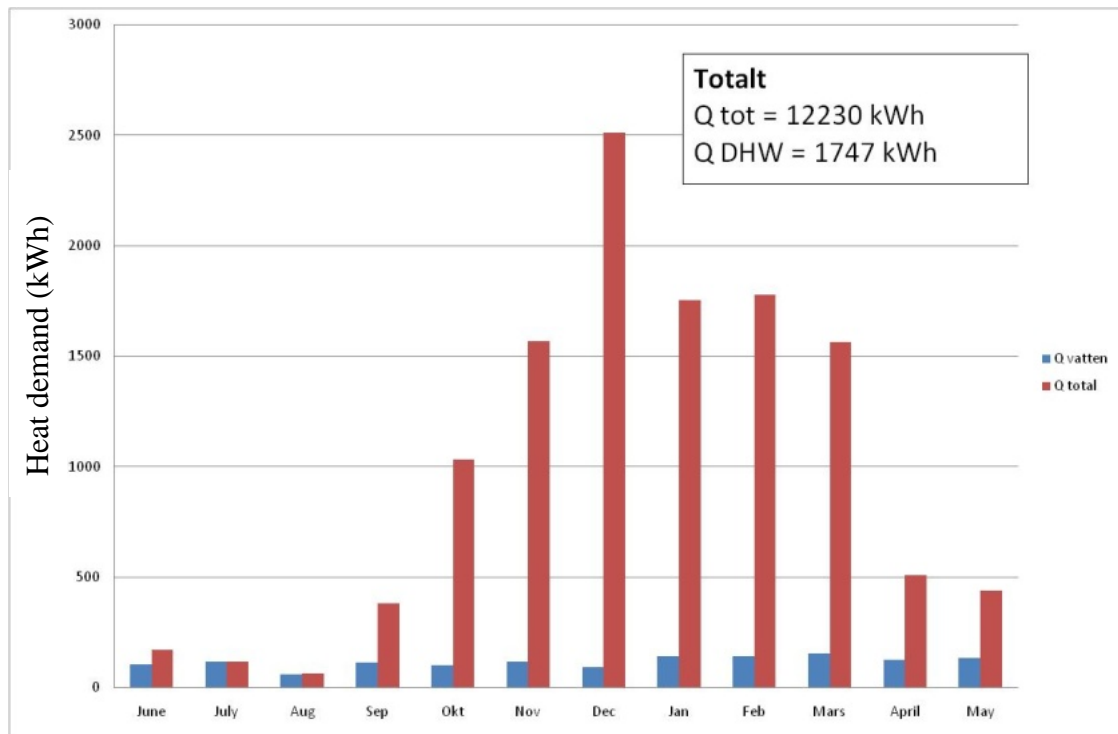


Figure 19. Used heat or space heating and DHW heating per month for site 5. Blue bars represent amount of energy for DHW preparation, red bars represent Space heating demand.

In Figure 20, it can be seen that the heat pump is completely shut off during summer, since the SPF_{H1} and SPF_{H2} are zero, while the SPF_{H3} and SPF_{H4} values are high. The reason for this is the definition of SPF_{H1} - SPF_{H4} , see Figure 20, where the absorbed heat from the solar panels delivered in the heating system are divided by the electricity consumption by the circulation pumps and control system when calculating the SPF-values. The figure also illustrates the reduced demand for heating via heat pump in April, May and September, when there is still a significant contribution from the solar panels.

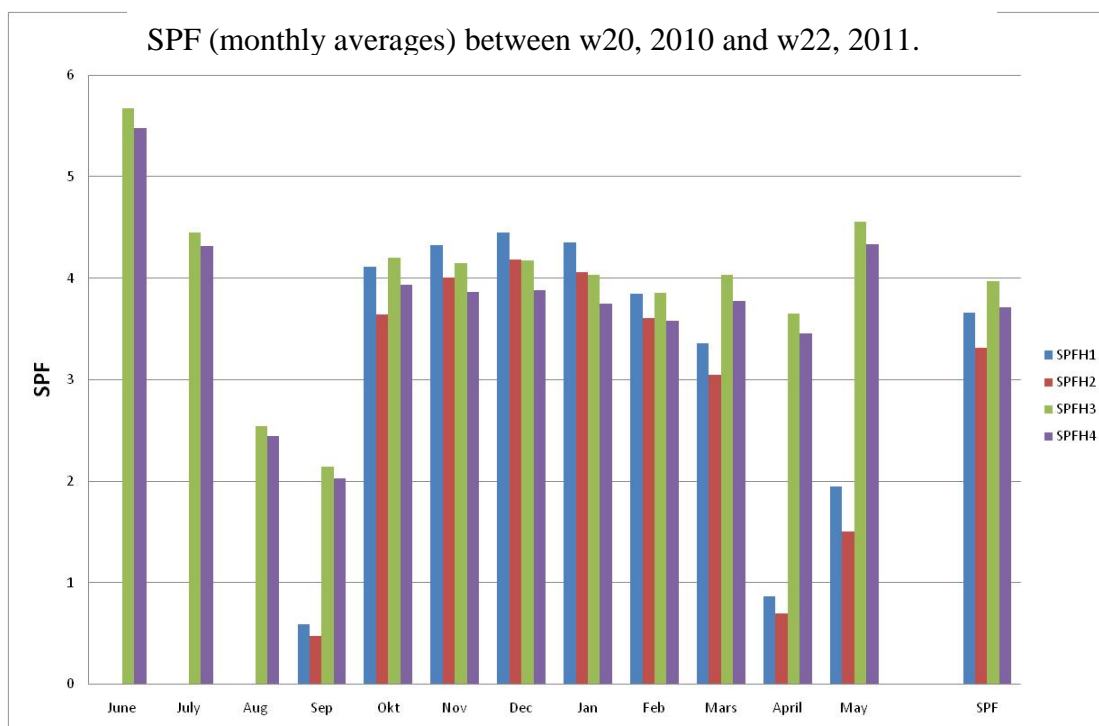


Figure 20. SPF_{H1} - SPF_{H4} values for site 5 (SE) where the heat pump is assisted by solar heating.

Based on the calculated values, the CO₂ reduction compared to if the sites had been heated by electric radiators or with oil boiler was calculated. The results of this calculation are shown in Table 12, with calculations considering both the Swedish average electricity generation (Swedish mix) and coal condensing power production. In both cases, heat pump saves CO₂ emissions. In the Swedish study, coal condensing was chosen as a “worst case” to compare with. In the subsequent section 7.3, CO₂ savings were recalculated to compare with EU-mix of electricity generation instead for comparison with the Swiss and British studies.

Table 12. CO₂ reduction from using heat pump compared to electric radiators or oil boiler.

CO ₂ reduction (kg CO ₂ -eq)				
	Electric radiators		Oil heating	
	Swedish mix	Coal condensing	Swedish mix	Coal condensing
Site 1	301	9068	4480	141
Site 4	390	11767	5213	1466
Site 5	296	8934	4091	829

Conclusions from the analysis of the sites in Sweden are:

- There is a linear relationship between heat demand for space heating and ambient temperature
- Field measurements where the results are calculated for different predefined system boundaries provides knowledge of the parameters that affect heat pump system efficiency
- When the heat pump system is compared with alternative heating systems, it is important to define the system boundaries to account for the electricity components included in order to make fair comparisons
- Electric energy savings compared to electrical radiators can be as high as 75%
- The level of CO₂-reduction by use of heat pumps depends on how the electricity used in the heat pump and auxiliary equipment is assumed to be produced
- SPF varies between 4,8 and 3,4 for SPF_{H1} for all the five evaluated sites
- SPF varies between 4,1 and 2,9 for SPF_{H4} for all the five evaluated sites
- SPF decreases normally with decreasing heat demand for space heating in relation to domestic hot water demand, which should be considered for the future when construction of low-energy houses will be more frequent

6.3 UK

6.3.1 Description of the HP sites included (EST study)

The Energy Saving Trust (EST) monitored 83 heat pumps in residential properties across Great Britain from April 2009 to April 2010, covering a range of technologies (ground to water, water to water, air to water and exhaust air) and a range of heat emitters (underfloor heating, radiators, each with and without domestic hot water production). From this campaign, some sites were chosen for a more detailed analysis. The sample included a mix of air- and ground-source heat pump systems (around a third of the sample being air-source). In the study, SPF_{H4} was used as the system boundary, and according to this metric, the average performance was 2.82 for the ground-source heat pumps in the trial and 2.45 for the air-source heat pumps in the trial

Overall, 78% of Ground Source Heat Pumps and 63% of Air Source Heat Pumps [24] were found to equal or surpass the limiting value of 2.5 for SPF_{H2} established under the Renewable Energy Directive, and these installations can therefore be classified as sources of renewable energy.

Heat pumps are generally considered to be an efficient technology, with significant potential for reducing the emissions of greenhouse gases. However, in the UK, it is important to note that heat pumps generally operate for 24 hours a day, unlike standard gas, oil or electric storage heating systems, which are used only for part of the day.

Best practice is often described simply in terms of SPF⁴. Furthermore, the carbon coefficients of different fuels, now, and in the future, must be included in the calculation.

6.3.2 Experimental set-up

There are many ways of defining system efficiency. For the purposes of the EST trial, two different efficiencies were calculated: the system efficiency and the heat pump efficiency.

The seasonal efficiency has been defined as the efficiency of the entire system, i.e:

$$SPF_{System} = \frac{(Q_{space\ heating} + Q_{domestic\ hot\ water})}{(E_{heat\ pump} + E_{boost\ heat} + E_{immersion} + E_{defrost} + E_1 + E_2)}$$

Where:

Q space heating = useful heat supplied by the space heating system

Q domestic hot water = heat of domestic hot water actually used.

E_{heat pump} = electricity supplied to heat pump

E_{boost heater} = electricity supplied to supplementary boost heater (which may be located within the heat pump)

E_{immersion} = supplementary electricity supplied to hot water cylinder.

E_{defrost} = electricity used for defrost

E₁ = electricity used by circulation pump for the fan or ground loop.

E₂ = electricity used by the circulation pump that circulates hot water round radiators/heating system.

Note that Q domestic hot water is the heat of the domestic hot water actually used. **This means that heat losses from the hot water tank, or any buffer tanks, are not counted as useful heat in this definition.** This definition is equal to SEPAMO SPF_{H4}. Like with the Swedish study, this means that SPF values are somewhat under estimated when considering the heat output from the heat pump.

Where possible, the SPF of the heat pump itself is also measured. This is defined as:

⁴ DECC considers that, in the UK context, this is incorrect, and that the overall energy use for heating must also be taken into account.

$$SPF_{Heat\ pump} = \frac{(Q_{heat\ pump})}{(E_{heat\ pump} + E_1)}$$

Where:

$Q_{Heat\ pump}$ = heat output from the heat pump

This definition is equal to SEPAMO SPF_{H2} except that the electricity for defrost should be included in the denominator.

Note that, in some cases, the boost heater and domestic hot water cylinder are located inside the heat pump and so electricity use by immersion and boost heater has been estimated and subtracted from the measured electricity consumption.

6.3.3 Summary of results

A wide range of performance was found, from good to poor. Figure 21 shows the ground source heat pump system SPF (equivalent to SEPAMO SPF_{H4}) and Figure 22 shows the air source heat pump system SPF in the trial.

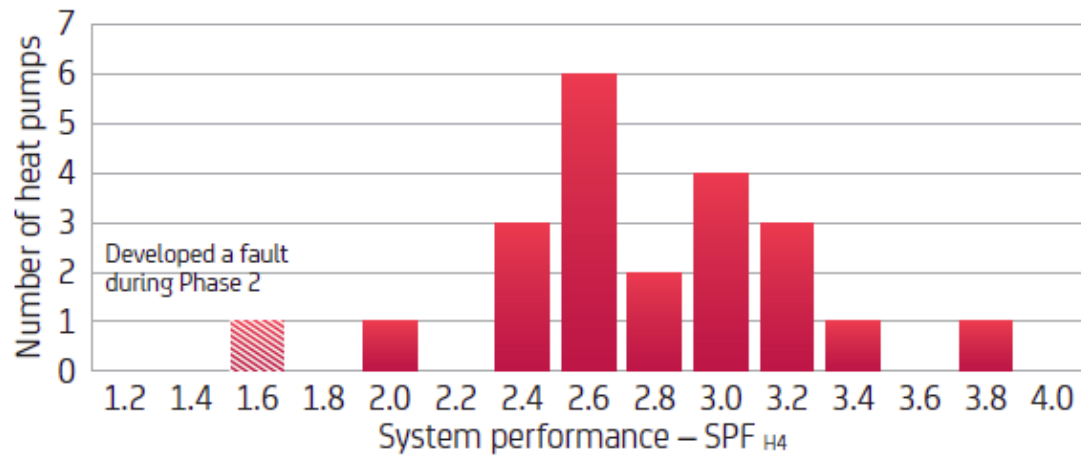


Figure 21. Heat pump system SPF (equivalent to SEPAMO SPF_{H4}) for the ground source heat pumps in the field trial [27].

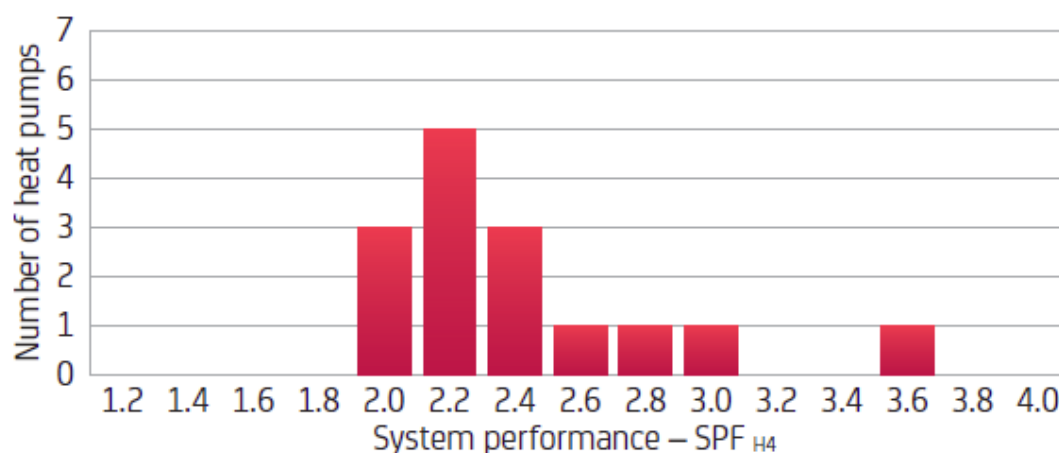


Figure 22. Heating system SPF for the air source heat pumps in the field trial. (The heating system SPF is similar to SEPEMO SPF_{H4}) [27].

6.3.4 Examples of best practices

Of the 14 sites for which the pump SPF_{H4} was ≥ 2.8 , three were air source and the remainder were ground source. With the exception of one air source heat pump, data from the air source heat pumps that performed well (SPF_{H4} ≥ 2.8) were supplied to the trial by the manufacturer.

The remaining heat pumps with good performance are all ground source heat pumps. They include 8 manufacturers/installers and include both vertical boreholes and horizontal ground loops. Somewhat surprisingly, five of the systems have radiators and eight also heat domestic hot water.

6.3.5 Carbon savings

Heat pumps are generally operated 24 hours a day, 7 days a week throughout the winter months, unlike conventional gas, oil or storage heating systems, which are operated intermittently.

In the UK, the standard heating pattern with a gas boiler is 2 hours in the morning and 6 hours in the evening during weekdays and around 16 hours per day at the weekend. Many heat pumps, however, are set to run 24/7. For properties with low thermal mass or poor insulation, we anticipate that moving to 24 hour heating will increase energy demand. Energy and carbon savings should be adjusted to account for this. For the purposes of this study, we have assumed that moving to a 24 hour heating pattern raises average internal temperatures by around 1 degree C and that this would result in an increase in space heating demand of 10 %.

Gastec and EA Technology have estimated the following heat demands (Table 13, expressed in degree days) for a typical UK house at with a range of different internal temperatures:

Table 13. Heat demand (expressed in degree days) for a typical UK house.

24 hour average internal temperature (degrees C)	Degree Days	% relative to 18 degrees C
17	2 490	91.2%
17.5	2 610	95.6%
18	2 730	100%
18.5	2 850	104.4%
19	2 970	108.8%
19.5	3 090	113.2%
20	3 210	117.6%
20.5	3 330	122.0%

By changing from intermittent heating to 24 hour heating, the 24 hour average internal temperature of the house is expected to increase by between 1 and 2.5 degrees, which would lead to an increase in heat demand of 8.8-22 %.

For the purposes of this analysis, it has been assumed that, on average, replacing an existing gas, oil, or electric storage heating system with a heat pump would increase overall heat demand by 10 %.

The next factor to consider is carbon (i.e. emission of CO₂); based on the 2008 carbon factor for electricity, we find the following results from the EST field trial:

- Carbon savings are large when heat pumps replace electric storage heating (Figure 23. Note that all the sites are well below the 1:1 carbon emissions line).
- Most of the heat pumps in the trial produce carbon savings relative to oil, although some of the worst performers do not (Figure 24).
- On average, the heat pumps in the field trial do not save carbon relative to gas. However, virtually all the good performers (those with pump SPF's of 2.8 or above) do save relative to gas, Figure 25. The two exceptions have good heat pump SPF's but poor system SPF's, caused by poor insulation, tank losses and large circulation pumps on the heating side.

It is essential to observe that these findings refer to the 2008 carbon (CO₂) factor for electricity. UK policy is to decarbonise the electricity supply progressively, so that the average carbon factor will fall from 0.52 kg CO₂-eq/kWh in 2008 to 0.11 kg CO₂-eq/kWh by 2030 (see Table 14). This means that heat pumps installed today will save CO₂ as compared to both oil and gas.

Finally, it is important to note that improvements in SPF, both of the heat pump itself and of the system, will increase CO₂ savings.

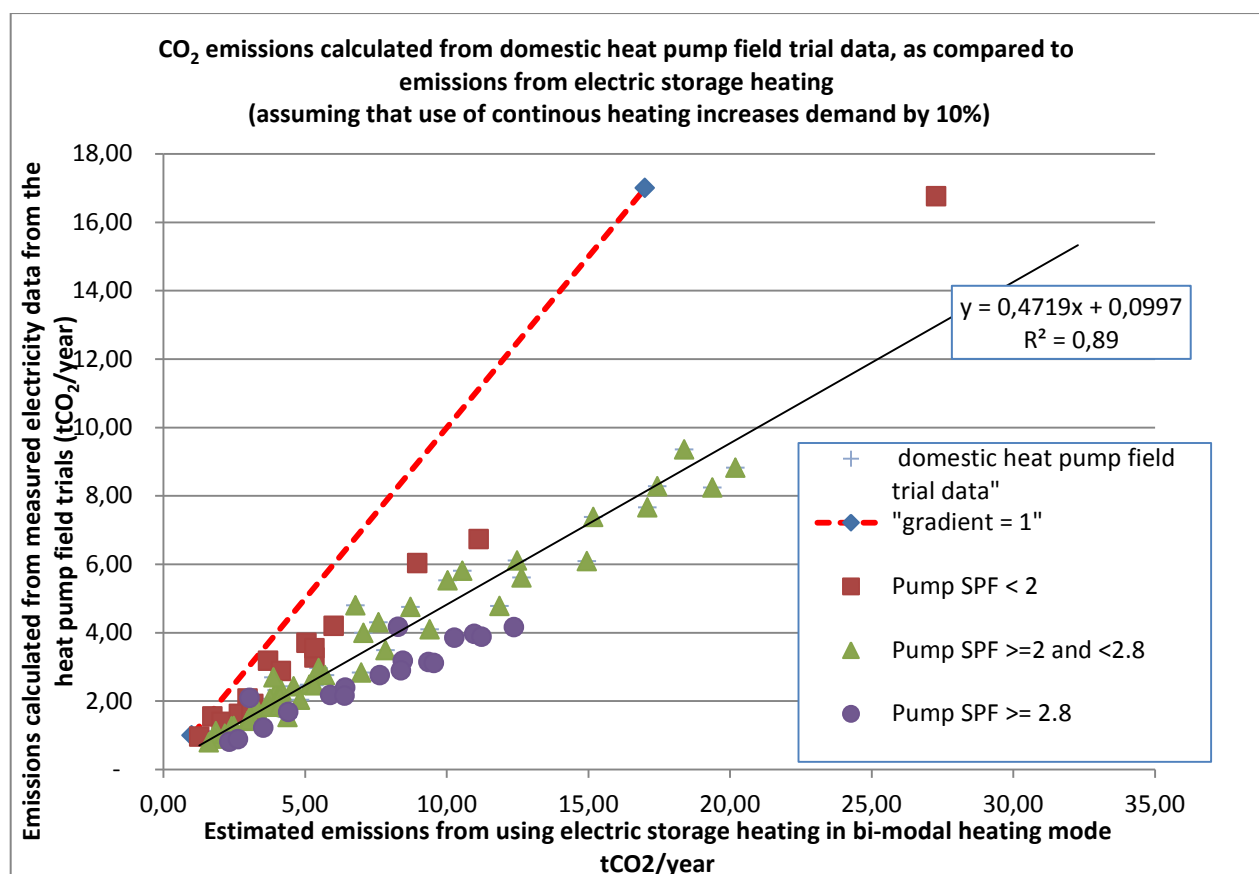


Figure 23. Estimated CO₂ emissions from using a heat pump as a function of the estimated emissions from electric storage heating (using the 2008 grid carbon factor, 0.52 kgCO₂/kWh).

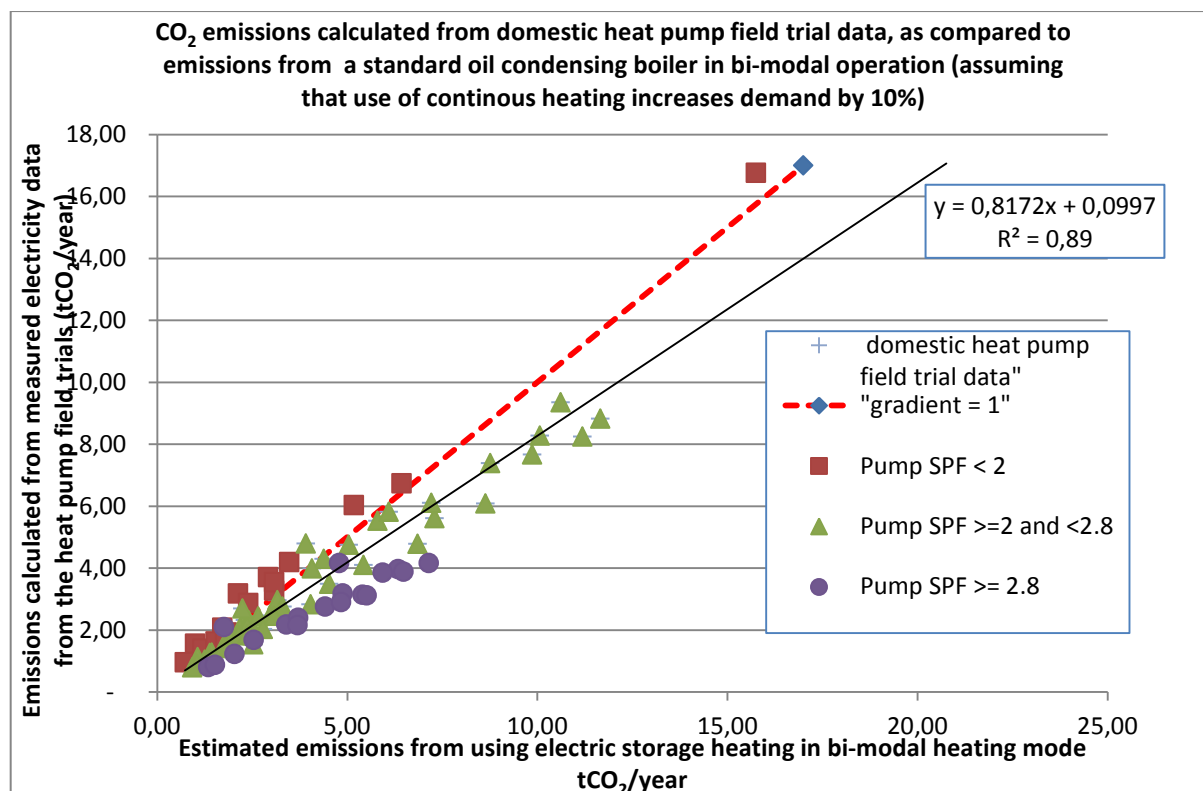


Figure 24. Estimated CO₂ emissions from using a heat pump as a function of the estimated emissions from a standard oil condensing boiler (using the 2008 grid carbon factor, 0.52 kgCO₂/kWh).

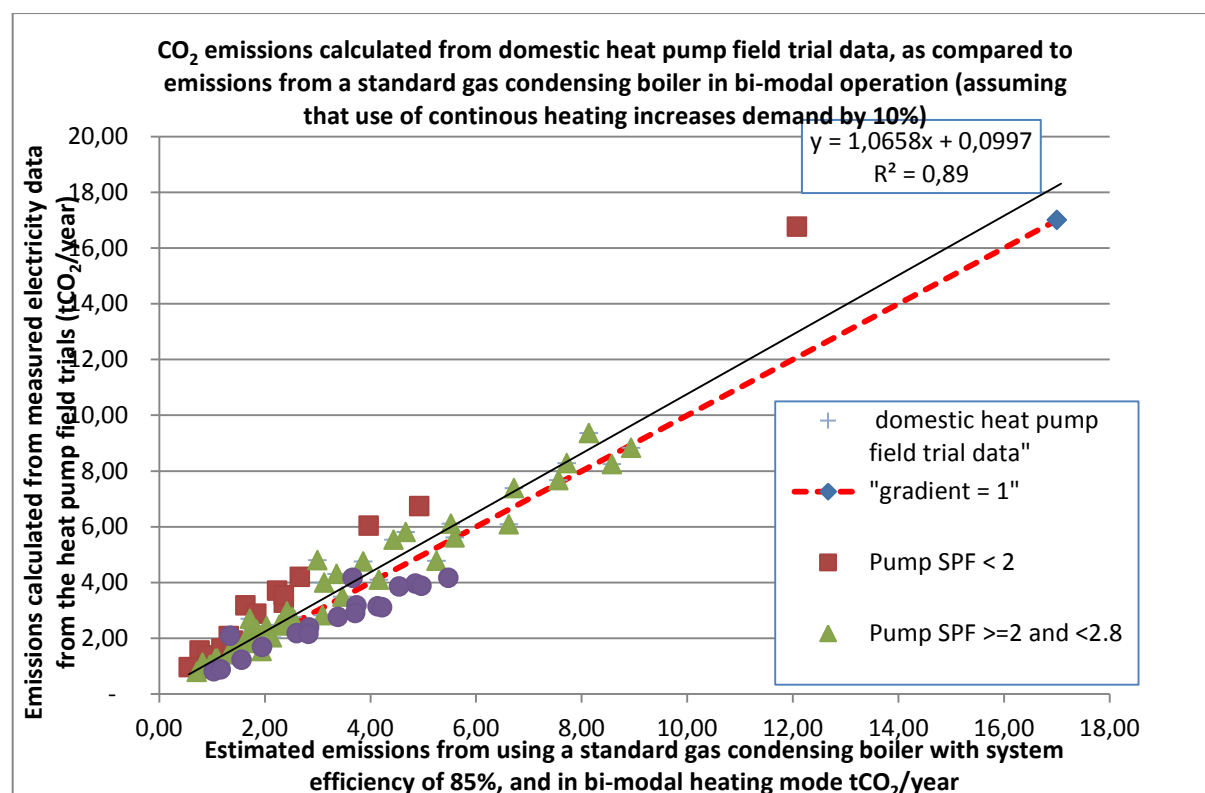


Figure 25. Estimated CO₂ emissions from using a heat pump as a function of the estimated emissions from a standard gas condensing boiler (using the 2008 grid carbon factor, 0.52 kgCO₂/kWh).

Table 14. Predicted average and marginal carbon factors for electricity at the point of generation and at the point of use (i.e. after correction for transmission and distribution⁵). – UK figures

Year	Long-run marginal (kgCO ₂ e/kWh)		Grid average (kgCO ₂ e/kWh)	
	Consumption-based	Generation-based	Consumption-based	Generation-based
	Domestic		Domestic	
2010	0.372	0.341	0.505	0.462
2011	0.365	0.335	0.487	0.446
2012	0.358	0.328	0.535	0.490
2013	0.350	0.321	0.497	0.455
2014	0.342	0.313	0.436	0.400
2015	0.333	0.305	0.461	0.422

⁵

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/483282/Data_tables_1-20_supporting_the_toolkit_and_the_guidance.xlsx

2016	0.324	0.297	0.383	0.351
2017	0.314	0.288	0.328	0.300
2018	0.304	0.279	0.317	0.290
2019	0.294	0.269	0.298	0.273
2020	0.282	0.258	0.265	0.243
2021	0.270	0.248	0.234	0.214
2022	0.258	0.236	0.215	0.197
2023	0.245	0.224	0.183	0.168
2024	0.231	0.211	0.192	0.176
2025	0.216	0.198	0.180	0.165
2026	0.200	0.183	0.160	0.147
2027	0.184	0.168	0.159	0.145
2028	0.167	0.153	0.133	0.122
2029	0.148	0.136	0.116	0.106
2030	0.129	0.118	0.112	0.103
2031	0.118	0.108	0.106	0.097
2032	0.107	0.098	0.100	0.091
2033	0.098	0.090	0.086	0.079
2034	0.089	0.082	0.085	0.078
2035	0.081	0.074	0.071	0.065
2036	0.074	0.068	0.069	0.063
2037	0.068	0.062	0.060	0.055
2038	0.062	0.056	0.054	0.049
2039	0.056	0.051	0.055	0.050
2040	0.051	0.047	0.051	0.047
2041	0.046	0.042	0.046	0.042
2042	0.045	0.041	0.045	0.041
2043	0.040	0.037	0.040	0.037
2044	0.035	0.032	0.035	0.032
2045	0.036	0.033	0.036	0.033
2046	0.033	0.030	0.033	0.030
2047	0.030	0.028	0.030	0.028

2048	0.031	0.028	0.031	0.028
2049	0.028	0.025	0.028	0.025
2050	0.028	0.025	0.028	0.025

6.3.6 Case: Site 492

From the data, it was shown that the supply temperature was increased almost linearly with decreasing outdoor temperatures, while the return temperature was relatively steady at 35°C until outdoor temperatures reached 5°C, see Figure 27. From this figure it can also be seen that temperature lifts between 30 and 50 K were observed.

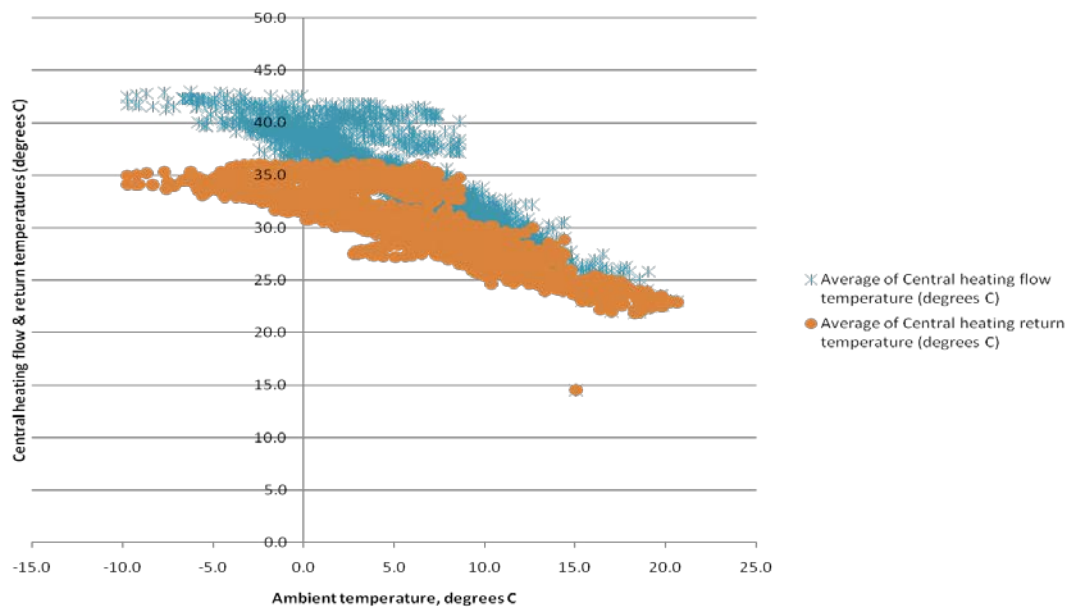


Figure 26. Average and return temperatures of the heat distribution system, site 492 (UK).

The monitoring setup in the UK sites allowed detailed analysis of evaporator and condenser temperatures. At some operation conditions, low condenser temperature seems to have resulted in poor performance, even if the evaporator temperature was relatively high (blue dots), Figure 27.

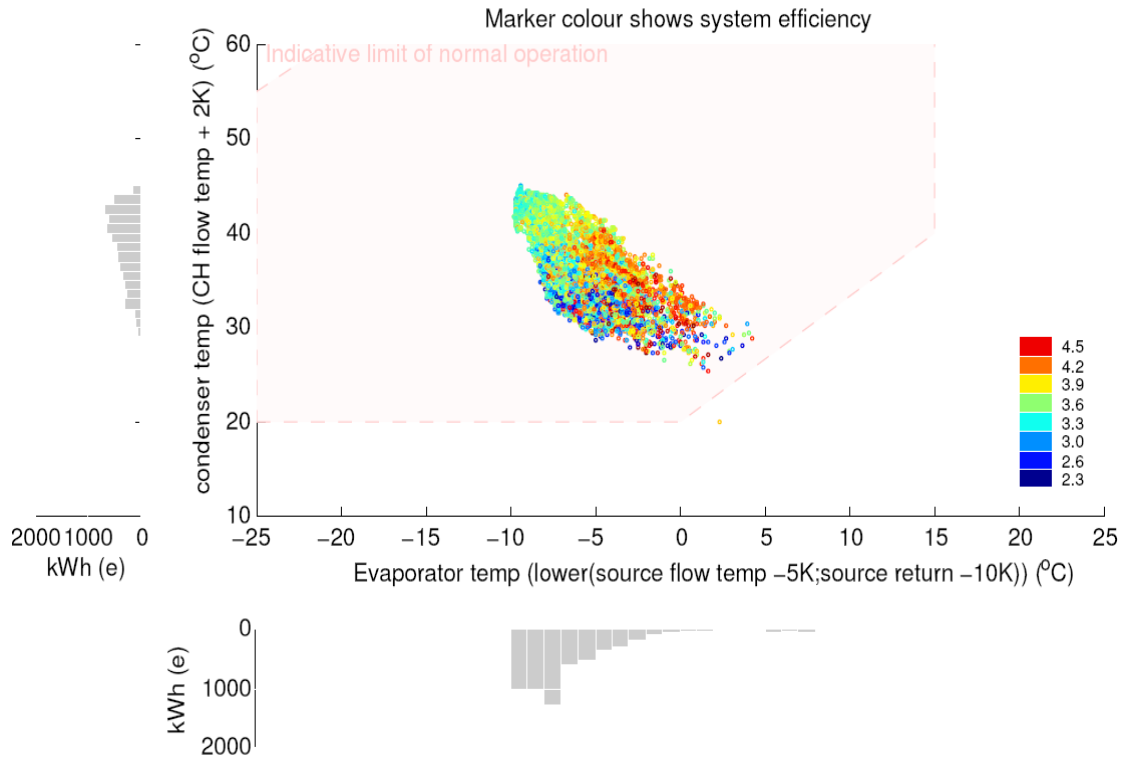


Figure 27. System efficiency (SPF_{H4}) as a function of condenser and evaporator temperature, site 492 (UK)

It can be seen from Figure 28 that the heat pump operates in backup heat mode only for short periods of time (dots on line with gradient equal to 1). The plotted operational points lie between gradient 3 and 4 for most of the time. In this figure, the gradient is a representative of the COP/SPF value, so the performance is very good.

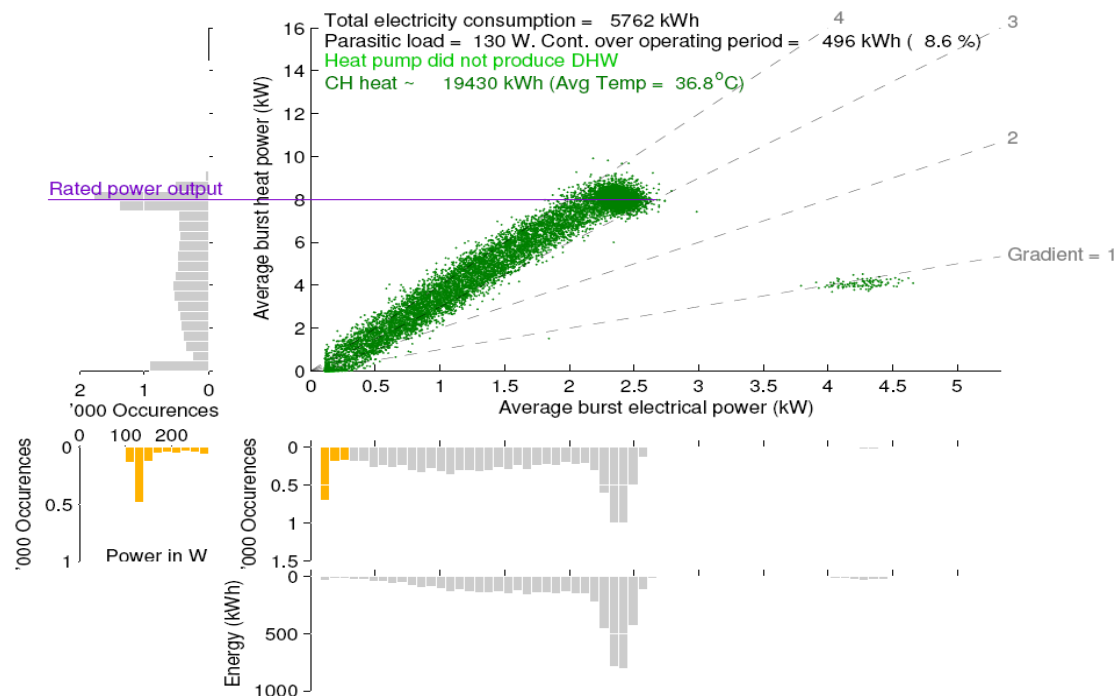


Figure 28. Burst operation. The figure show heat output versus electric back-up use.

Figure 29 show hourly SPF versus ambient temperature. It can be noted in this figure that the main number of operating hours is in the temperature range 0-10 degrees C. It can also be observed that occurrences of operation in backup mode are when temperatures are relatively high (2-8 degrees C). Whether this is due to malfunction of the heat pump or very high heat demands are not known.

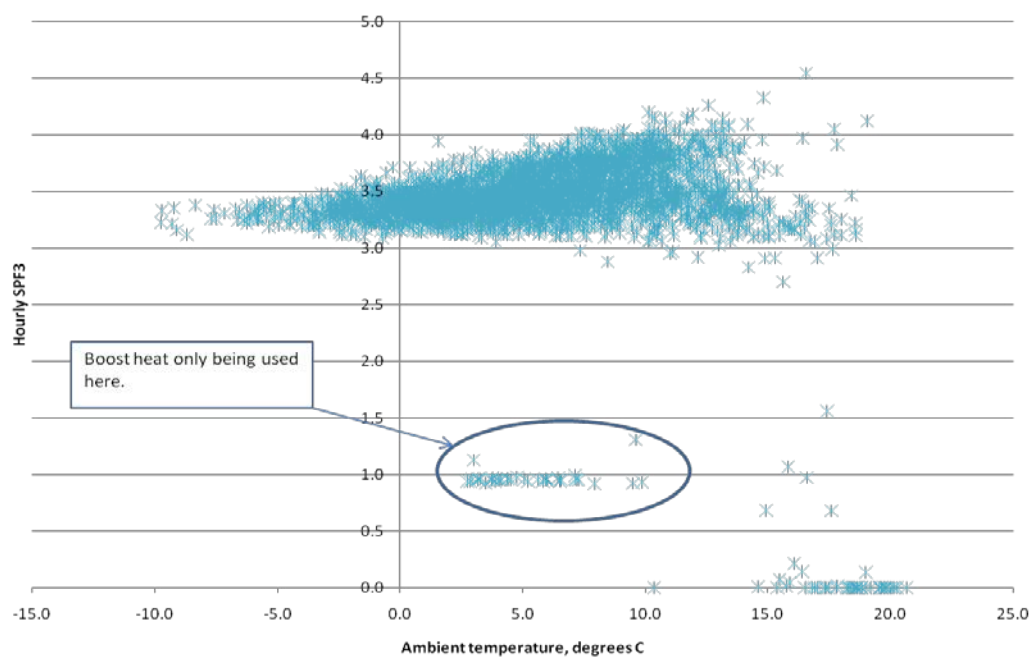


Figure 29. Hourly SPF_{H3} vs outdoor temperature.

Figure 30 show hourly heat delivered from the heat pump in kW versus outdoor temperature. From this figure it can be noted that the heat pump maximal capacity (8kW) is reached in times of cold weather, but also when the temperatures are up to 5 degrees C, indicating that the heat pump could be under dimensioned for really cold weather occurrences. From zero to 15 degrees C, there is a linear relationship between heat delivered and outdoor temperature.

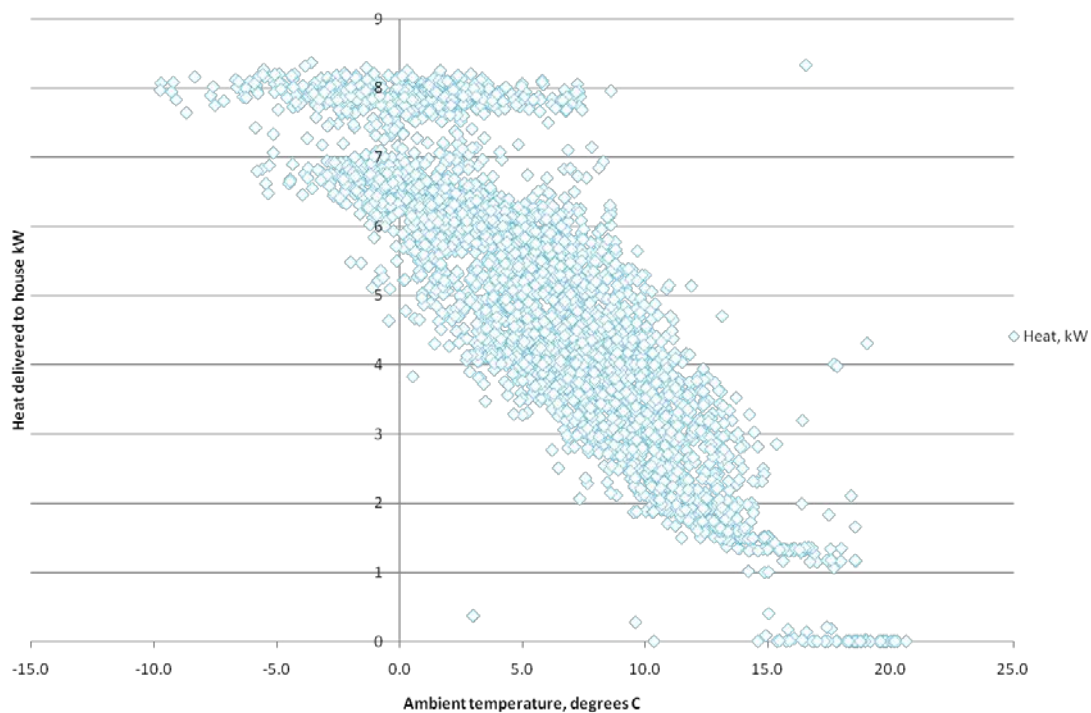


Figure 30. Delivered heat vs outdoor temperature.

The heat pump is used 24 hours per day. A gas boiler or electric storage heater would be used only for around 8-10 hours per day during weekdays and around 14 hours per day at weekends. For this reason, we estimate that the useful heat demand when a heat pump is used would be around 10% higher compared to when a gas boiler is used. In addition, we estimate that the efficiency of a gas boiler is only 85%.

Energy used and CO₂ emissions for the example are shown in Table 15 below:

Table 15. Comparison of different heating systems and corresponding CO₂ emissions using 2008 electricity carbon factor (0.49 kgCO₂/kWh).

	Electricity, kWh	Renewable heat, kWh	Gas, kWh	Total annual emissions, tCO ₂
Heat Pump	5 772	13 692	0	2.77
Gas Boiler	0	0	20 608	3.81
Electric Storage heater	17 518	0	0	3.24

Short conclusions from the evaluation of the UK monitoring with respect to CO₂ savings:

- CO₂ savings relative to gas is already now a reality, and will increase as the electricity grid decarbonises.

6.4 Switzerland

In Switzerland, the probably most long-running field monitoring project in the world, the FAWA-project [15] was chosen for analysis. Since 1995, as part of the field analysis of heat pump systems (FAWA) the technical aspects of numerous installations up to about 20 kW heating capacity were assessed and documented. A total of about 250 sites were monitored. The main reasons for conducting the project were to ensure good quality installations and good operational experiences (high SPF) over a long time period. The heating period used in FAWA begins on 1 October and ends on 30 April.

An aging of heat pumps with respect to a dropping of the seasonal performance factor was not encountered during the last 10 years. In fact, the systems performed on a high level of reliability. The availability of heat pump systems was found to be around 99.5 %.

Buildings with a too large specific energy demand will not be accepted as good examples, even if heat pump is performing well. Moreover, the heat pump must respect a COP minimal according to the European Eco Label . So the minimum SPF has to respect values detailed in the Table 16, according to the proposal from Switzerland.

Table 16. Switzerland's proposal for good performing heat pump systems.

	Heating only		Heating and domestic hot water	
	old	new	old	New
Air	3.0	3.2	2.9	3.1
Brine	4.5	4.7	4.4	4.5
water	5.0	5.2	4.8	5.0

6.4.1 Description of the HP sites included (FAWA study)

In the FAWA project, a number of heat pumps have been monitored for more than ten years, see Table 17. The system boundaries were chosen as Figure 31 depicts. As can be seen in the figure, JAZ 3 corresponds to SPF_{H3} in SEPEMO. No system boundary with heating system distribution pumps was included in this study. The results in the FAWA study were mainly based on the JAZ 2. JAZ 3 was however also presented,

and in the Annex, the results were recalculated so that SPFH3 levels could be presented, as can be seen on the last line of Table 17. It can also be noted from Figure 31 that the heat delivered from the heat pump is monitored, meaning that domestic hot water tank losses are accounted for as DHW, and not space heating. As discussed previously, the possible contribution of these losses must be assessed for each site, and this has not been done in the FAWA study.

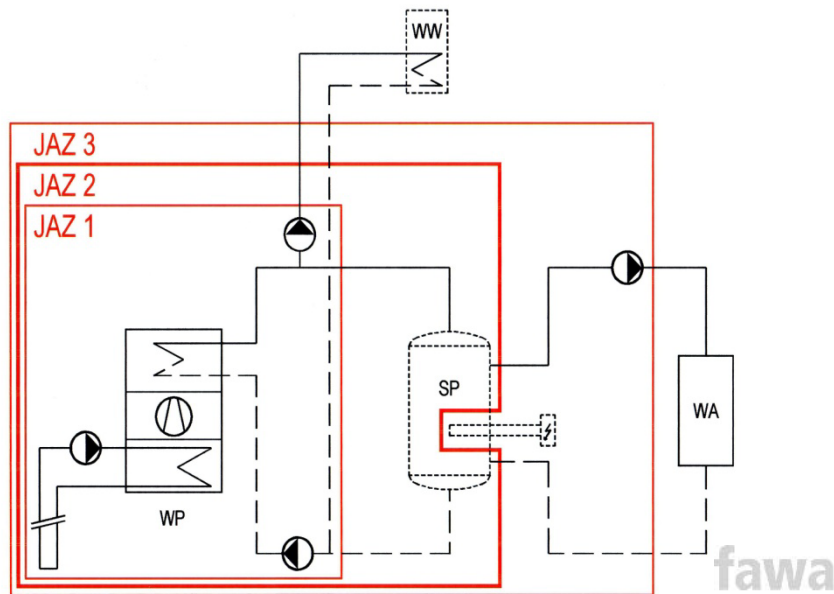


Figure 31. System boundaries in the Swiss FAWA-project.

Table 17. Selected FAWA monitoring objects.

Installation	1079	1096	1105	1220	1222	1039	1055	1059	1060	1067	1118	1119	1126	1203	1206	1069	1115	1226	1227
Heat Source	Outdoor air	Outdoor air	Outdoor air	Outdoor air	Outdoor air	EWS	EWS	EWS	EWS	EWS	EWS	EWS	EWS	EWS	EWS	EWS	EWS	EWS	EWS
Heat Source medium	Air	Air	Air	Air	Air	Brine	Brine	Brine	Brine	Brine	Brine	Brine	Brine	Brine	Brine	Brine	Water	Water	Water
Sanitary hot water preparation	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Monitoring period	9	8	7	1	1	13	12	12	12	11	7	7	7	2	2	10	6	1	1
Runtime, St_1	1857	1127	1717	1238	2095	2044	2156	1865	1288	1197	2271	1777	820	2247	1249	1641	2518	1304	2007
Runtime, St_2	1862	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Starts, St_1	5132	3253	1978	1074	1059	1649	1553	4579	375	978	1086	2713	1930	2043	1070	1218	1558	907	1488
Starts, St_2	4188	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Readings	25	27	31	22	16	36	33	47	34	31	18	20	24	34	36	22	22	18	21
E_1	7023	3324	3399	2565	2624	3959	2782	3975	2497	2936	5031	3797	2224	3648	2796	3375	3205	1555	4121
E_2	7023	3324	3399	2565	2624	3959	2782	3975	2497	2936	5031	3797	2224	3648	2796	3375	3205	1555	4121
E_3	7305	3932	3556	2786	2675	4462	3083	4169	2595	3393	5191	3893	2528	3690	2874	3823	3373	1610	4131
Q_1	21806	12110	12282	8436	8941	17246	13025	17423	10674	11454	24019	16594	12089	17548	13876	15774	14642	8229	19170
Q_2	21617	11826	12115	8375	8842	17749	13326	17617	10771	11264	24179	16689	11914	17591	13955	16222	14811	8284	19180
Q_3	21899	12434	12272	8596	8893	17749	13326	17617	10771	11721	24179	16689	12218	17591	13955	16222	14811	8284	19180
JAZ_1	3,11	3,68	3,62	3,29	3,41	4,41	4,70	4,41	4,28	4,05	4,77	4,36	5,49	4,81	4,96	4,70	4,57	5,29	4,65
JAZ_2	3,08	3,59	3,57	3,26	3,37	4,54	4,81	4,46	4,32	3,97	4,80	4,39	5,41	4,82	4,99	4,83	4,62	5,33	4,65
SPF_3	3,00	3,17	3,45	3,09	3,32	4,01	4,33	4,24	4,16	3,52	4,66	4,28	4,86	4,77	4,85	4,25	4,39	5,15	4,64

Looking at Table 17 and Figure 32, the units with combined space heating (SH) and domestic hot water (DHW) production cannot be said to have a generally lower SPF, than those who only perform space heating, since the unit performing best of all is a combined SH+DHW unit. It can also be seen in Figure 32 that the air source heat pumps in general have very good performance, with SPF_{H3} of 3.0 and above.

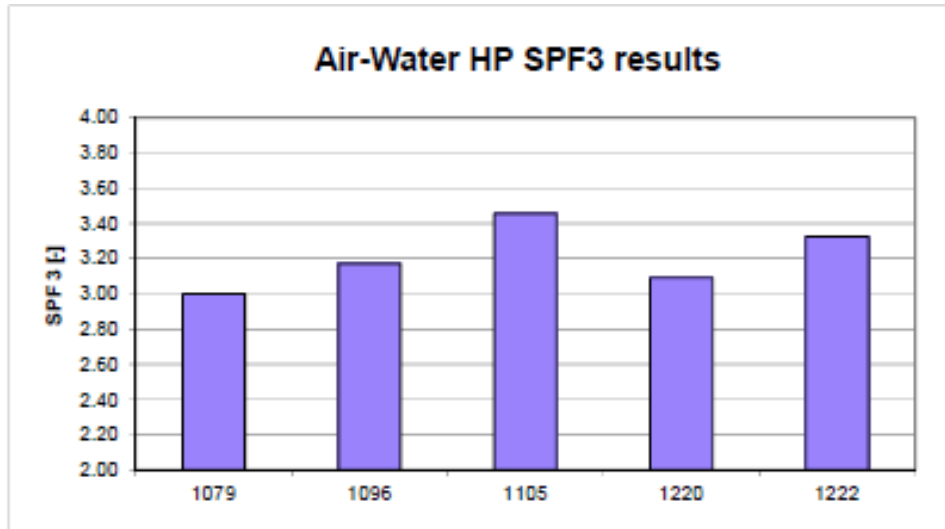


Figure 32. ASHP SPF_{H3} for some selected sites (CH).

GSHP's in Switzerland are generally designed for 100 % heat pump operation without any backup heating, i.e. monovalent operation. As can be seen in Figure 33, all units perform very well with SPF calculated at H3 boundary, with only one unit performing lower than SPF of 4.

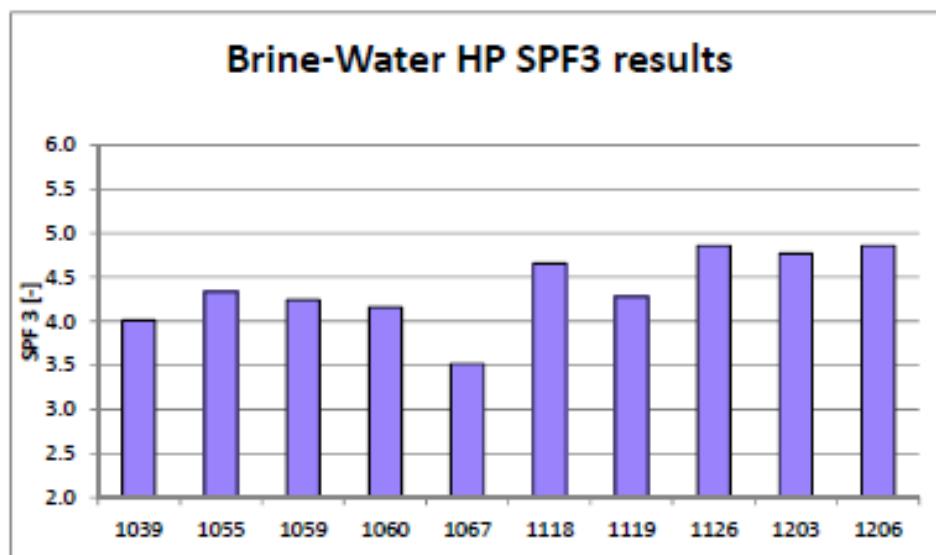


Figure 33. GSHP SPF_{H3} for borehole units using brine (CH).

Figure 34 shows the mean values from the recalculated FAWA-values at SPF_{H3} level for all heat pumps in the Swiss study evaluated in this annex.

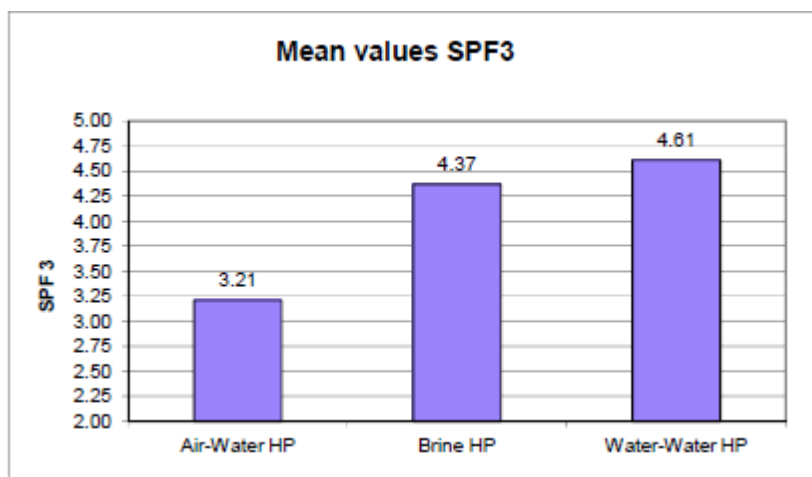


Figure 34. Mean SPF3 for different categories of heat pumps in Switzerland.

6.5 Other field measurement projects

In order to compare the results of this annex with other field monitoring projects, a short review has been made on the German HP Efficientz project, and a large Danish field monitoring project. Key findings from these projects are presented in the following paragraphs.

6.5.1 Germany

The HP Efficientz project was conducted by Fraunhofer ISE between 2005 and 2010, with about 110 heat pumps being evaluated. In the monitoring period (July 2007 to June 2010, the average SPF for the GSHP's was 4.1, and 2.9 for ASHP's. In the studied objects, underfloor heating systems were dominating, and heat pumps were designed for minimum auxiliary electricity use.

Fraunhofer ISE has performed many field monitoring projects according to the structure illustrated in Figure 35. After the SEPOMO project, also Fraunhofer report SPF according to boundaries defined in that project. Positioning of sensors follow the requirements set up also in this project in order to log and calculate electricity consumption, delivered heat to the building, and additionally information about heat uptake from the heat source, Figure 36. It should be considered the difference in the German study compared to the Swedish and British studies that domestic hot water is measured before the hot water tank in the German study when comparing SPF values between these studies.

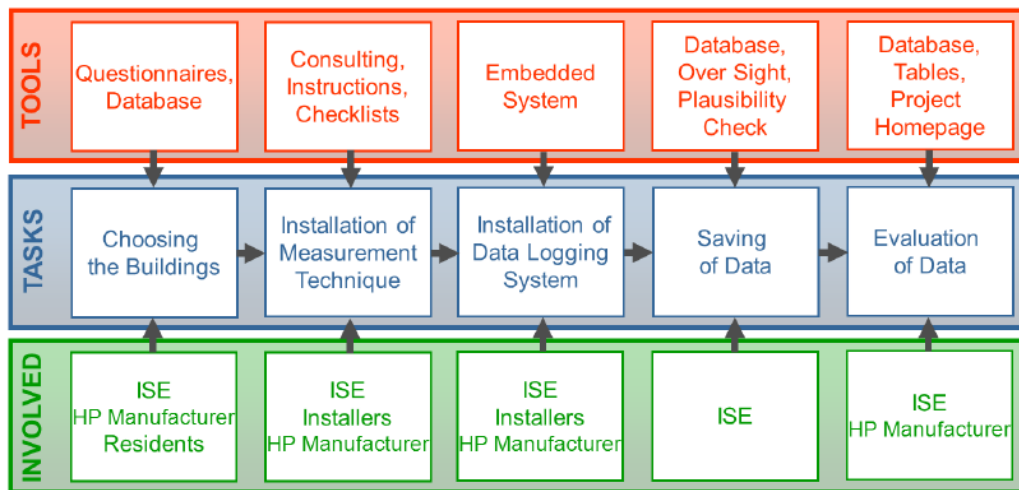


Figure 35. Structure of the Fraunhofer ISE monitoring project(s).

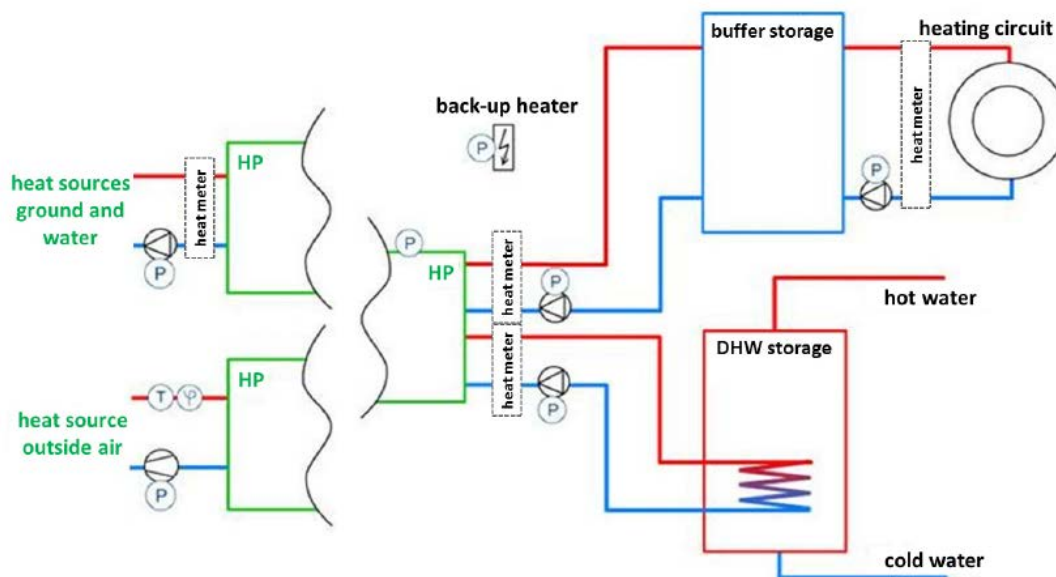


Figure 36. Fraunhofer ISE monitoring positions.

The Fraunhofer ISE monitoring sites have shown to have comparably high GSHP source temperatures during the heating season, on average 7.1°C for borehole source. The corresponding value of the outdoor temperature is 2.7 °C for ASHP during heating season.

Since the German heat pump systems are generally designed for small amounts of auxiliary heating SPF_{H2} and SPF_{H3} are very similar, and in many cases identical.

In the HP-Efficiency project, a total of 77 heat pumps were monitored between July 2007 and June 2010 in two campaigns. After the first year of the campaign, some adjustments were made to some installations where the performance was not as

expected. In the study, mainly underfloor heating was used as heat distribution, see Figure 37, and heat sources being mainly ground source, see Figure 38.

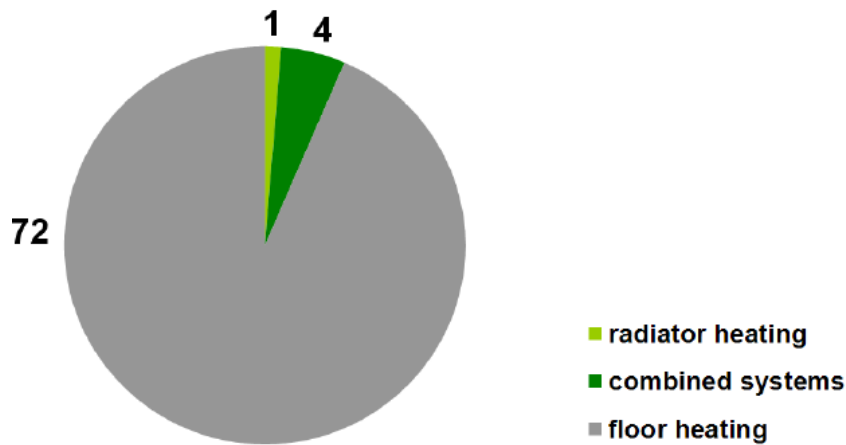


Figure 37. Heat distribution systems by type (DE).

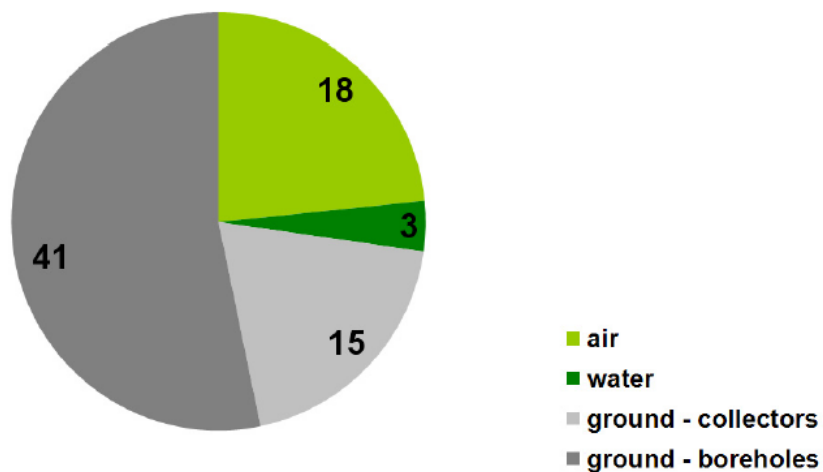


Figure 38. Heat sources by type (DE).

System boundaries as depicted in Figure 39 differ somewhat from the SEPEMO boundary definitions, where Fraunhofer include backup heating in the SPF 2 in the figure, while this is not the case for SEPEMO SPF_{H2} . There is also a difference in the outer system boundary in that Fraunhofer does not account for the circulators in the building. In the SEPEMO definitions [7], they are included in the SPF_{H4} level together with the circulator pumps for the domestic hot water storage that are included in the SPF 3 level by Fraunhofer.

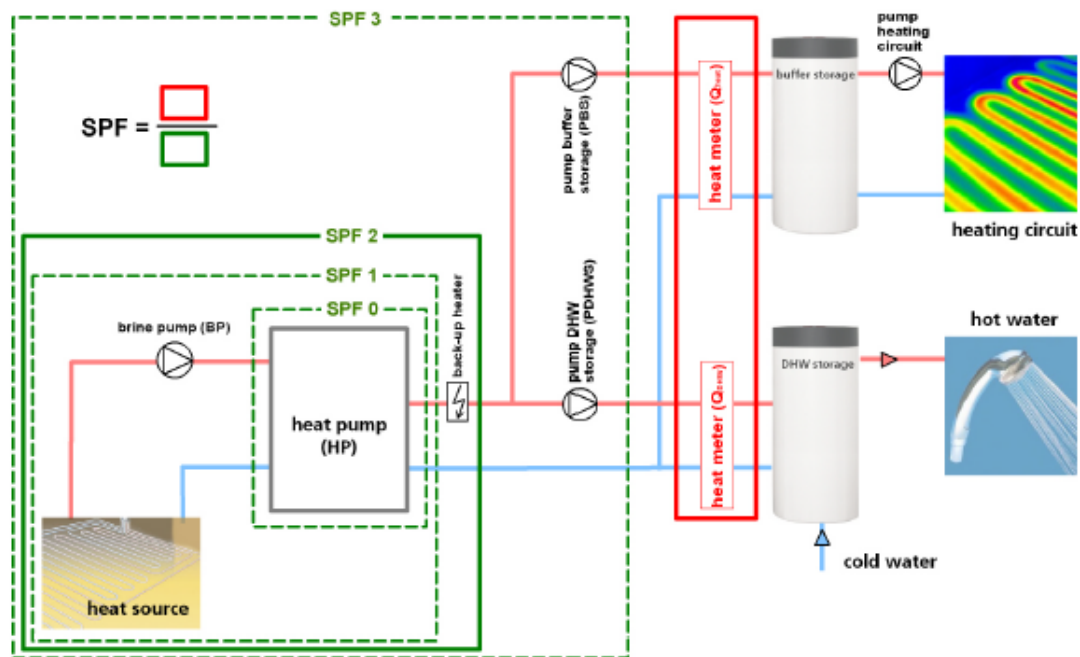


Figure 39. System boundary description for the Fraunhofer Project WP Efficientz.

Figure 40 presents monthly average SPF 3 according to the Fraunhofer boundary definition in the WP Efficientz project.

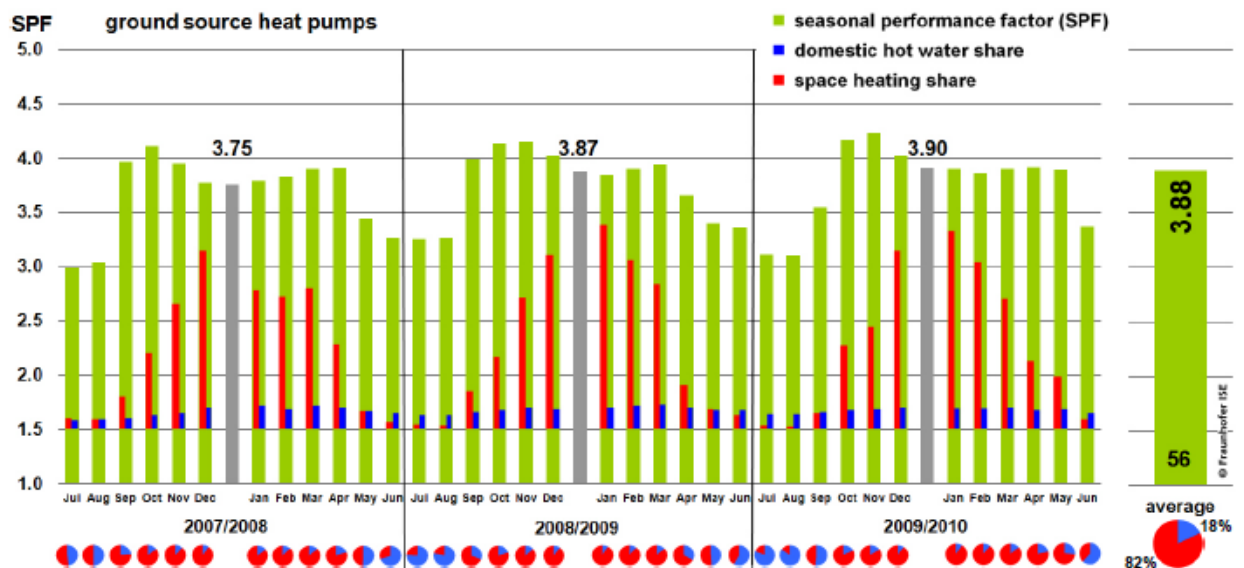


Figure 40. Average monthly SPF's for GSHP's in the study.

Similar to already observed installations, the SPF degrades when including more of the equipment in the heat pump system, as shown in Figure 41. Note the very small

degradation between boundaries SPF 1 and SPF 2 (Figure 41), indicating very low auxiliary electric heating.

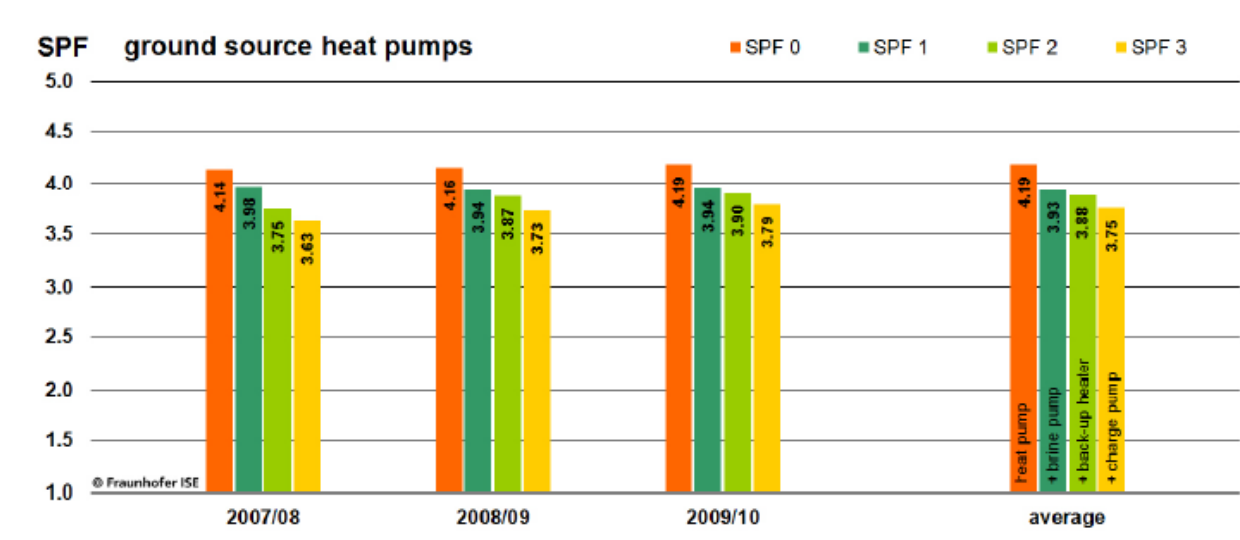


Figure 41. SPF degradation in the Fraunhofer project.

With an average SPF 3 of 3,88 and a lowest SPF 3 of just above 3 for the whole monitoring period, it can be noted that about half of the monitored heat pumps qualify as good examples for new built buildings according the definitions in this Annex, see section 5.6.

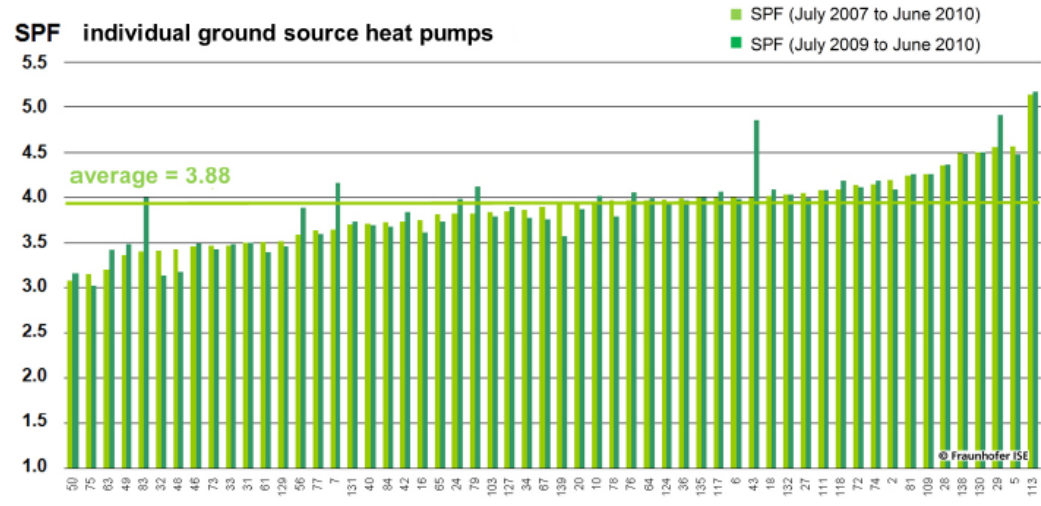


Figure 42. SPF 3 values for the GSHPs monitored by Fraunhofer GSHP

6.5.2 Denmark

In Denmark, a project to evaluate heat pumps in the field was carried out in 2010-2012. Originally, a total of 300 heat pumps were to be included in an evaluation

program, but for various reasons it was only possible to get a total of 170 heat pump installations in the program in the end.

The measurements dealt with in this project were made from 1 April 2010 to 30 October 2012.

Measurements were made in two successive measurement periods with the first year being the “acclimatization” period. Since the buildings were new, abnormal energy consumption was expected that year, due to dry out of building materials etc.

The energy consumption of all circulation pumps is fully included in the measurements. The results from the field measurements were supposed to be compared with results based on test results according to certain standards. However, for the resulting parameters from these standards, e.g. COP and SPF or SCOP, only pumping energy due to internal losses are included. Out of the 170 monitored heat pumps, about 144 presented reliable data for an evaluation.

Out of the systems evaluated, the vast majority, 132 units were GSHPs with horizontal heat exchangers, and only 12 ASHPs, see Figure 43. Most of the heat pumps were installed in buildings with combination of underfloor heating and radiators, but also buildings with radiators only, or underfloor heating only occurred, as Figure 44 shows.

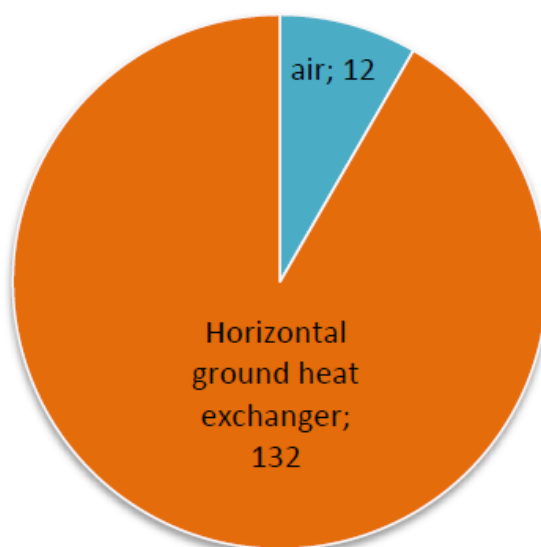


Figure 43. Classification of heat pump types included the Danish field study.

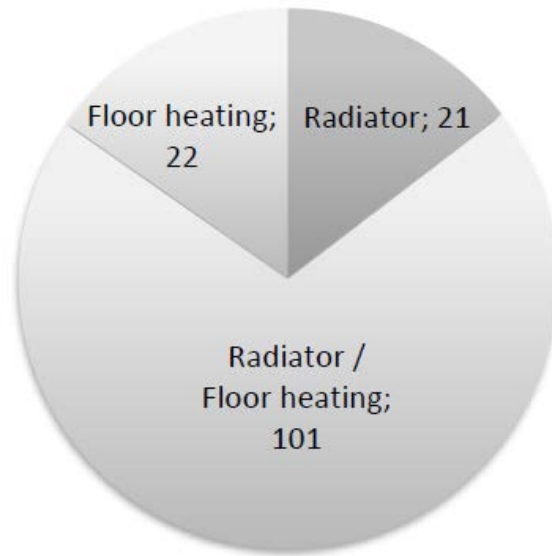


Figure 44. Classification according to heat distribution system.

The reported values from the Danish study were with SPF H3 boundary conditions for because this is the kind of efficiency that the consumer experiences and relates to, see Figure 45. This classification is very similar to the Fraunhofer ISE study and the SEPEMO SPF_{H3}. Important to note is that the Danish study does not monitor DHW production. Instead, the DHW production is estimated based on the number of occupants in the house, or on the energy use profiles during summer months, when no heating need exist. This number is therefore very uncertain. Tank losses from domestic hot water storage are not included in space heating, but instead in DHW use. Considering a total SPF H3 for the heat pump system, this is no problem, but for an exact separation of space heating and DHW use, this model is infeasible.

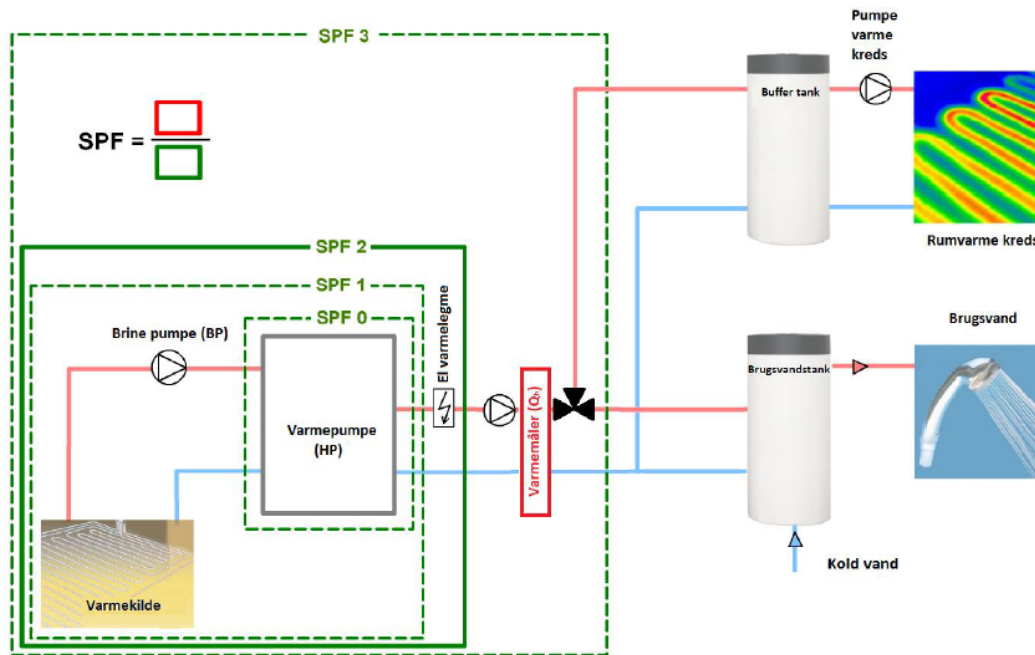


Figure 45. SPF H3 boundary in the Danish study.

From the calculated SPF values for GSHP (Figure 46) and ASHP (Figure 47) it can be seen that low temperature systems such as underfloor heating generally has higher SPF than high temperature systems as radiators, which is quite obvious. Considering that the buildings where the heat pumps were installed in are new, the SPF's are a little too low for GSHP to be classified as good examples, according the threshold values defined for this project in section 5.6, but ASHPs with underfloor heating qualify. In Figure 46 and Figure 47, Bars to the left represents radiator only systems, in the middle is combined radiator and underfloor heating systems, and bars to the right are underfloor heating only systems. Two years (2010-2011 and 2011-2012) are presented.

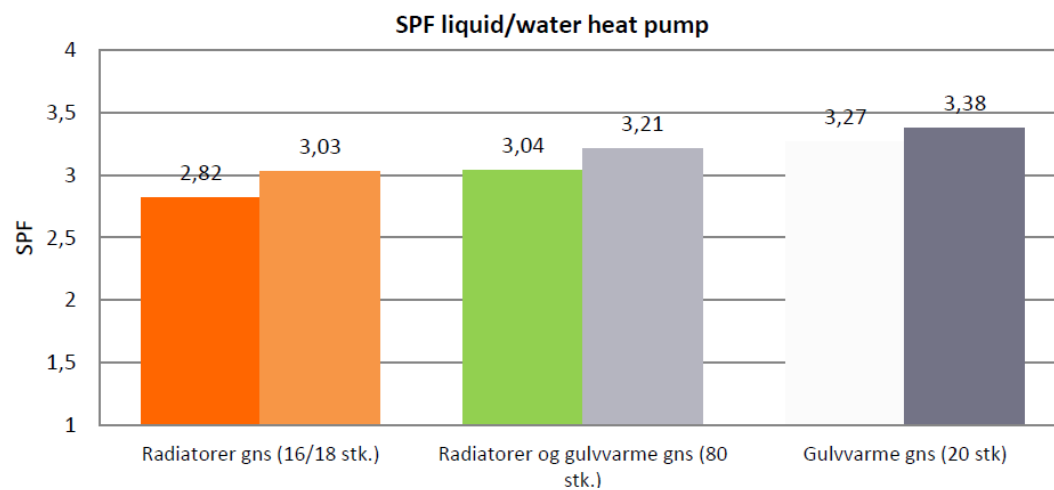


Figure 46. Calculated SPF 3 for GSHPs (DK).

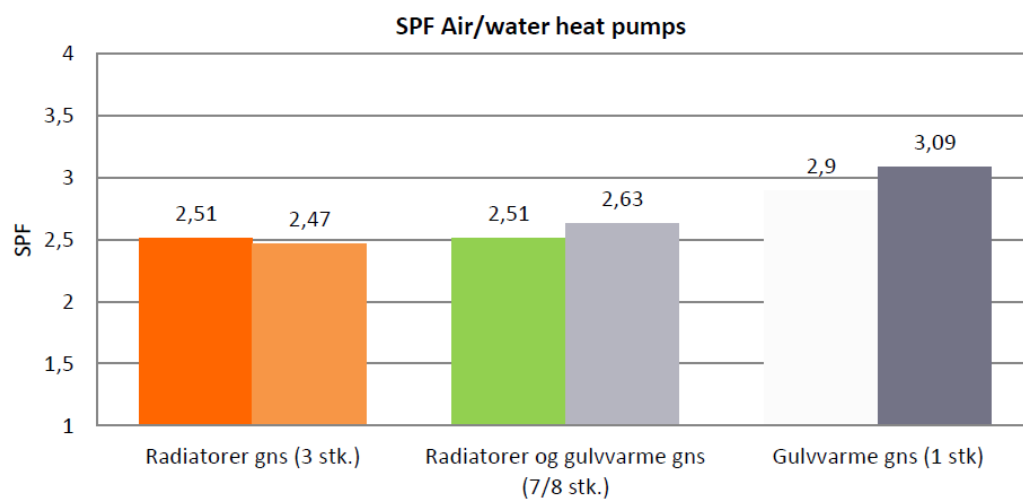


Figure 47. Calculated SPF_{H3} for ASHPs (DK).

7 ANALYSIS OF RESULTS FROM MEASUREMENTS

7.1 Determined SPF values for the HP systems

In this project we set out that to be considered to be a good heat pump system, SPF_{H3} values according to the table below should be achieved as a minimum.

Table 18. SPF_{H3} values for different heat pump systems to be considered good performing systems.

	ASHP, new	ASHP, retrofit	GSHP, new	GSHP, retrofit
SPF_{H3}	3,2	2,8	3,9	3,3

Based on the evaluations of SPF based on measurement results in this project, all heat pumps from the field tests in Sweden, UK and Switzerland are examples of good heat pump installations. The monitored SPF_{H3} for DHW production has been estimated to between 2,0 and 3,1 based on the heat delivered to the hot water buffer tank.

7.2 Yearly cost savings by using heat pumps

The running costs with a heat pump are in all cases lower than the costs from the alternative heating methods we have included in this study. For Swedish conditions, the running costs are 54% higher with an oil boiler than with an electric heater, and 390–610% higher with oil compared with a heat pump [16]. The cost differences in Switzerland are not as high as in Sweden due to a lower price difference between oil and electricity. In Switzerland, the running costs are 30–140% higher with oil boiler than with a heat pump [15]. In the United Kingdom, the heat pumps have been compared with gas-combi boilers and electric heaters. The heat pumps are in most cases the cheapest heating method, followed by the gas-combi boiler and the electric heater, but in one case, the gas-combi boiler is marginally cheaper than the heat pump [23, 24].

7.3 CO₂ savings by using heat pumps

When estimating CO₂ savings by using heat pumps, it is of greatest importance how the electricity is assumed to be produced. In this study, we have used the electricity mix in EU and compared with the electricity mix in the country that each heat pump is located in.

For Swedish conditions, the trend is the same for all of the three sites:

- The highest CO₂ emissions are obtained from an electric heater, if the electricity is assumed to be produced with an EU grid mix. The CO₂ emissions

from the oil heater and the electric heater are significantly higher than the emissions caused by the heat pump.

- If a Swedish grid mix is used in the calculations, the oil heater is by far the greatest emitter of CO₂. The oil heater causes emissions that are 550% higher than the emissions from the electric heater.

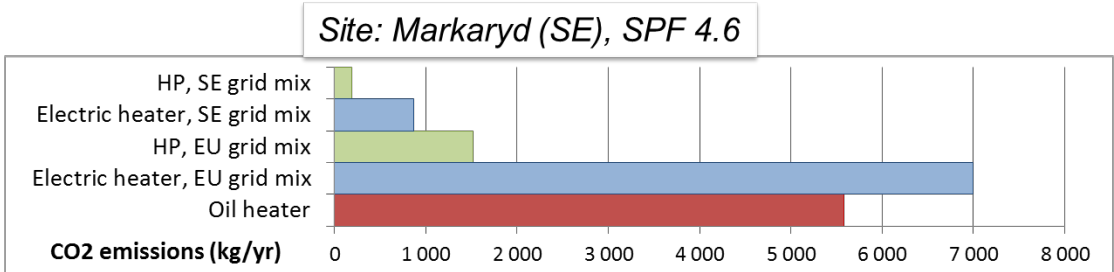


Figure 48. CO₂ emissions from different heating alternatives. The electricity used for heating is assumed to be produced from a Swedish grid mix and an EU grid mix. The oil boiler is assumed to have an efficiency of 82%.

For Swiss conditions, the CO₂ emissions are 140–280% higher from the oil heater than from a heat pump with EU grid mix, and 500–900% higher than a heat pump with the Swiss grid mix.

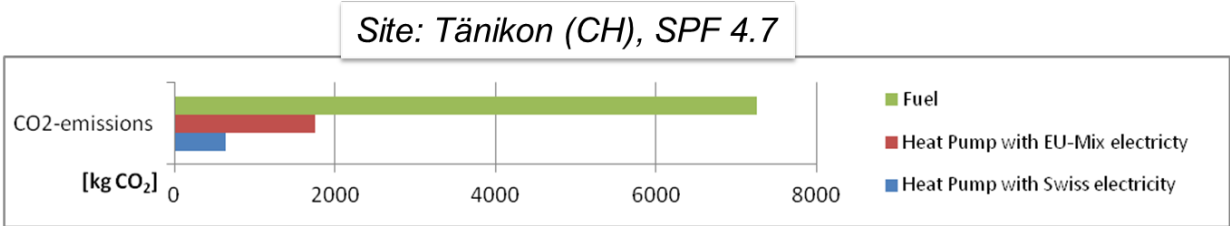


Figure 49. CO₂ emissions from different heating alternatives. The electricity used by the heat pump is assumed to be produced from a Swiss grid mix and an EU grid mix. The oil boiler is assumed to have an efficiency of 82%.

The electricity generation technologies in the UK cause higher CO₂ emissions than that of Sweden and Switzerland. Nevertheless, the CO₂ emissions from a gas-boiler are in all of the included cases higher than that of the heat pumps.

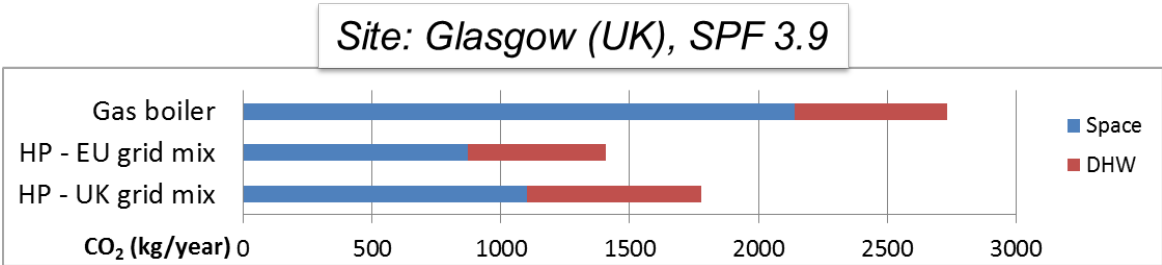


Figure 50. CO₂ emissions from different heating alternatives. The electricity used by the heat pump is assumed to be produced from a UK grid mix and an EU grid mix. The gas boiler is assumed to have an efficiency of 85%.

Considering the fact that the UK government has set as one of its priorities to decarbonise the electricity generation (see the figure below), heat pumps should come out as even better options to reduce CO₂ emissions in the years to come.

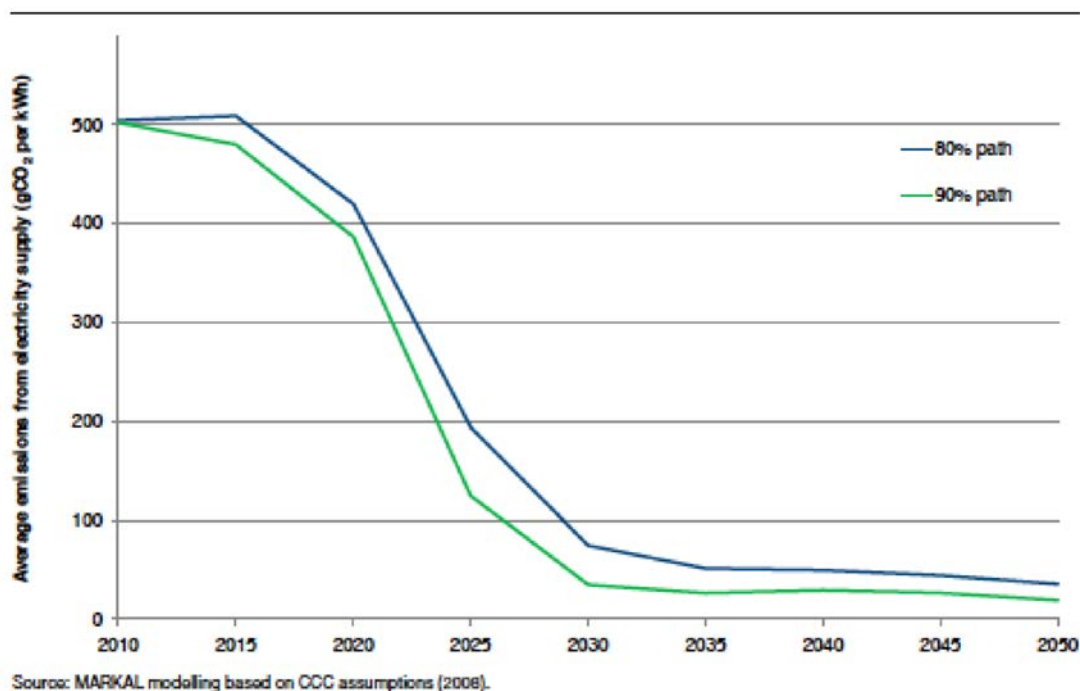


Figure 51. Carbon-intensity of UK electricity generation under 80 % and 90 % emissions targets for 2050 (Markal).

Decarbonisation on this scale would transform the market position of heat pumps in the UK heat market. Instead of delivering heat with carbon intensity not qualitatively different from gas-fired condensing boilers, by 2030, heat pumps would have something like an 8-fold advantage over the current incumbent technology. Supported by a steadily rising carbon price, the message to dwelling occupants would change from marginal to unambiguous.

8 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn from this joint research project where field monitoring data from 12 heat pump installations in Sweden, UK and Switzerland have been evaluated, and further data from a number of previously performed field measurements in Germany and Denmark have been surveyed.

It is important to clearly communicate system boundary for the field measurement results. SPF_{H4} is probably the most relevant to house owners, but SPF_{H3} is the most relevant when comparing to other heating systems and was therefore used in this report. Even if the system boundary is set out, there is the need to clearly define how e.g. tank losses from DHW tanks are treated, since this has to be assessed individually for each monitoring site. It is therefore also important to note if the domestic hot water is monitored before or after the tank.

If the domestic hot water energy use is monitored as tapped hot water, there is need to have monitoring equipment that is fast enough to capture the tappings. On the other hand, if the heat is monitored as delivered heat to the hot water tank, the monitoring equipment has to be precise to capture the small temperature difference of the heating media.

In determining the tank losses, either models to predict the losses should be available, or lab tested standing losses should be used, and depending on how the tank is placed, corrections should be made to allocate the heat correctly.

The SPF_{H3} values monitored in the Swiss part of the project are generally higher than the values for the Swedish part. One reason for this is probably that in Switzerland, heat pump systems have been designed for 100 % energy coverage by the heat pump, and the backup has been there more for heat pump failure situations, whereas in Sweden, heat pumps have been designed to use backup heaters in the coldest periods of the heating season, resulting in higher overall use of backup heat.

Considering the stricter regulations from the EU, it is likely to see more systems designed for 100 % capacity by the heat pump also in Sweden. Follow-up studies of this would therefore be very valuable for the future. Looking at the German field study, SPF 3 (approximately the same as SPF_{H3}) of 3.9 is achieved, on average.

On reason for these relatively high SPF values is that measurements were made in new built houses with predominately underfloor heating, and in addition a relatively high source temperature was noted for these GSHPs

The Danish study show lower values, especially for GSHP with radiator systems (3.0 - 3.2) but also with floor heating systems (3.3-3.4)

Location, building heating system, capacity fit, and user behaviour influence the performance of the heat pumps systems.

In this project minimum SPF_{H3} values for heat pump systems to be considered as good examples were defined to for ASHP and GSHP both for retrofit and new built installations. Compared to EU policies these values are reasonable and relatively high especially considering the requirement for SPF_{H2} of 2.5 to be considered a renewable energy source according the RES Directive.

9 COMMUNICATION TO STAKEHOLDERS

Communication in this project was set to develop a database of monitoring results from good heat pump installations. The examples can be distributed as good examples. We have compiled a 2-page summary of the monitored sites with the following information:

General information

- Country
- City
- Type of building
- Activity (household, office, industry, storage etc.)
- Type of HP
- Type of distribution system
- Measurement period

Building information

- Country
- City
- Average outdoor temperature Degreedays (Calculate according to local and EU calculation method)
- Building type
- Year of construction
- Heated building area divided into temperature zones
- Building energy category/ label
- Heat losses from building
- Number of persons / family (if household)
- Number of persons / m² (if office or storage etc.)
- Alternative heat system for comparing savings

Heating system information

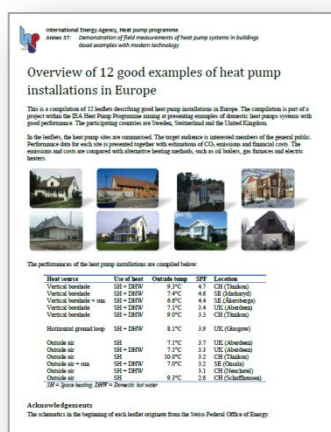
- Heat pump type
- Year of installation
- Purpose
- Heat source/sink
- Distribution system
- Operation mode, temperature settings

- Refrigerant
- Alternative/complementary heating system

Monitoring results

- Measuring period
- Measuring points
- Measurement equipment
- Uncertainty of measurements
- System boundary/boundaries
- Diagrams: In/Outdoor temperature, RH
Heat added to house (Space DHW)
Heat added to house vs outdoor temperature
Energy coverage ratio vs outdoor temperature
Energy added to HP-system for different system boundaries
(SPF1-SPF4)
Brine inlet- and outlet temp vs outdoor temp.
SPF for different system boundaries (SPF1-SPF4)
Energy savings compared to alternative heating
CO₂ savings compared to alternative heating
Supply temperature vs outdoor temperature
Users Diary

The compiled information is appended as appendix 1.



10 SUGGESTIONS FOR FURTHER WORK

In the project, it has been very fruitful to discuss and interpret monitoring results. The concept of defining a common set of monitored parameters and subsequent system boundaries to evaluate the monitored data has been rewarding, especially to be able to compare monitoring results from different projects.

Identified issues to be improved in the project have been:

- Develop a standardised way of evaluating the monitoring results.
By setting up standardized formats for how data should be sampled, filtered and collected, automated routines could be developed that allows for much faster evaluation of monitoring results.
- Develop a set of standard figures to be automatically generated.
If the atomization of the calculations can be made as described above, also the generation of figures can be made more automatic. This way, a lot of time can be saved to analyse the figures rather than constructing them.
- Develop standardized monitoring kits for SPF.
We have set requirements for the uncertainty etc. for monitoring equipment, but if we could come up with a special kit especially for e.g. SPF_{H3} monitoring, including installation manuals, time and money could be better used for additional monitoring sites in projects, instead of engineers having to figure out each time what equipment to use.
- Develop models or methods for estimating the tank losses from domestic hot water tanks, and further develop the SEPOMO methodology to have clear options for how the tank losses should be handled.
- Collect better cost data for the financial evaluation of heat pump investments
By having better cost data, not only for the operation, but also for the purchase and installation of the heat pump, LCC or Total Cost of Ownership could be calculated, which would help building owners in their investment decisions.
- Collect and further improve the set of monitoring results from new field monitoring projects. To follow up and see trends in the heat pump development, there is the need to continue to monitor projects globally, and share and learn from experiences made.

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12 APPENDICES

12.1 Site information sheets

Overview of 12 good examples of heat pump installations in Europe

This is a compilation of 12 leaflets describing good heat pump installations in Europe. The compilation is part of a project within the IEA Heat Pump Programme aiming at presenting examples of domestic heat pumps systems with good performance. The participating countries are Sweden, Switzerland and the United Kingdom.

In the leaflets, the heat pump sites are summarised. The target audience is interested members of the general public. Performance data for each site is presented together with estimations of CO₂ emissions and financial costs. The emissions and costs are compared with alternative heating methods, such as oil boilers, gas furnaces and electric heaters.



The performances of the heat pump installations are compiled below:

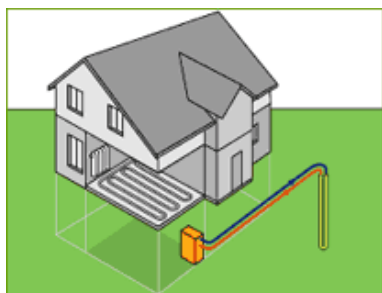
Heat source	Use of heat	Outside temp	SPF	Location
Vertical borehole	SH + DHW	9.3°C	4.7	CH (Tänikon)
Vertical borehole	SH + DHW	7.4°C	4.6	SE (Markaryd)
Vertical borehole + sun	SH + DHW	6.6°C	4.4	SE (Åkersberga)
Vertical borehole	SH + DHW	7.1°C	3.4	UK (Aberdeen)
Vertical borehole	SH + DHW	9.0°C	3.3	CH (Tänikon)
Horizontal ground loop	SH + DHW	8.1°C	3.9	UK (Glasgow)
Outside air	SH	7.1°C	3.7	UK (Aberdeen)
Outside air	SH + DHW	7.1°C	3.3	UK (Aberdeen)
Outside air	SH	10.0°C	3.2	CH (Tänikon)
Outside air + sun	SH + DHW	7.0°C	3.2	SE (Onsala)
Outside air	SH + DHW		3.1	CH (Neuchatel)
Outside air	SH	9.3°C	2.6	CH (Schaffhausen)

SH = Space heating, DHW = Domestic hot water

Acknowledgements

The schematics in the beginning of each leaflet originate from the Swiss Federal Office of Energy.

Heat pump ground/water – Sweden



City: Markaryd **Average outside temp:** 7.4°C

Country: Sweden **Average inside temp:** 24.1°C

Measurement period: June 2010 – May 2011

➤ Building type

- Heated surface: 185 m² (86 kWh heat/m²)
- Occupants: 4 (2 adults, 2 children)
- Construction year: 2009
- Construction: ☒ new

➤ Heating system features

- Installation year: 2009
- Rated heating output: 6 kW
- Heat source: ☒ vertical borehole ☒ exhaust air
- Use of heat: ☒ space heating & domestic hot water
- Heat distribution: ☒ underfloor heating & radiators
- Heating provision: ☒ electric heater



➤ Operational benefits

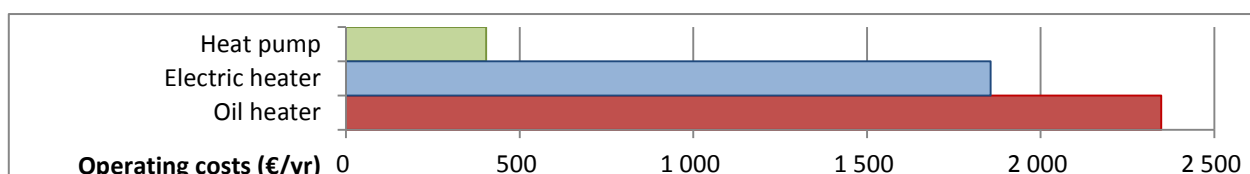
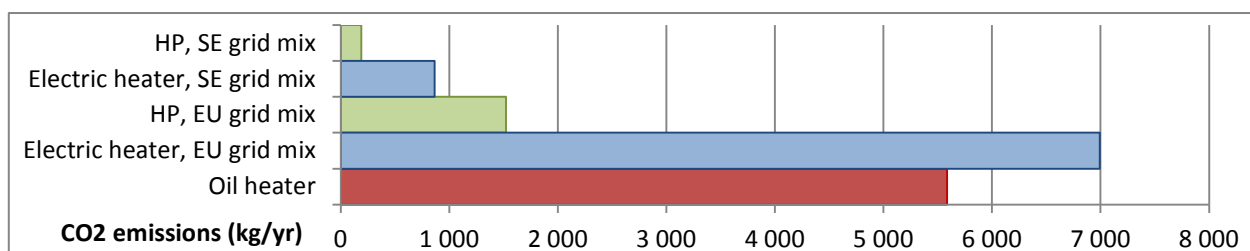
Electricity
3'500 kWh/year

Renewable energy
12'500 kWh/year

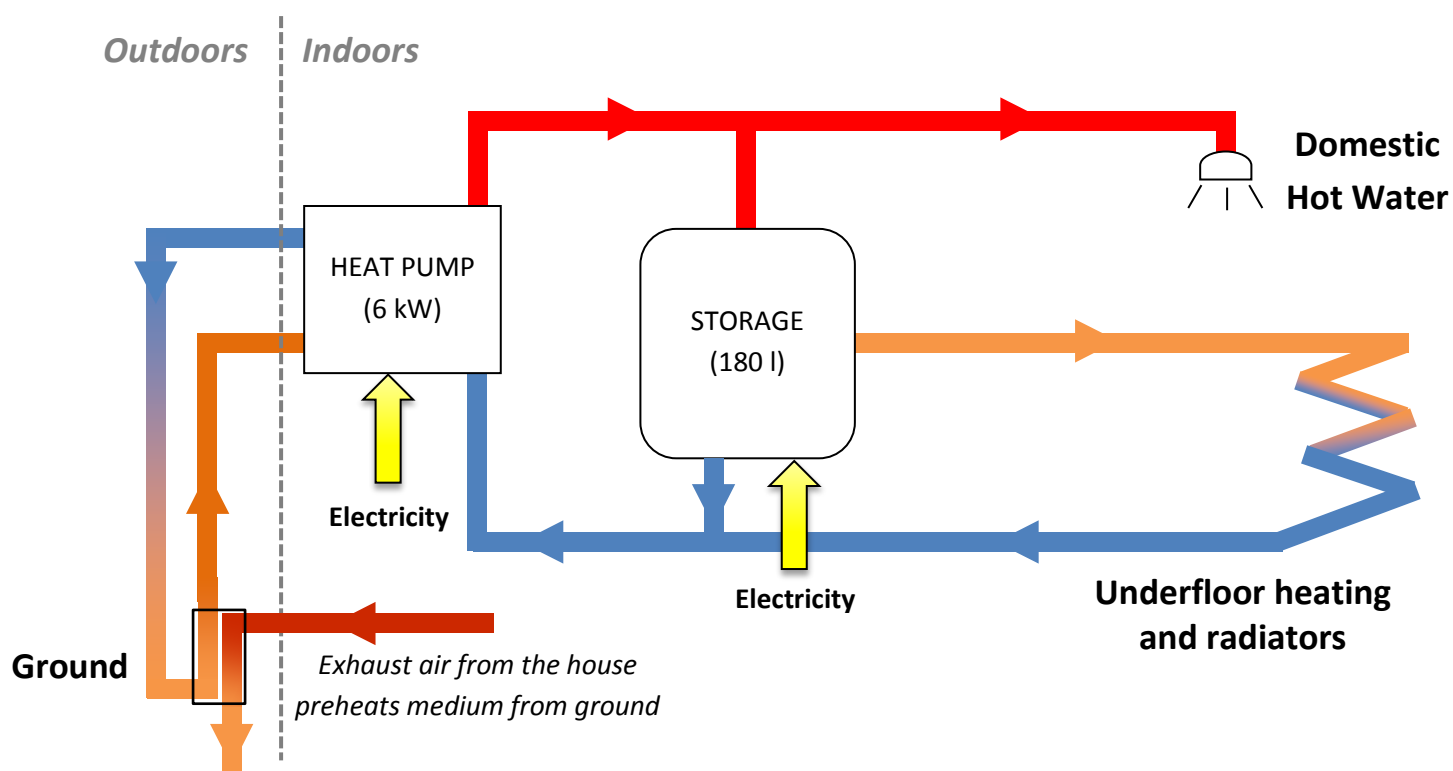


Heat
16'000 kWh/year

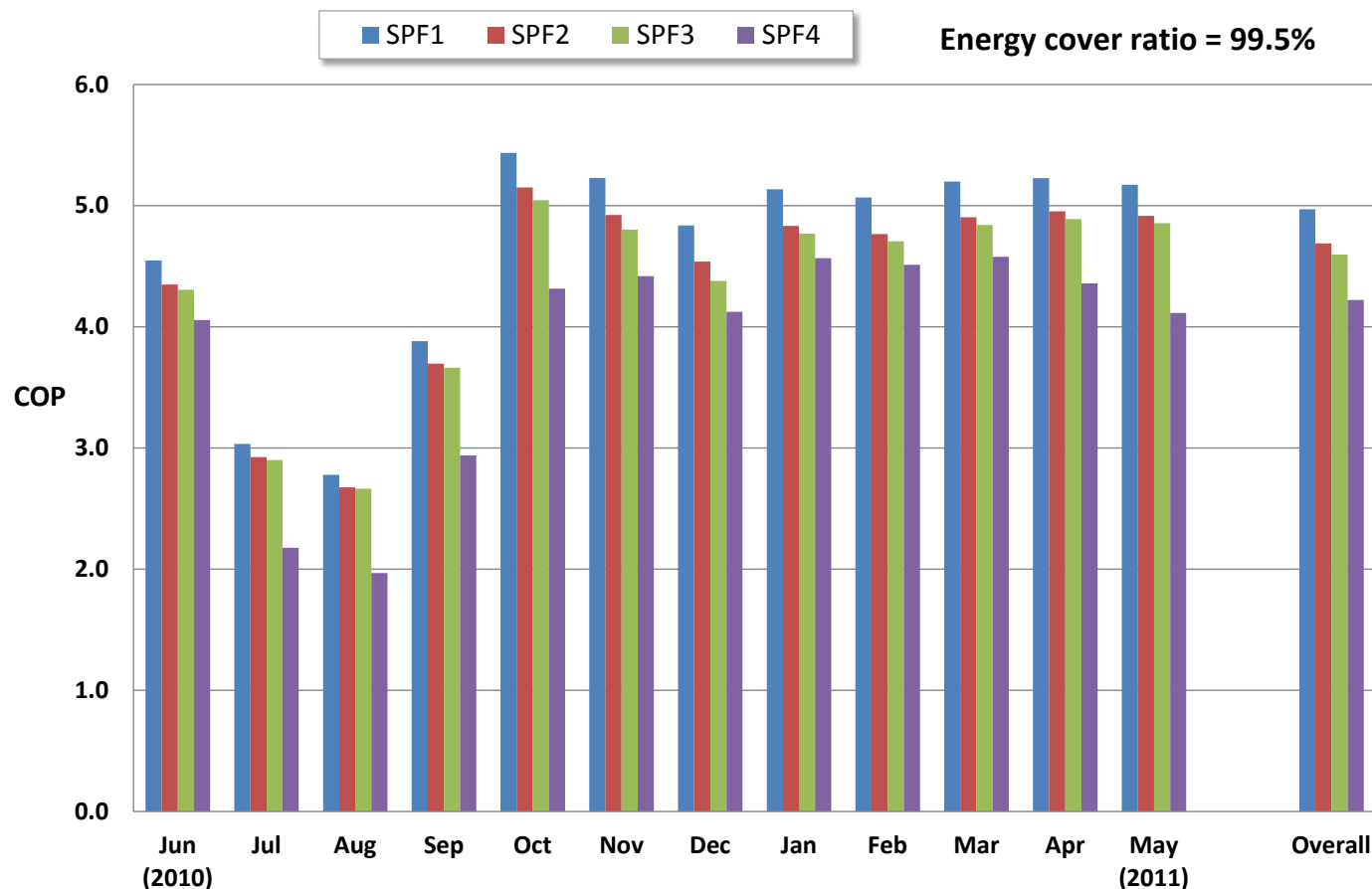
Out of 1 kWh electricity, the heat pump produces 4.6 kWh of useful heat (yearly average, SPF3).



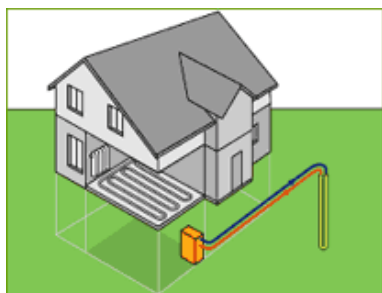
➤ System schematic



➤ Heat pump performance



Heat pump ground/water + solar collectors – Sweden



City: Åkersberga **Average outside temp:** 6.6°C
Country: Sweden **Average inside temp:** 22.7°C
Measurement period: June 2010 – May 2011

➤ Building type

- Heated surface: 200 m² (67 kWh heat/m²)
- Occupants: 4 (2 adults, 2 children)
- Construction year: 2009
- Construction: ☒ new

➤ Heating system features

- Installation year: 2009
- Rated heating output: 8 kW
- Heat source: ☒ vertical borehole ☒ sun (8 m²)
- Use of heat: ☒ space heating & domestic hot water
- Heat distribution: ☒ underfloor heating + radiators
- Heating provision: ☒ electric heater



➤ Operational benefits

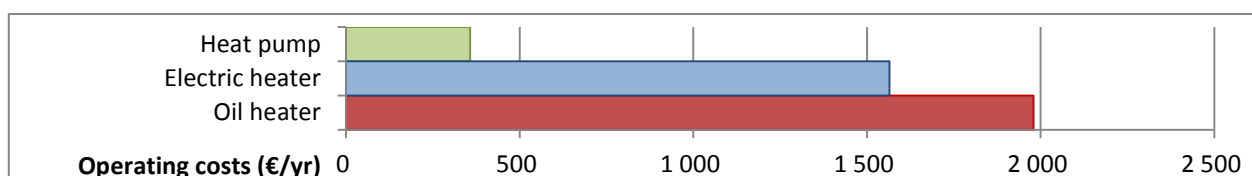
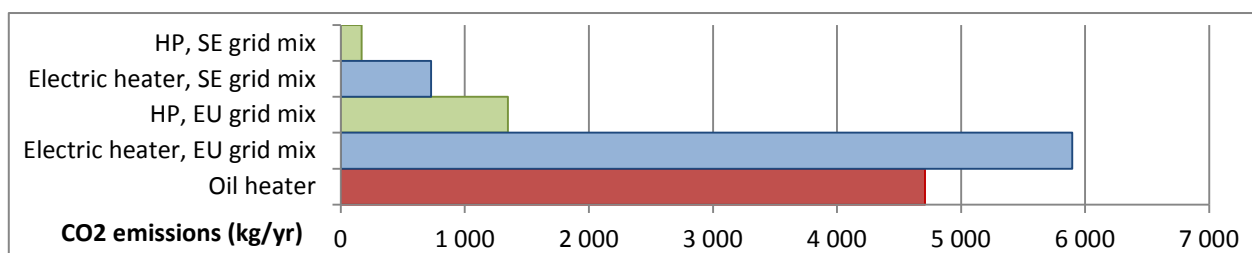
Electricity
3'100 kWh/year

Renewable energy
10'400 kWh/year

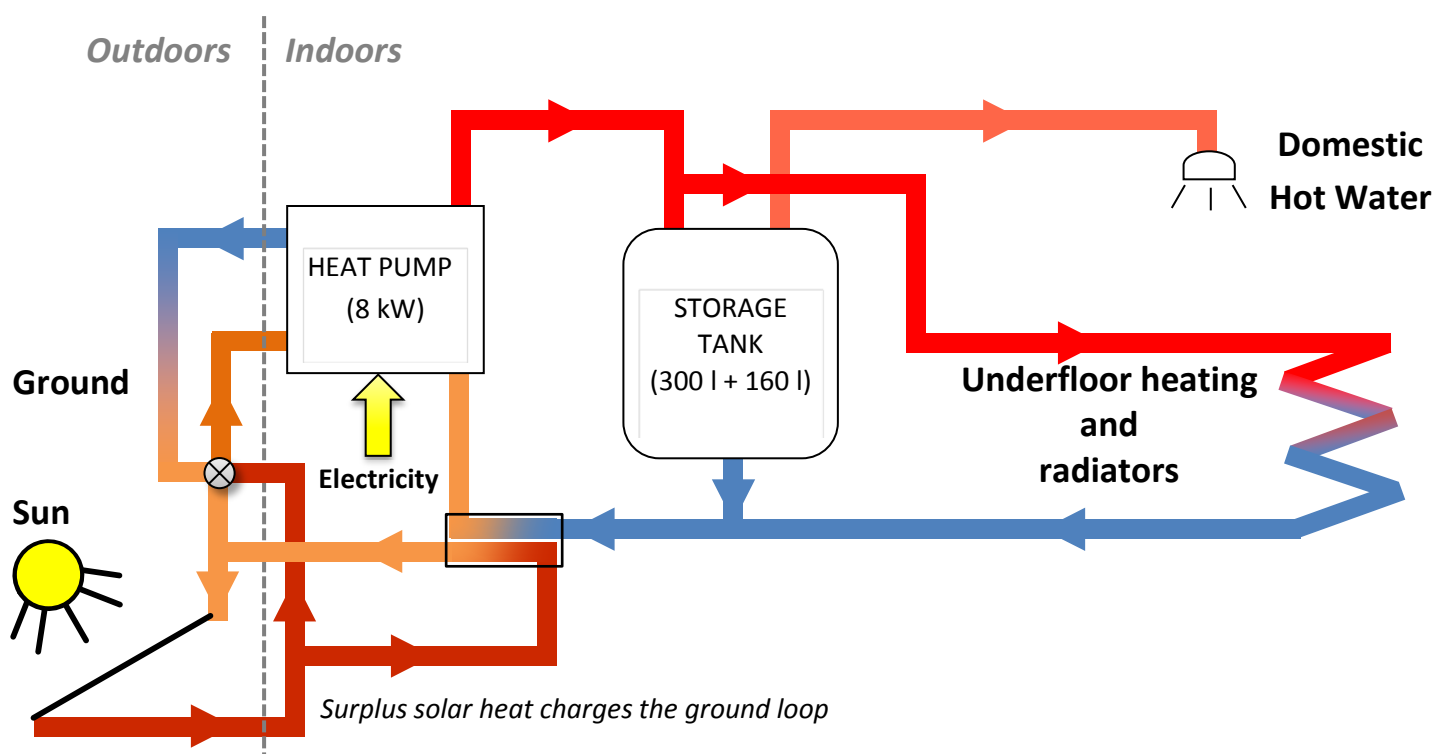


Heat
13'500 kWh/year

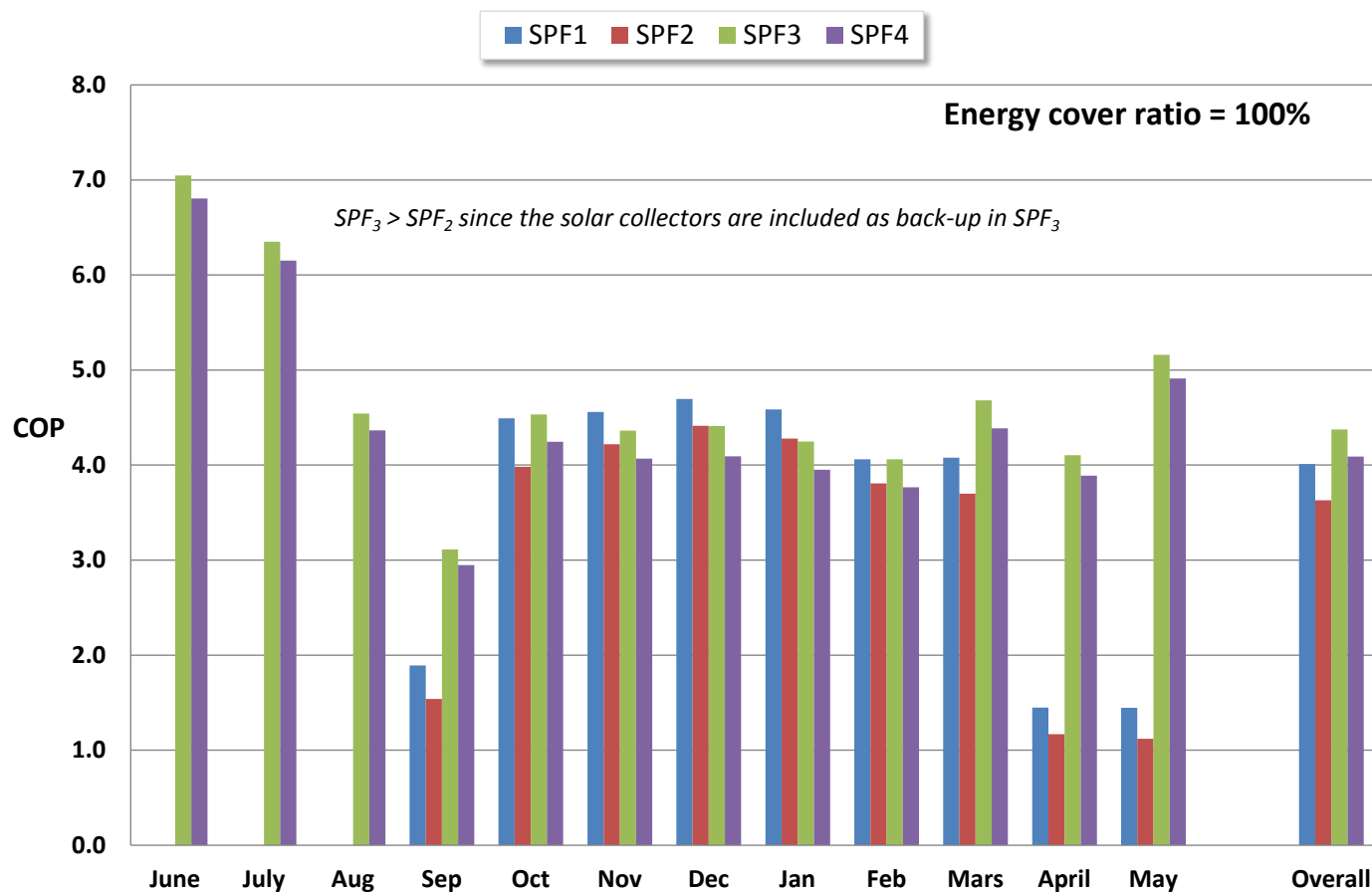
Out of 1 kWh electricity, the heat pump produces 4.4 kWh of useful heat (yearly average, SPF3).



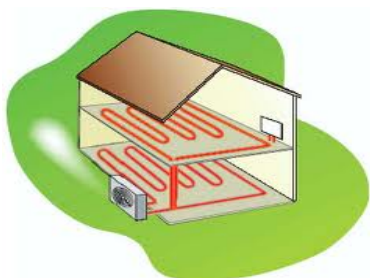
➤ System schematic



➤ Heat pump performance



Heat pump air/water + solar collectors – Sweden



City: Onsala **Average outside temp:** 7.0°C

Country: Sweden **Average inside temp:** 22.9°C

Measurement period: June 2010 – May 2011

➤ Building type

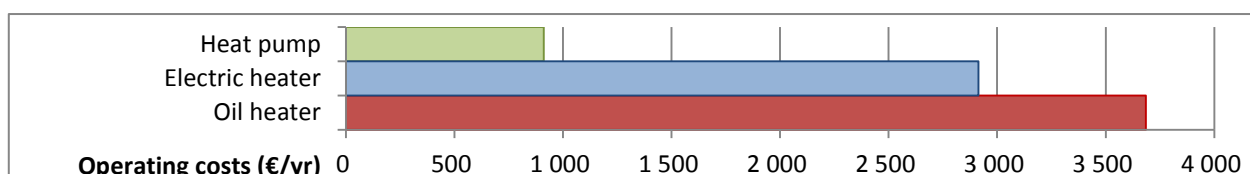
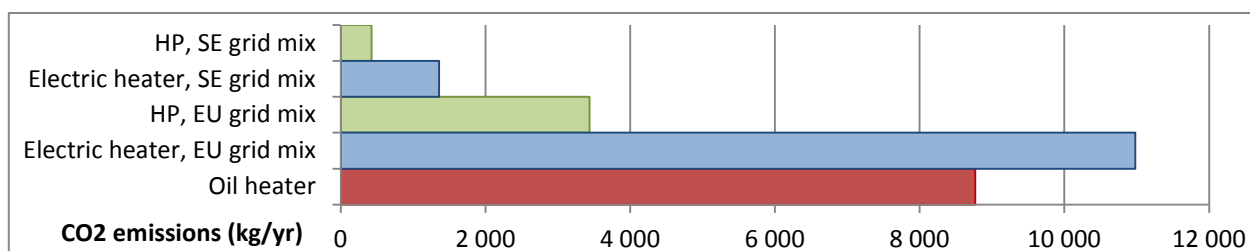
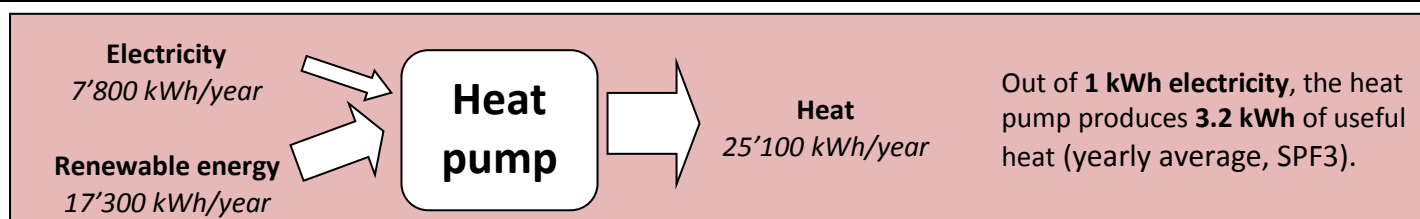
- Heated surface: 280 m² (90 kWh heat/m²)
- Occupants: 4 (2 adults, 2 teenagers)
- Construction year: 1991
- Construction: ☒ new

➤ Heating system features

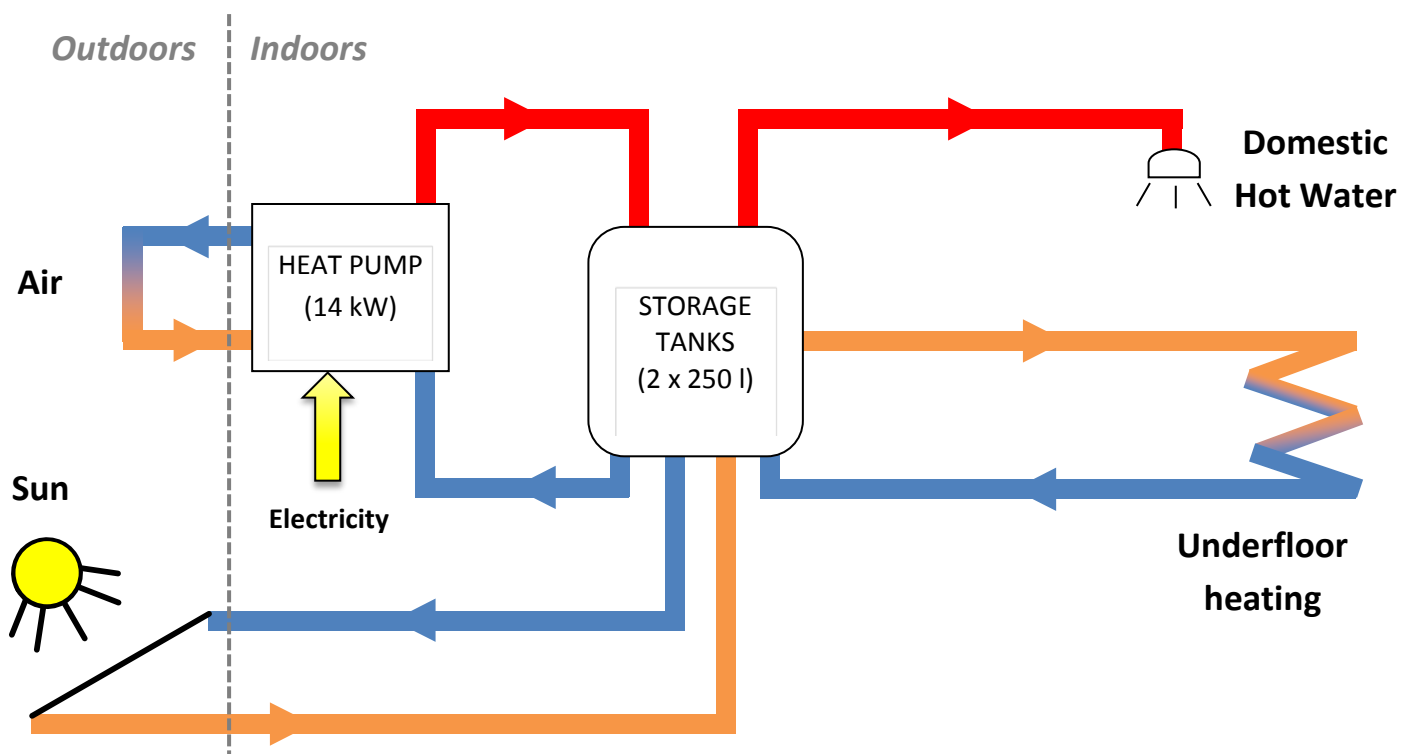
- Installation year: 2010
- Rated heating output: 14 kW
- Heat source: ☒ outside air ☒ sun (10 m²)
- Use of heat: ☒ space heating & domestic hot water
- Heat distribution: ☒ underfloor heating
- Heating provision: ☒ electric heater (turned off)



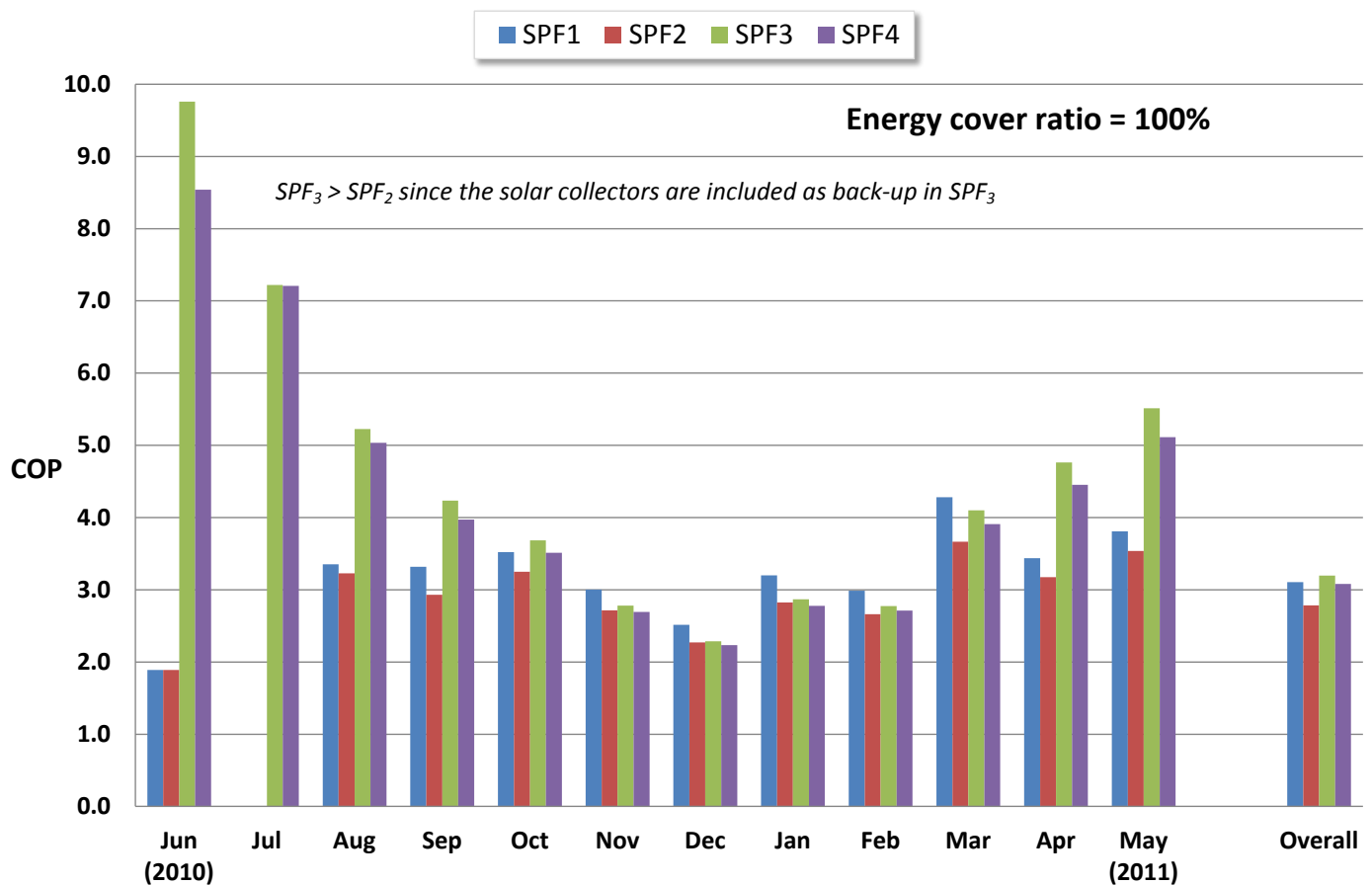
➤ Operational benefits



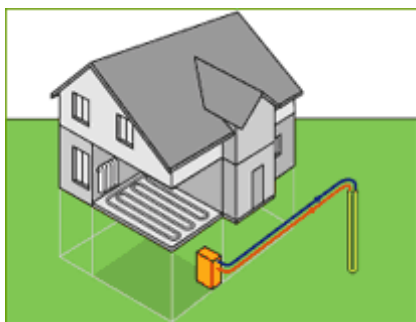
➤ System schematic



➤ Heat pump performance



Heat pump ground/water – Swiss lowlands



City: Tänikon

Altitude: 420 m

Region: Thurgovie

Average yearly temp: 9.3°C

Country: Switzerland

Measurement period: from 2003

➤ Building type

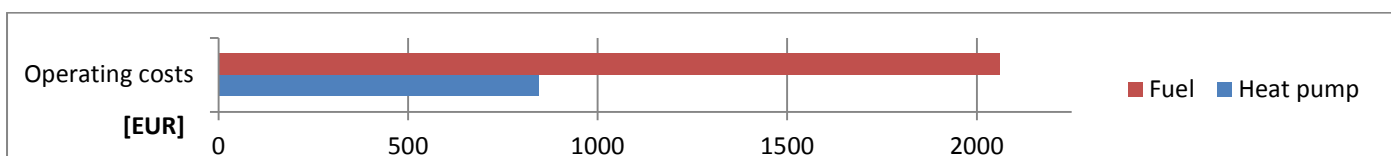
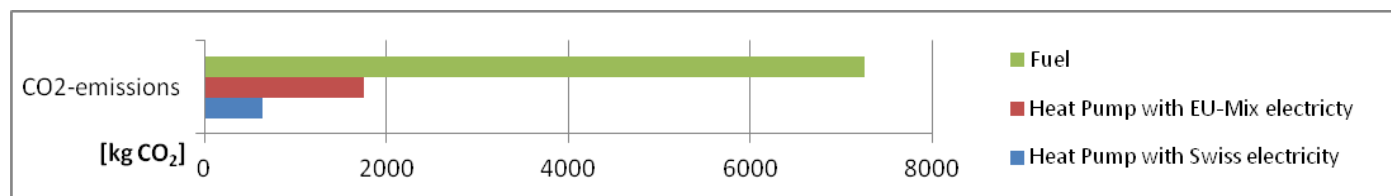
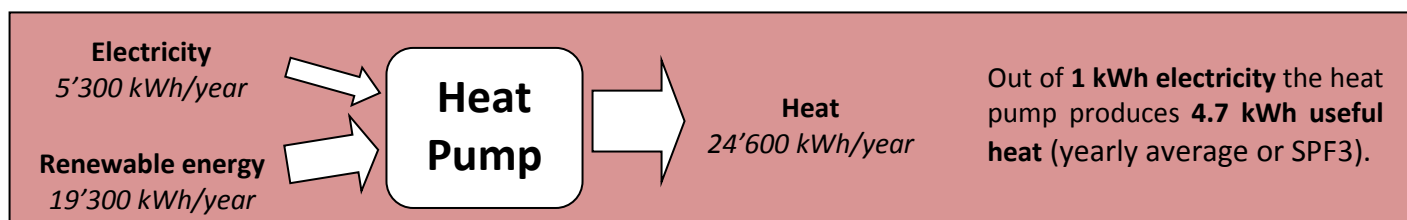
- Heated surface: 300 m²
- Construction year: 2003
- Number of occupants: 10
- Construction: ☒ new

➤ Heating system features

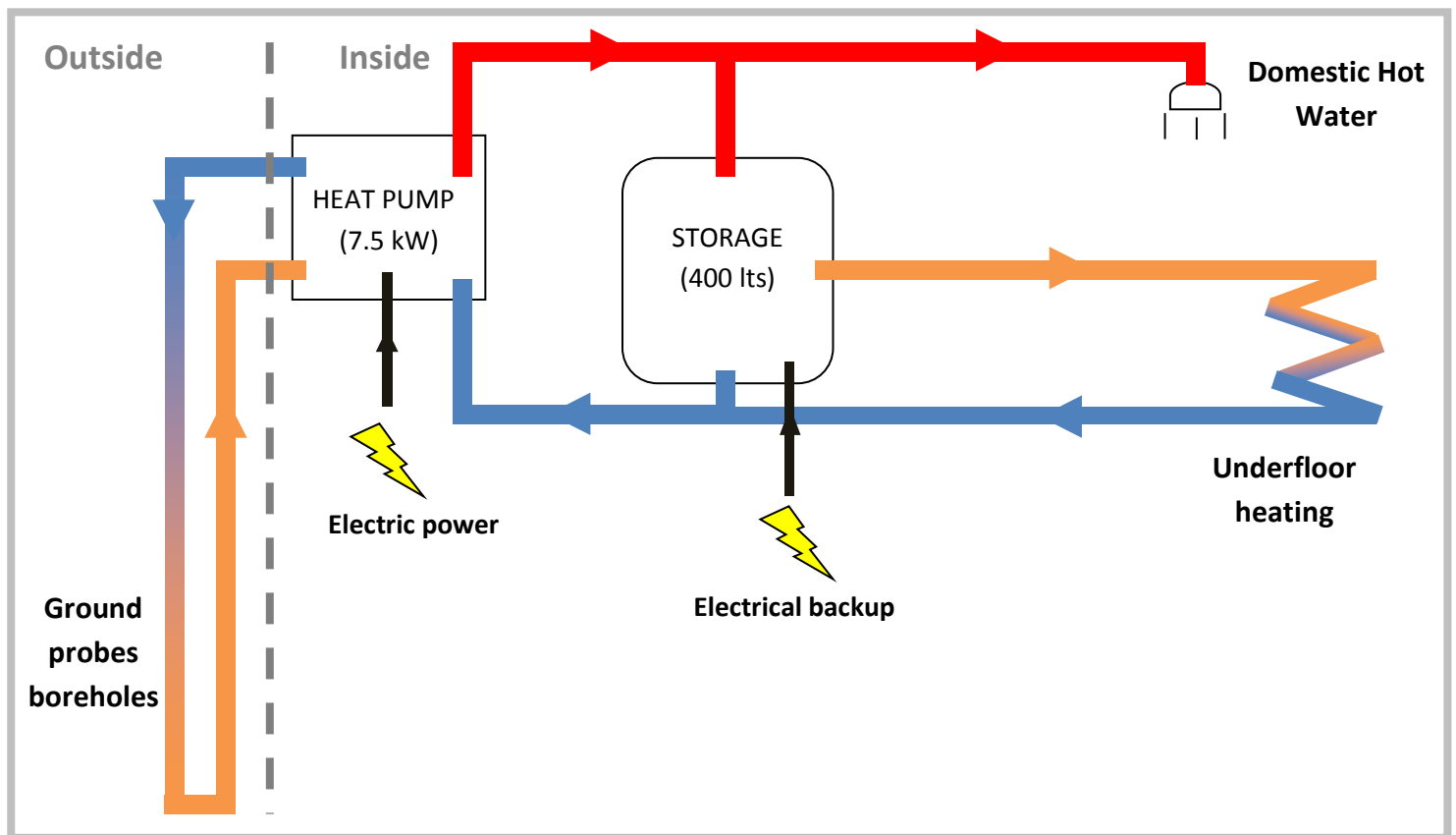
- Year of installation: 2003
- Rated heating output power: 7.5 kW
- Heat source: ☒ vertical borehole
- Use of heat: ☒ space heating and domestic hot water
- Heat distribution: ☒ under floor heating
- Heating provision: ☒ heat pump alone without backup



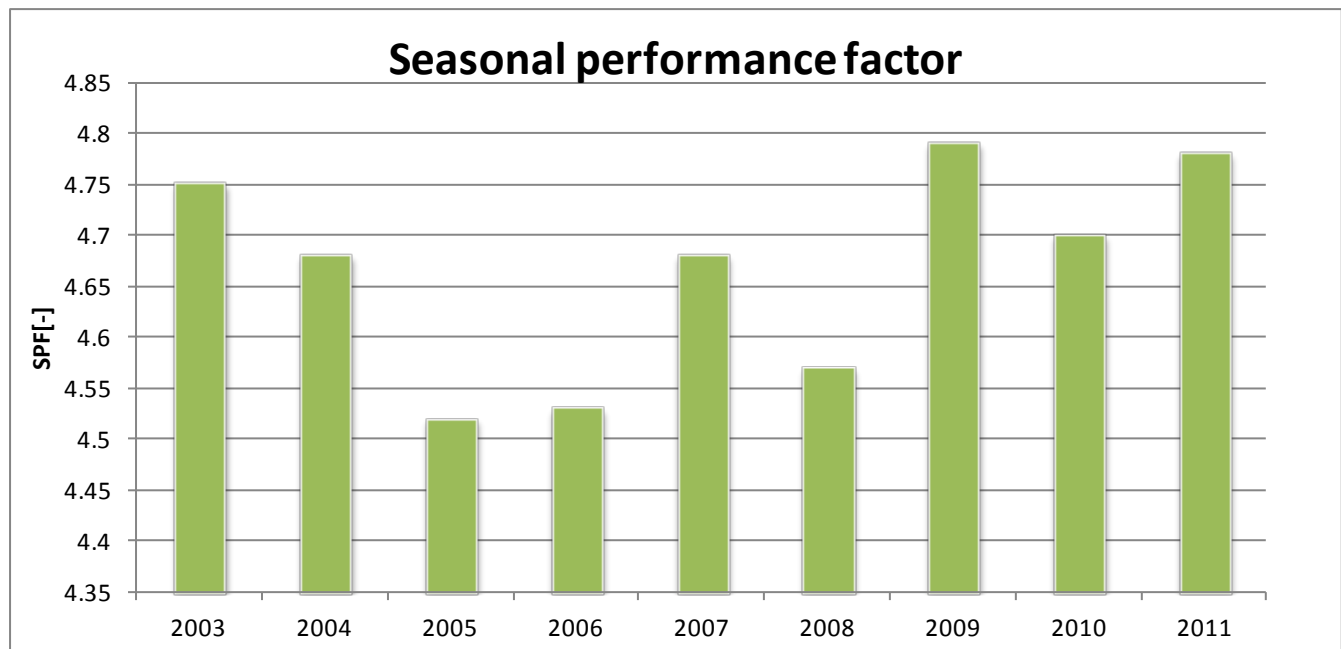
➤ Operational benefits



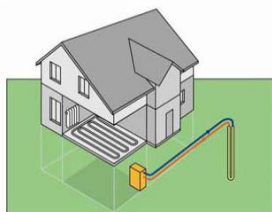
➤ System schematic



➤ Heat pump performance



Heat pump ground/water – Swiss lowlands



City: Tänikon

Altitude: 575 m

Region: Thurgovie

Average yearly temp: 9°C

Country: Switzerland

Measurement period: from 1999 to 2004

➤ Building type

- Heated surface: 132 m²
- Number of occupants: 1
- Construction year: 1820
- Construction: ☒ renovation

➤ Heating system features

- Year of installation: 1999
- Rated heating output power: 6 kW
- Heat source: ☒ vertical borehole
- Use of heat: ☒ space heating & domestic hot water
- Heat distribution: ☒ standard radiators
- Heating provision: ☒ heat pump alone without backup



➤ Operational benefits

Electricity
4'200 kWh/year

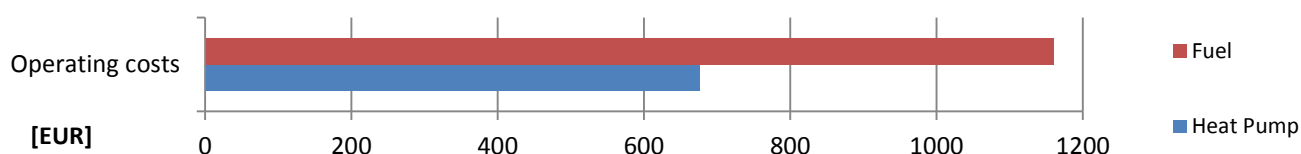
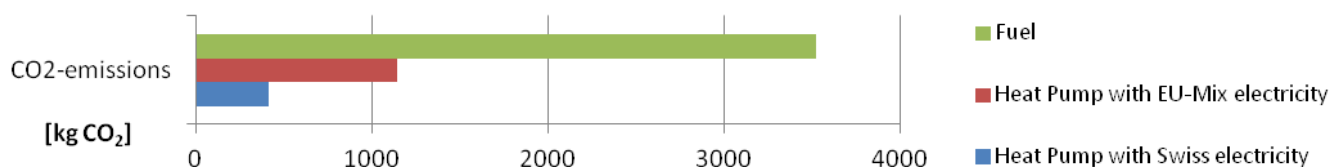
Renewable energy
9'800 kWh/year



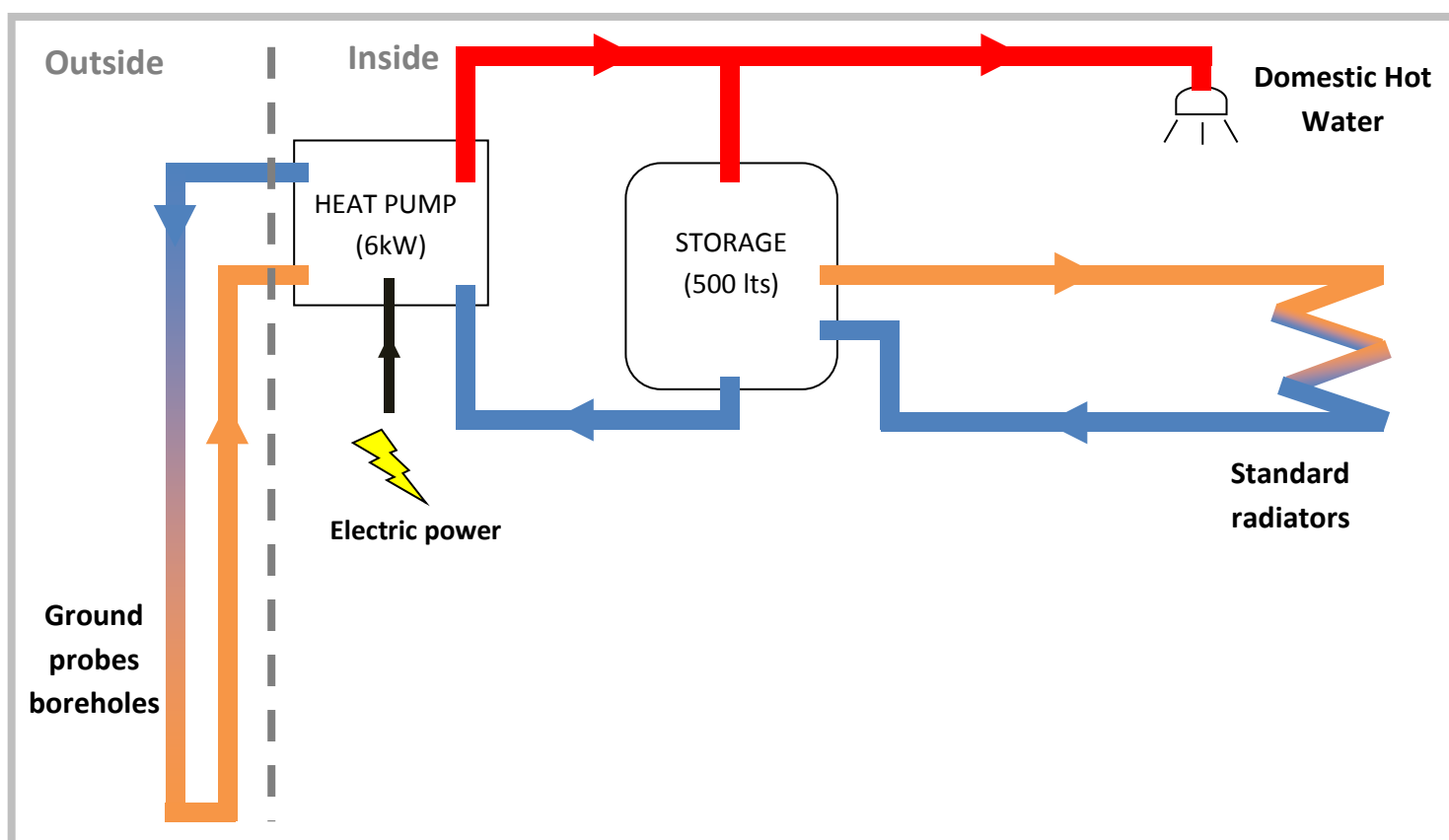
Heat Pump

Heat
14'000 kWh/year

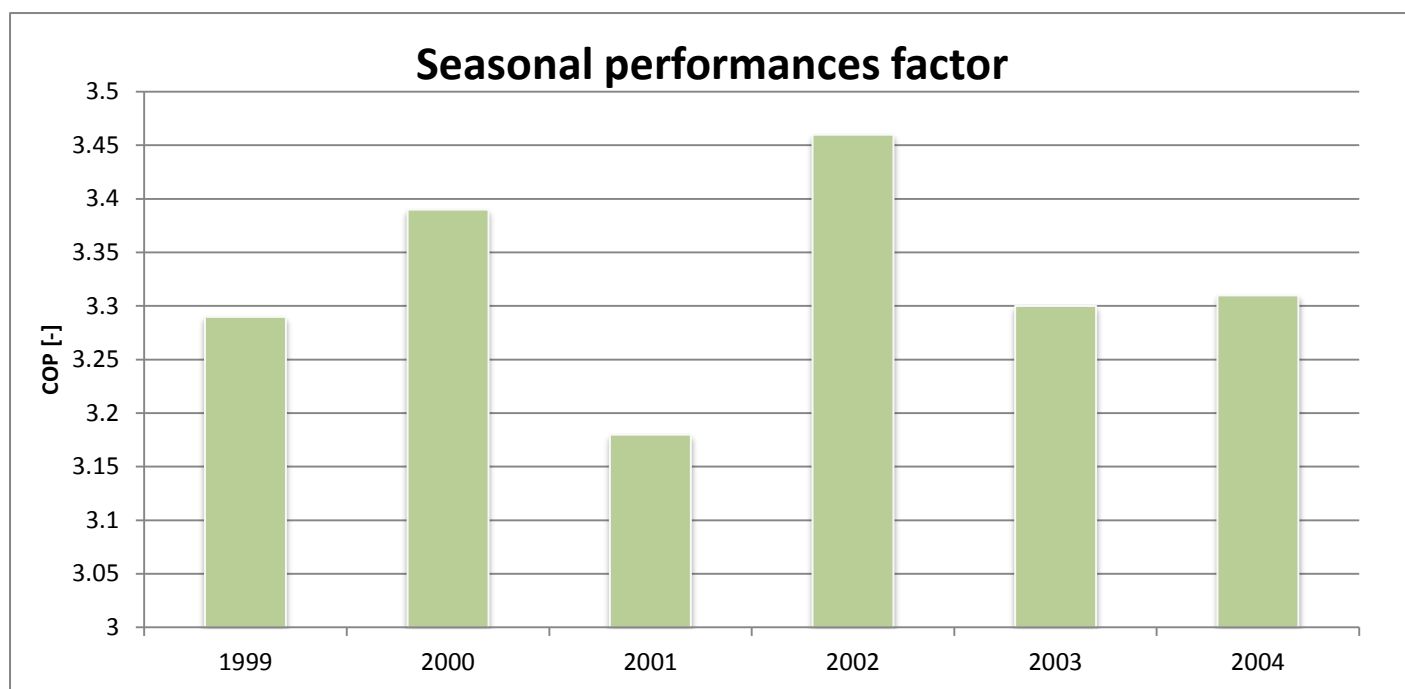
Out of 1 kWh electricity the heat pump produces 3.3 kWh useful heat (yearly average or SPF3)



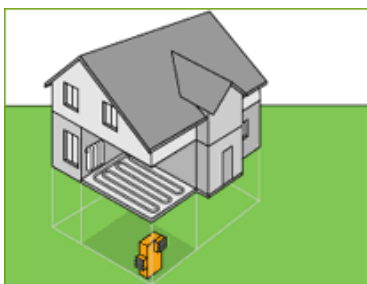
➤ System schematic



➤ Heat pump performance



Heat pump air/water – Swiss lowlands



City : Tänikon

Altitude : 420 m

Region : Thurgovie

Average yearly temp : 10°C

Country : Switzerland

Measurement period : from 2002 to 2011

➤ Building type

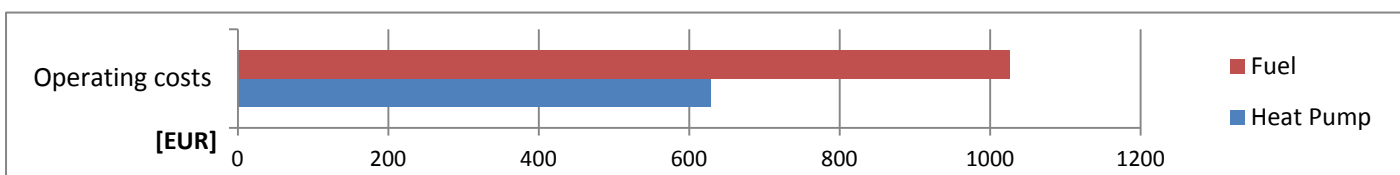
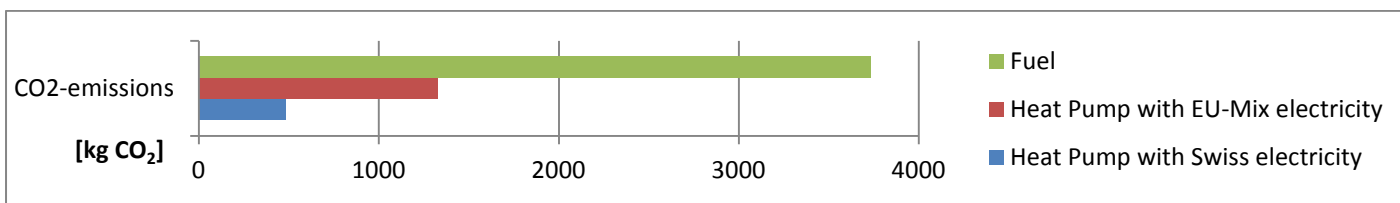
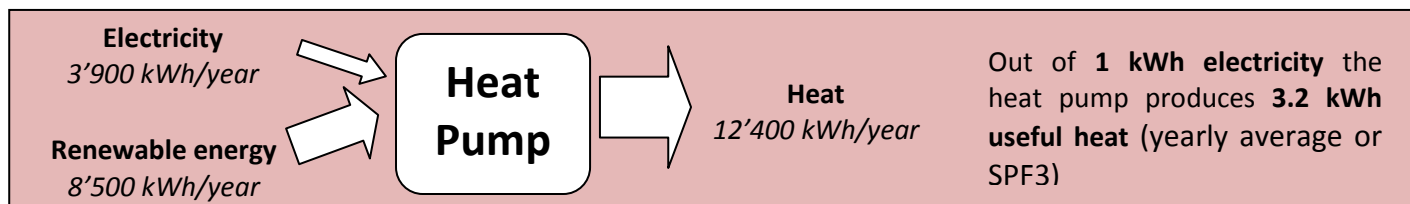
- Heated surface : 275 m²
- Number of occupants : 5
- Construction year : 2001
- Construction : ☒ new

➤ Heating system features

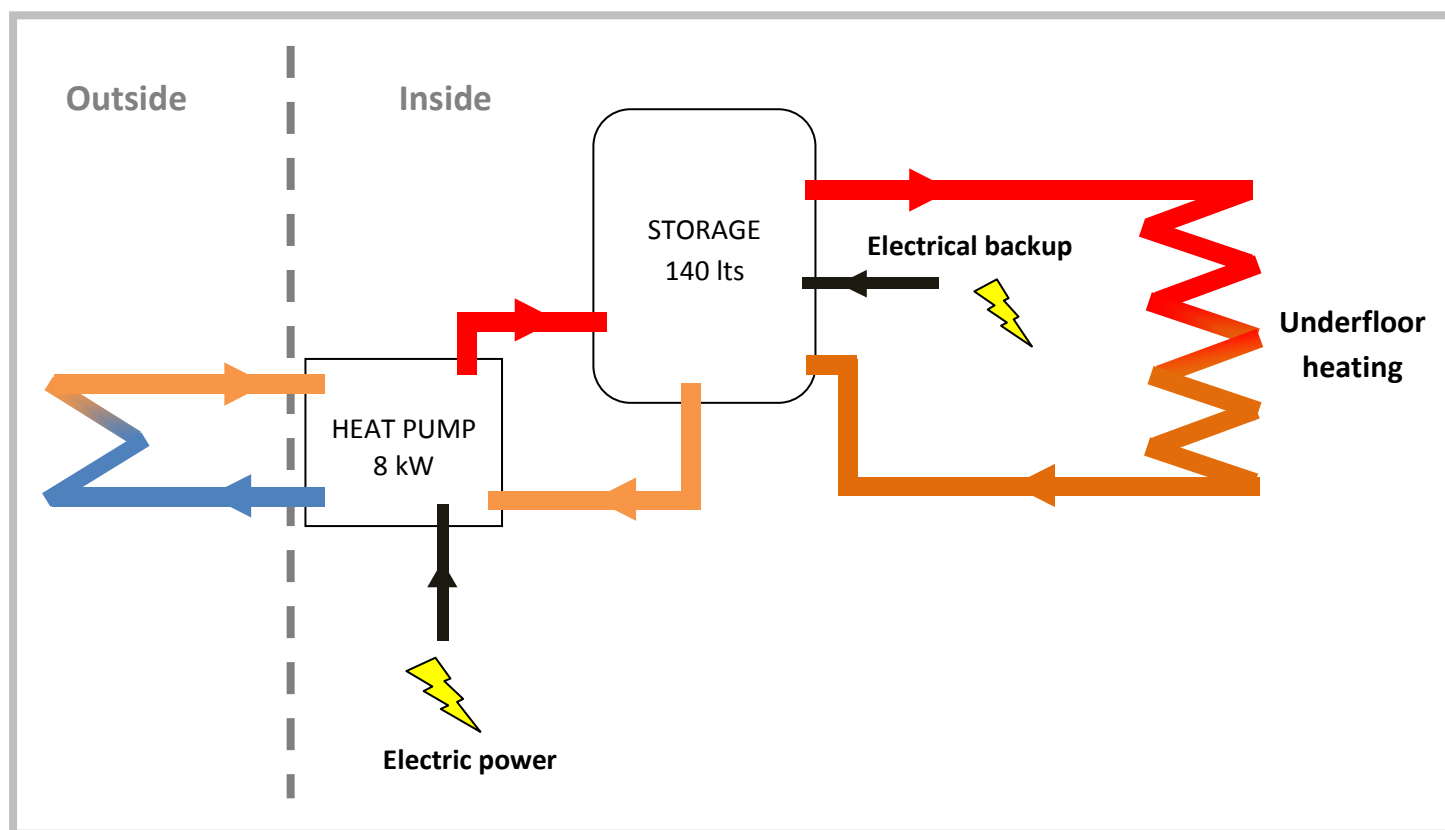
- Year of installation : 2001
- Rated heating output power : 8 kW
- Heat source : ☒ outside air
- Use of heat : ☒ space heating
- Heat distribution : ☒ under floor heating
- Heating provision : ☒ heat pump and supplementary system



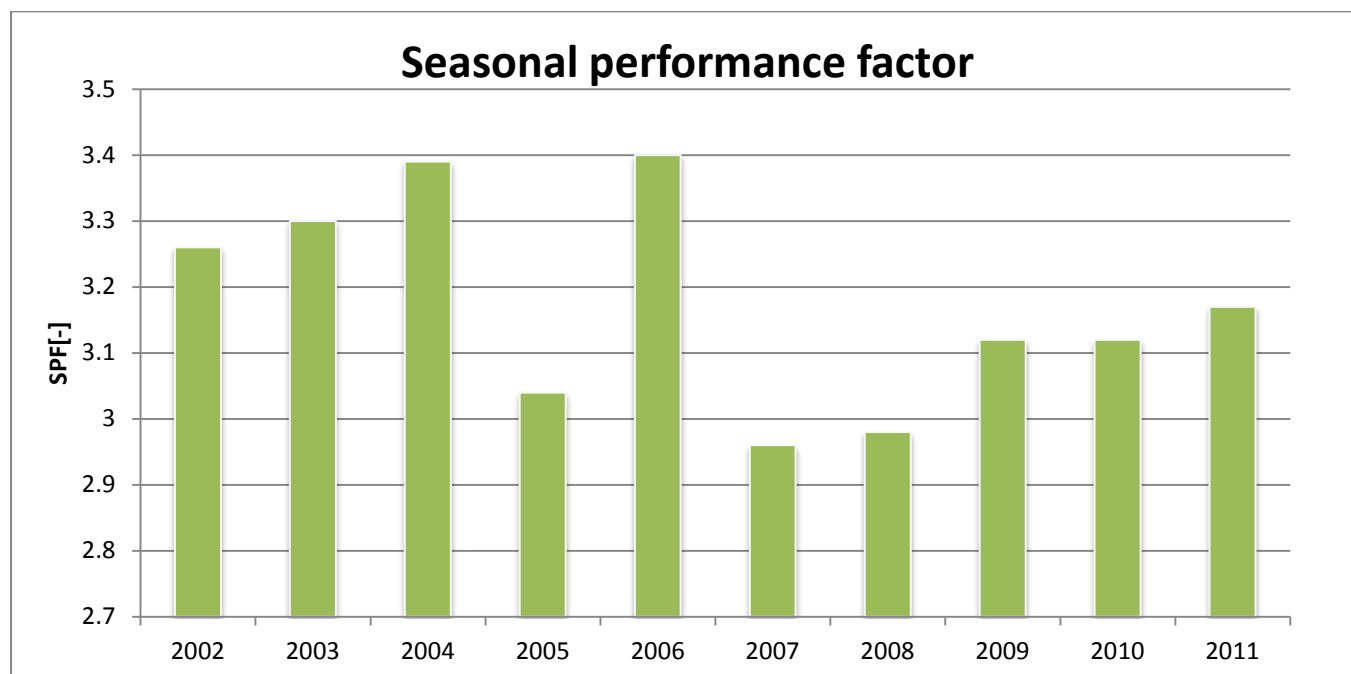
➤ Operational benefits



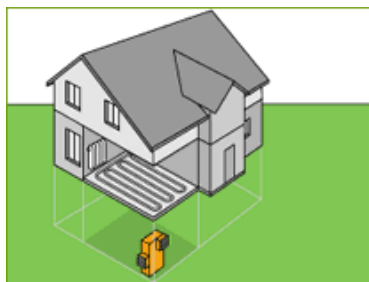
➤ System schematic



➤ Heat pump performance



Heat pump air/water – Swiss lowlands



City: Neuchâtel

Altitude: 480 m

Region: Neuchâtel

Average yearly temp: 9.5°C

Country: Switzerland

Measurement period: from 2010

➤ Building type

- Heated surface: 123 m²
- Number of occupants: 4
- Construction year: 1911
- Construction: ☒ renovation

Heating system features

- Year of installation: 2009
- Rated heating output power: 7 kW
- Heat source: ☒ outside air
- Use of heat: ☒ space heating and domestic hot water
- Heat distribution: ☒ standard radiators
- Heating provision: ☒ heat pump alone without backup



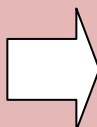
➤ Operational benefits

Electricity
6'900 kWh/year

Renewable energy
14'700 kWh/year

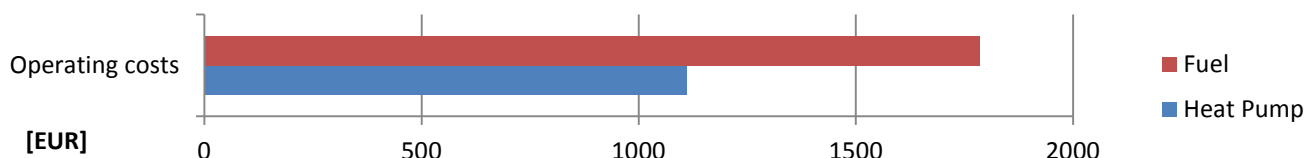
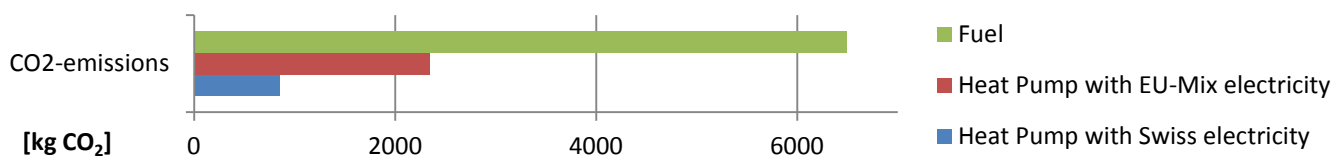


Heat Pump

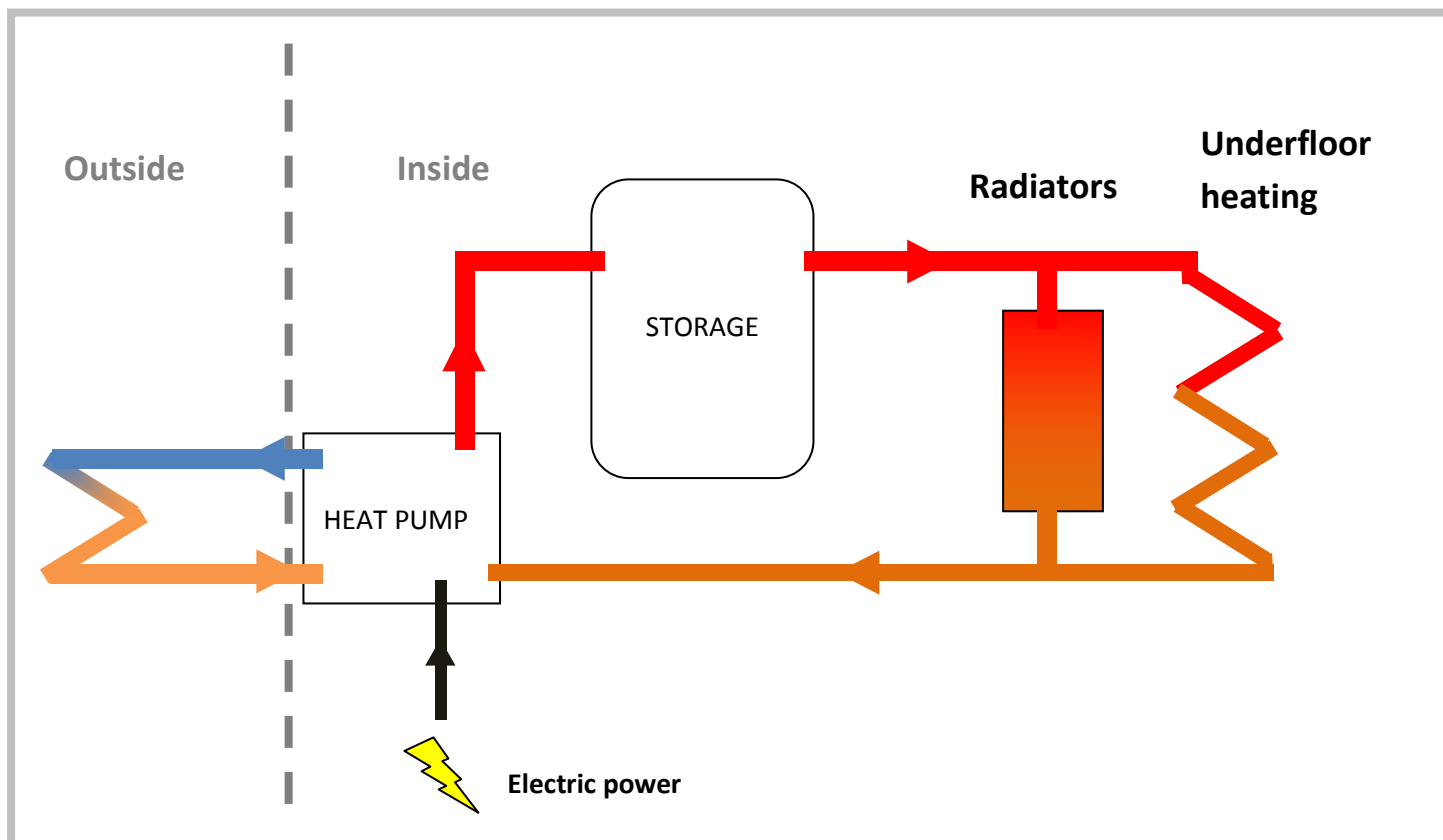


Heat
21'600 kWh/year

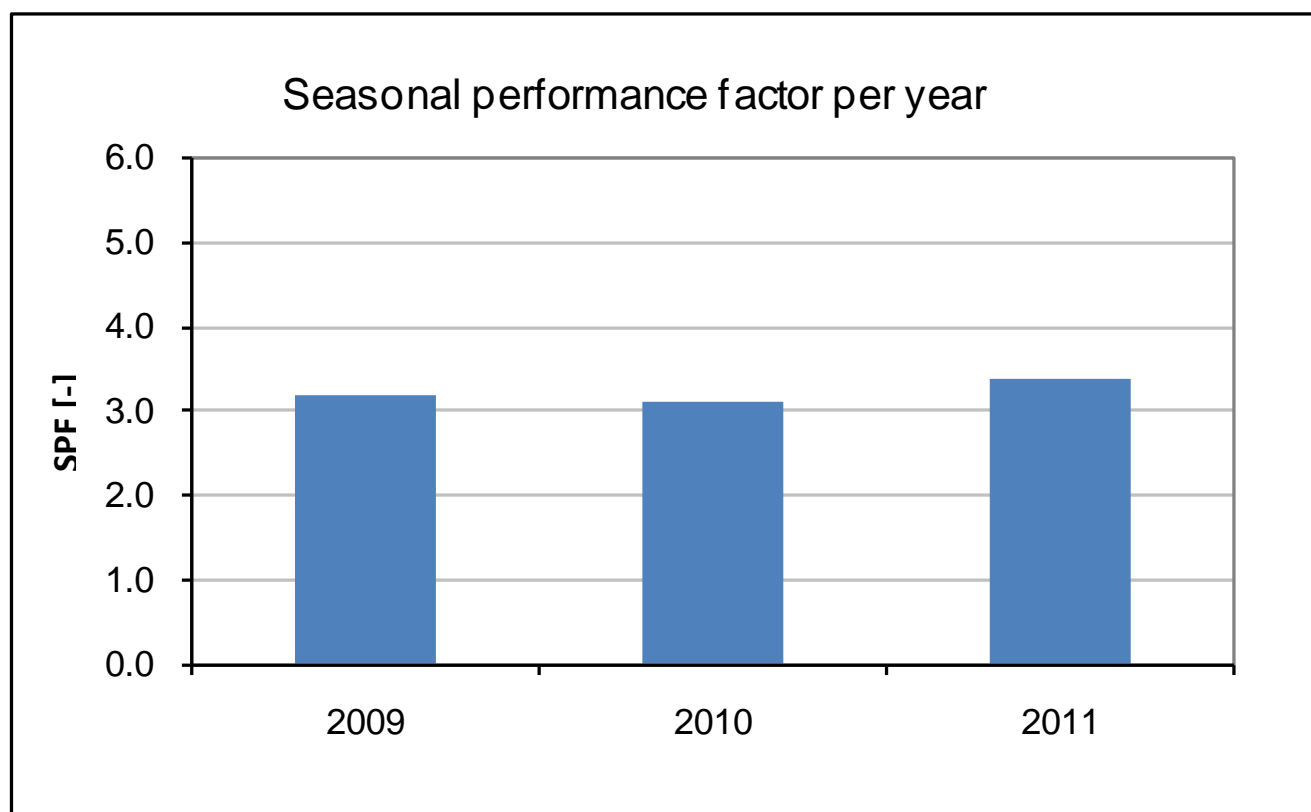
Out of 1 kWh electricity the heat pump produces 3.1 kWh useful heat (yearly average or SPF3)



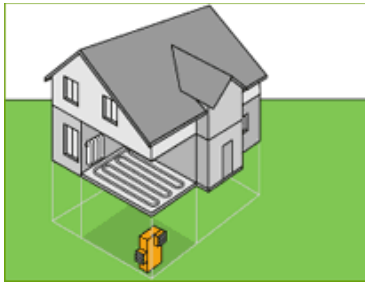
➤ System schematic



➤ Heat pump performance



Heat pump air/water – Swiss lowlands



City : Schaffhausen

Altitude : 420 m

Region : Schaffhouse

Average yearly temp : 9.3°C

Country : Switzerland

Measurement period : from 2003

➤ Building type

- Heated surface : 160 m²
- Number of occupants : 2
- Construction year : 1979
- Construction : ☒ renovation

➤ Heating system features

- Year of installation : 2003
- Rated heating output power : 9.6 kW
- Heat source : ☒ outside air
- Use of heat : ☒ space heating
- Heat distribution : ☒ under floor heating
- Heating provision : ☒ heat pump with backup



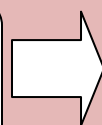
➤ Operational benefits

Electricity
7'500 kWh/year

Renewable energy
11'900 kWh/year

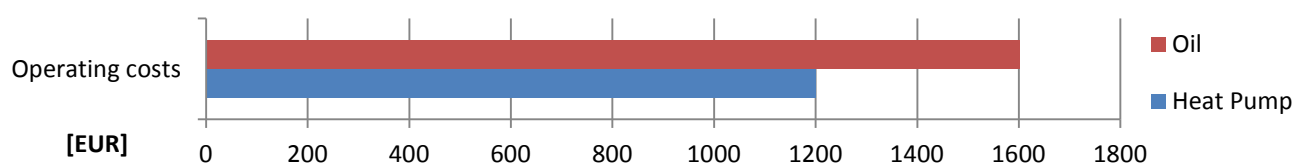
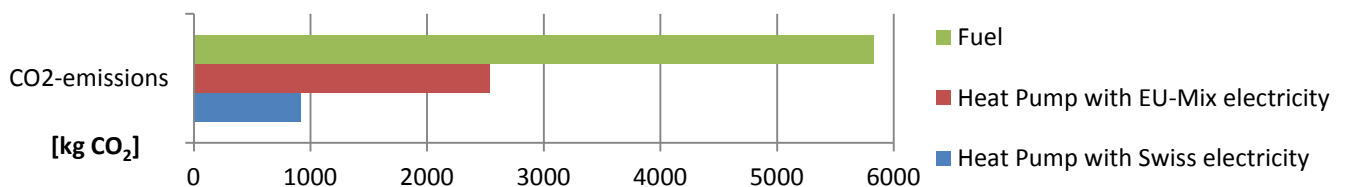


Heat Pump

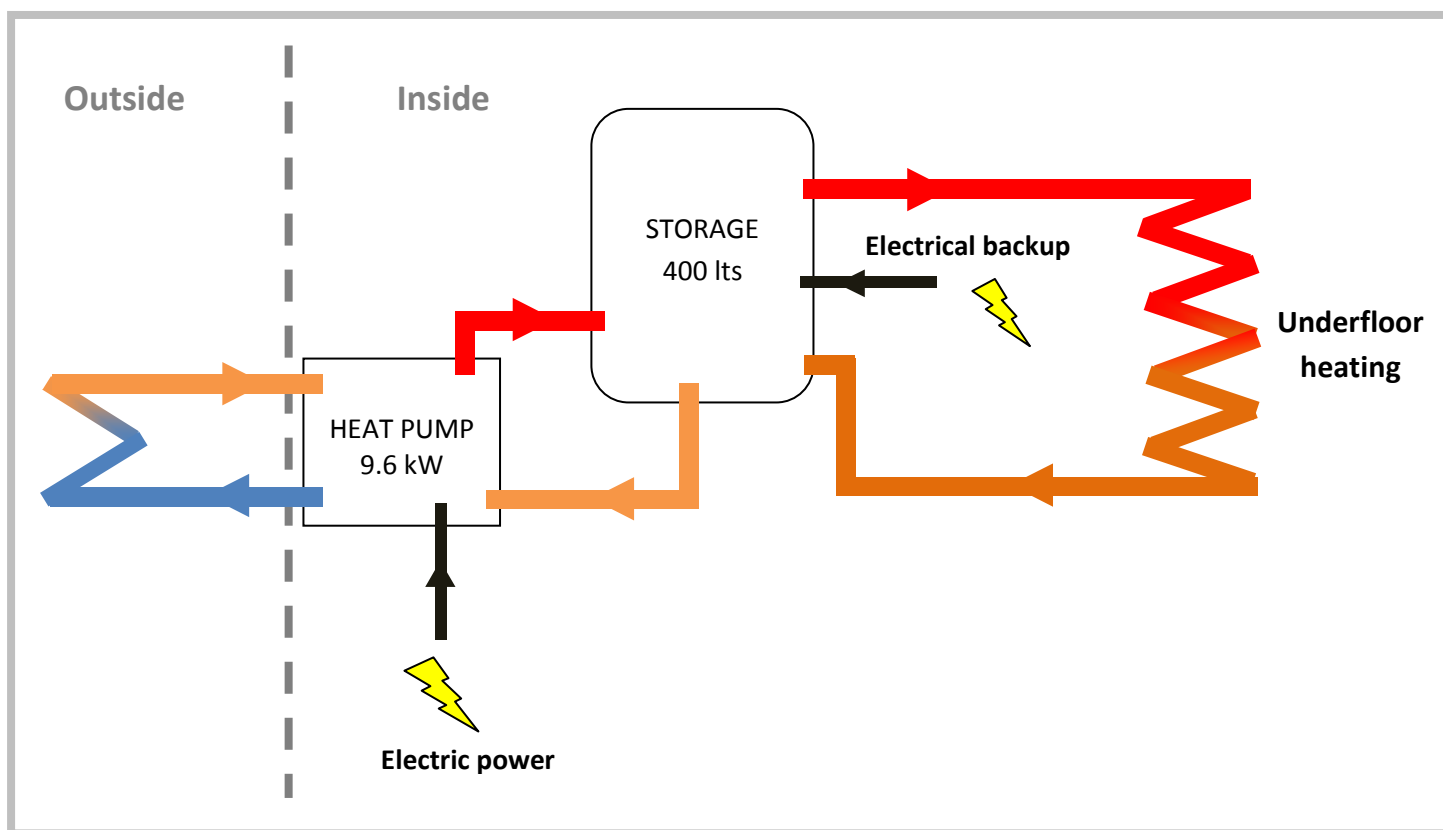


Heat
19'400 kWh/year

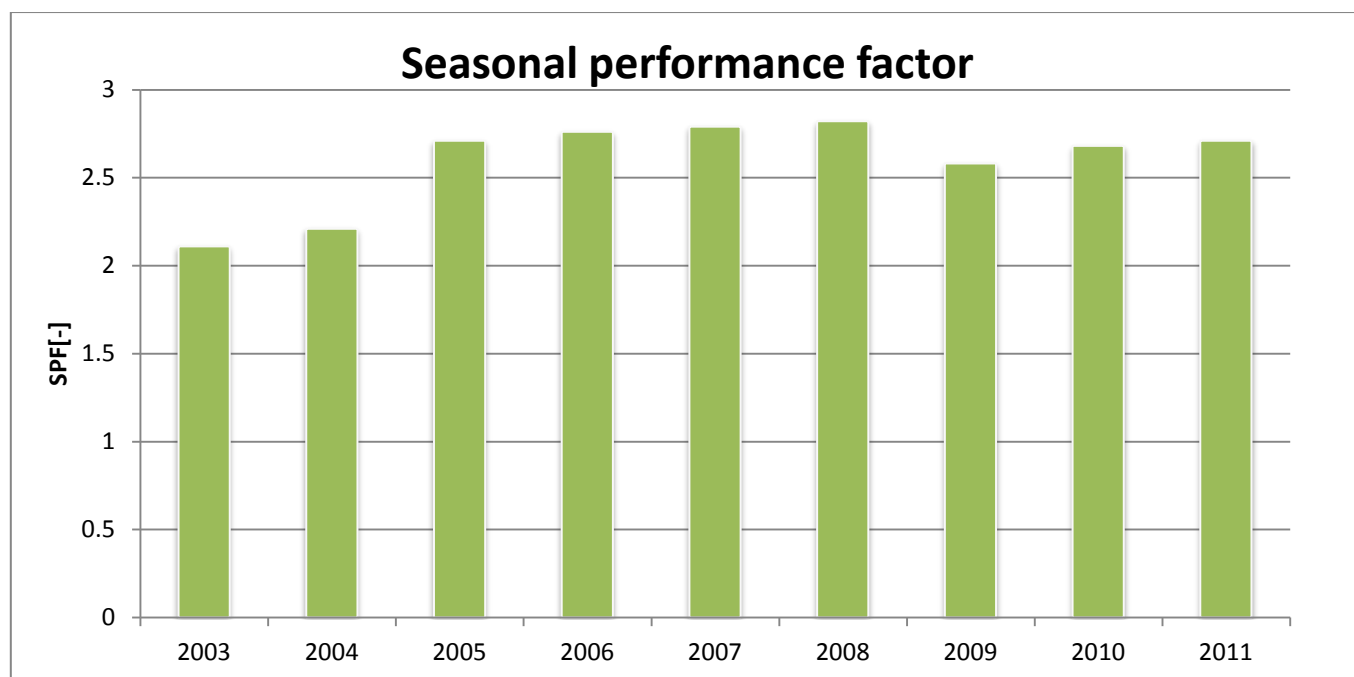
Out of 1 kWh electricity the heat pump produces 2.6 kWh useful heat (yearly average or SPF3)



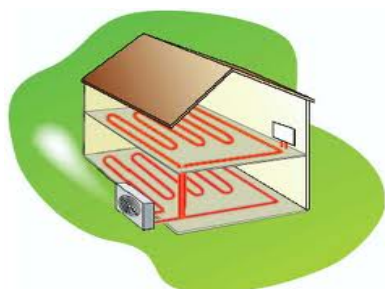
➤ System schematic



➤ Heat pump performance



Heat pump ground/water – Scotland, UK



City : Glasgow	Altitude : 8 m
Region : Dunbartonshire	Average yearly temp : 8.1°C
Country : UK	Measurement period :from (15/06/2011) to (31/03/2012)

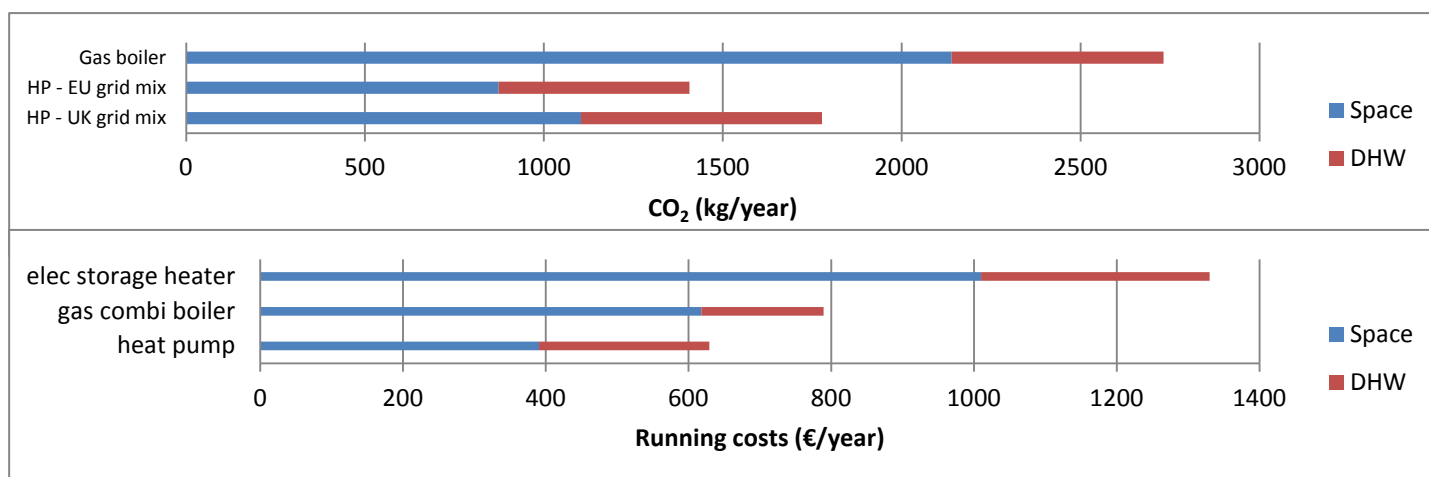
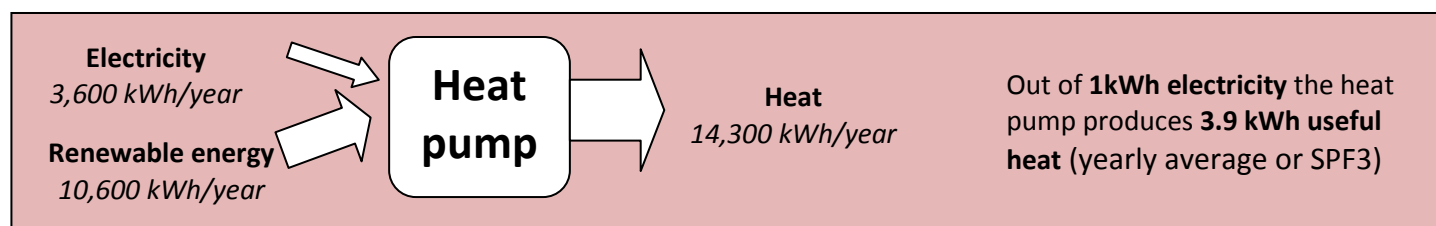
➤ Building type

- Heated surface : 226 m²
- Construction year : 2008
- Number of occupants : Working family
- Construction : ☒ new
- Energy rating: ☒ Energy Performance Certificate : 77 C rating ☒ SAP rating : 67

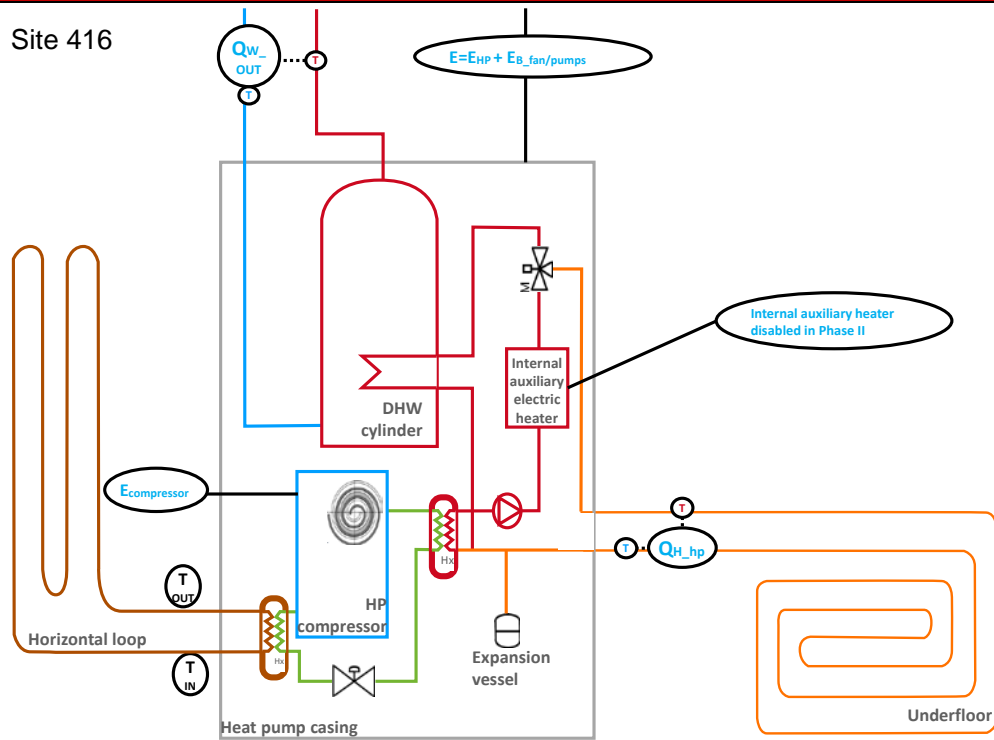
➤ Heating system features

- Year of installation : 2011
- Rated heating output power : 5kW
- Heat source : ☒ horizontal ground loop
- Use of heat : ☒ space heating and domestic hot water
- Heat distribution: ☒ underfloor heating
- Heating provision: ☒ heat pump alone without backup

➤ Operational benefits

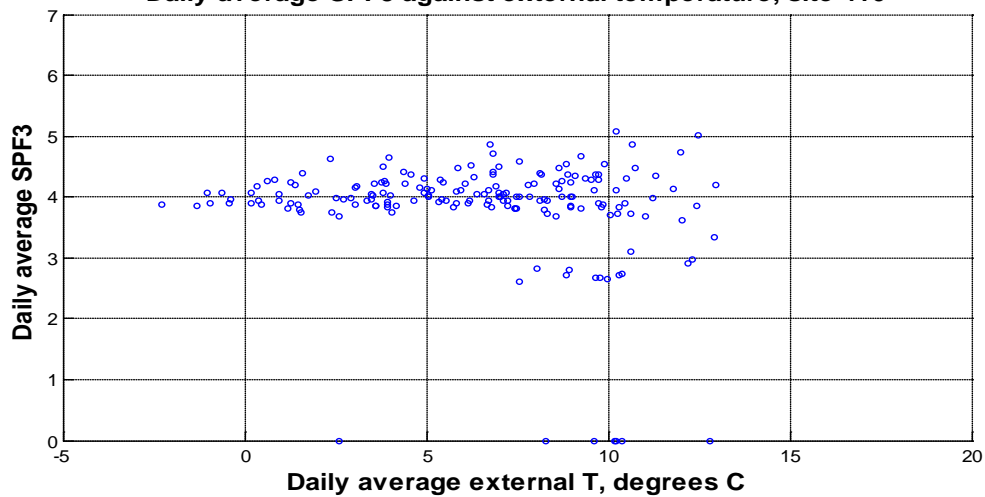


➤ System's schematic

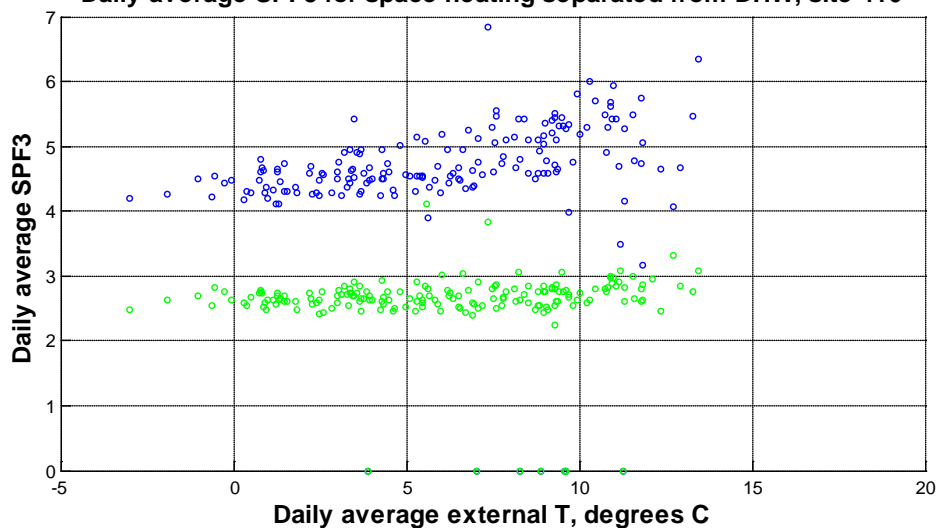


➤ Heat pump performance

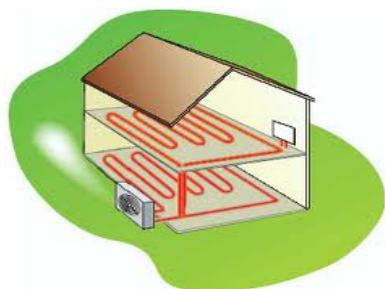
Daily average SPF3 against external temperature, site 416



Daily average SPF3 for space heating separated from DHW, site 416



Heat pump air/water – Scotland, UK



City : Aberdeen

Altitude : 66 m

Region :
Aberdeenshire

Average yearly temp : 7.1°C

Country : UK

Measurement period :from
(01/03/2011) to (31/03/2012)

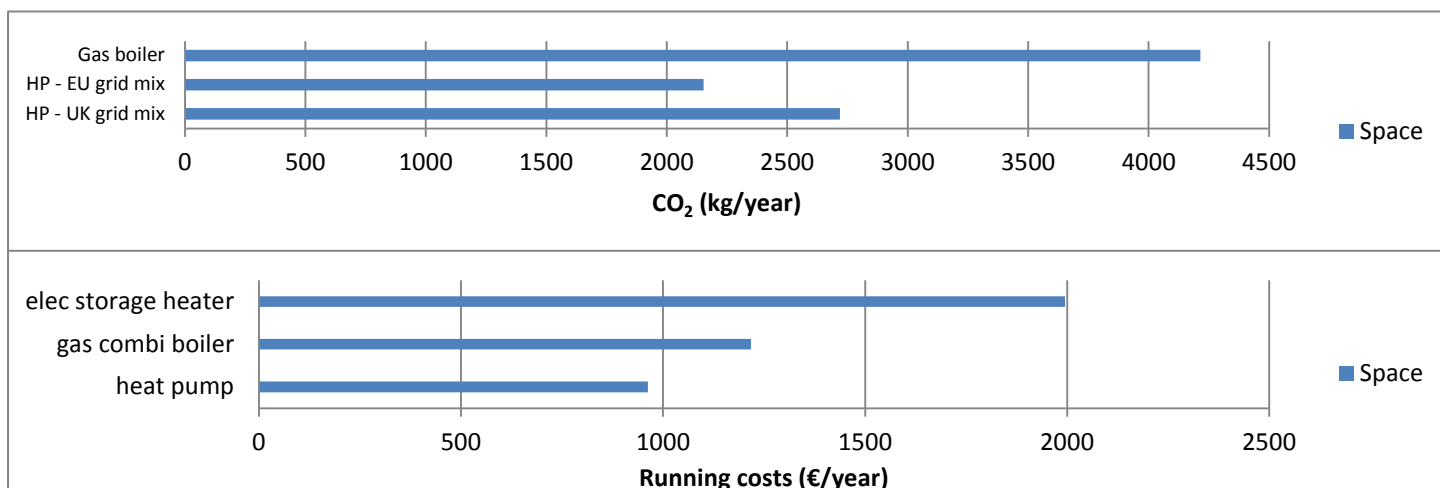
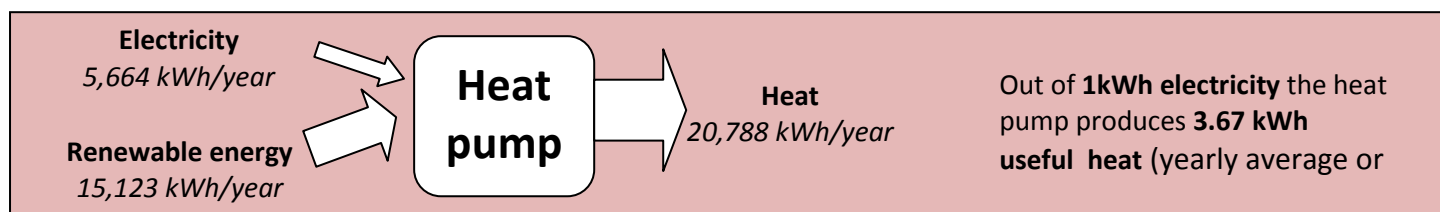
➤ Building type

- Heated surface : 251.3 m²
- Construction year : 2008
- Number of occupants : Working couple
- Construction : ☒ new
- Energy rating: ☒ Energy Performance Certificate : 63 D rating ☒ SAP rating : 44

➤ Heating system features

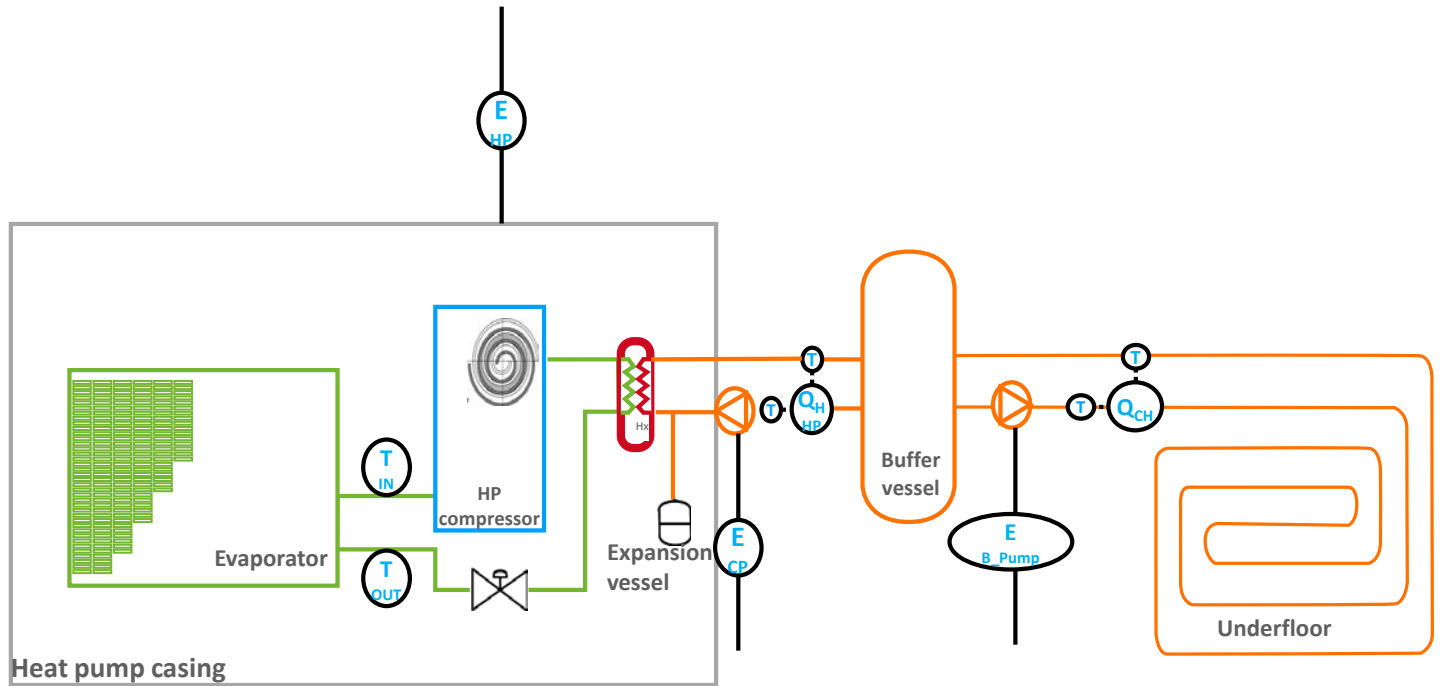
- Year of installation : 2011
- Rated heating output power : 7kW
- Heat source : ☒ outside air
- Use of heat : ☒ space heating
- Heat distribution: ☒ underfloor heating
- Heating provision: ☒ heat pump with internal backup

➤ Operational benefits



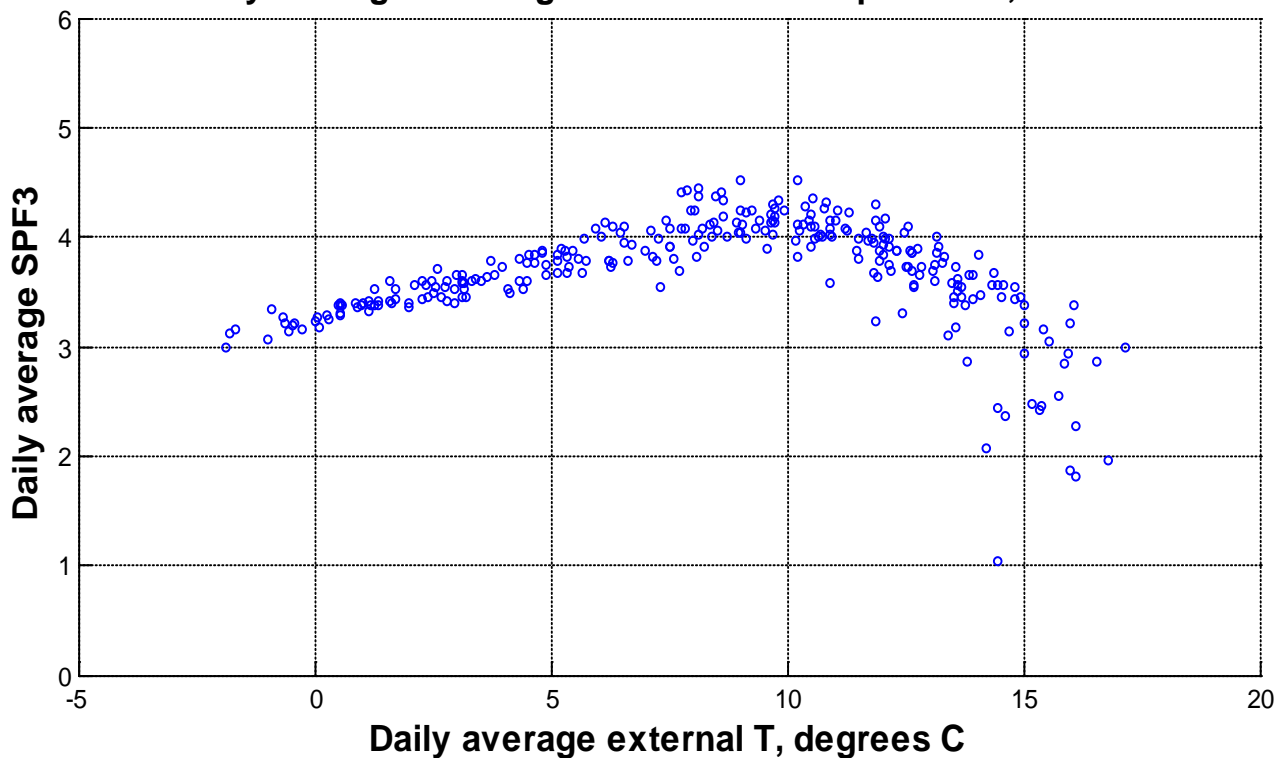
➤ System's schematic

Site 418

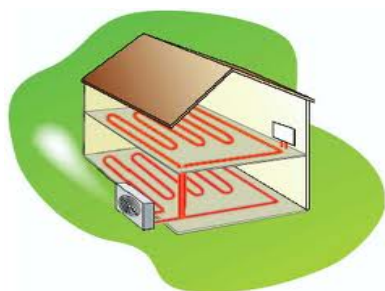


➤ Heat pump performance

Daily average SPF3 against external temperature , site 418



Heat pump ground/water – Scotland, UK



City : Aberdeen

Altitude : 66 m

Region :
Aberdeenshire

Average yearly temp : 7.1°C

Country : UK

Measurement period : from
(09/02/2011) to (31/03/2012)

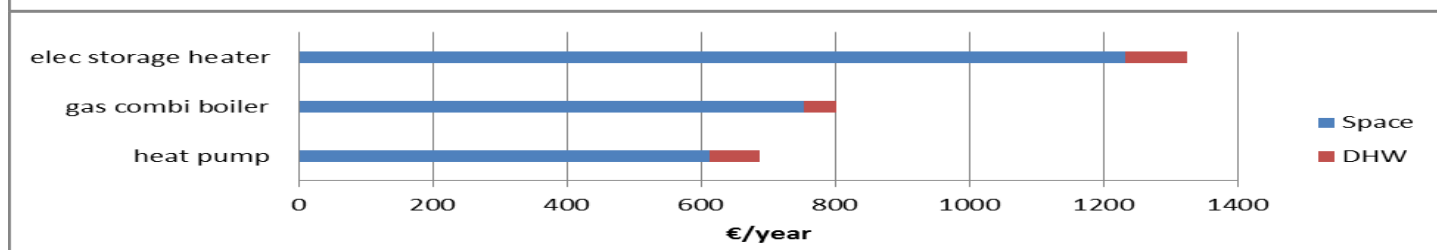
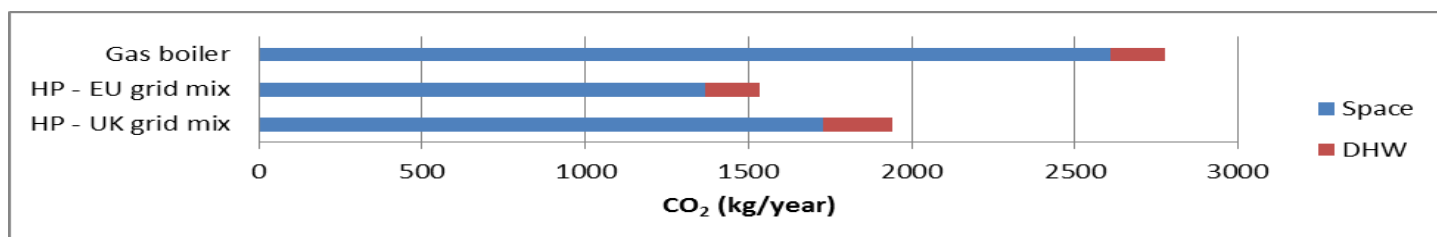
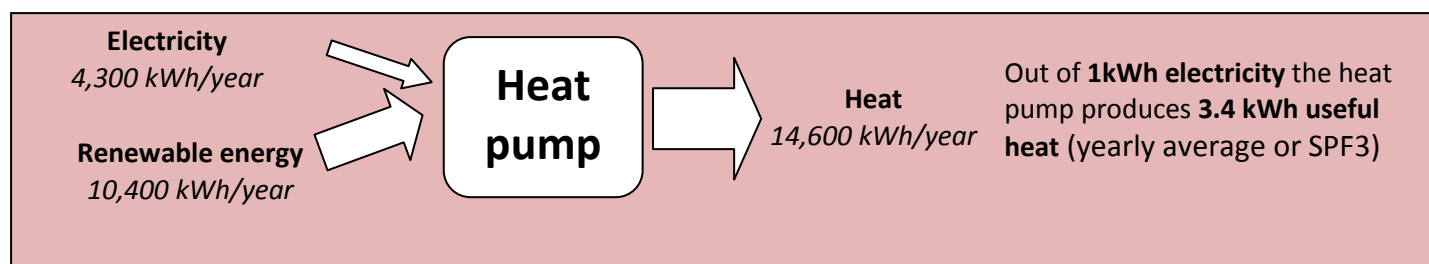
➤ Building type

- Heated surface : 126.5 m²
- Construction year : Main house pre 1900, extension 2006
- Number of occupants : Retired person
- Construction : ☒ renovation
- Energy rating: ☒ Energy Performance Certificate : 42 E rating ☒ SAP rating : 39

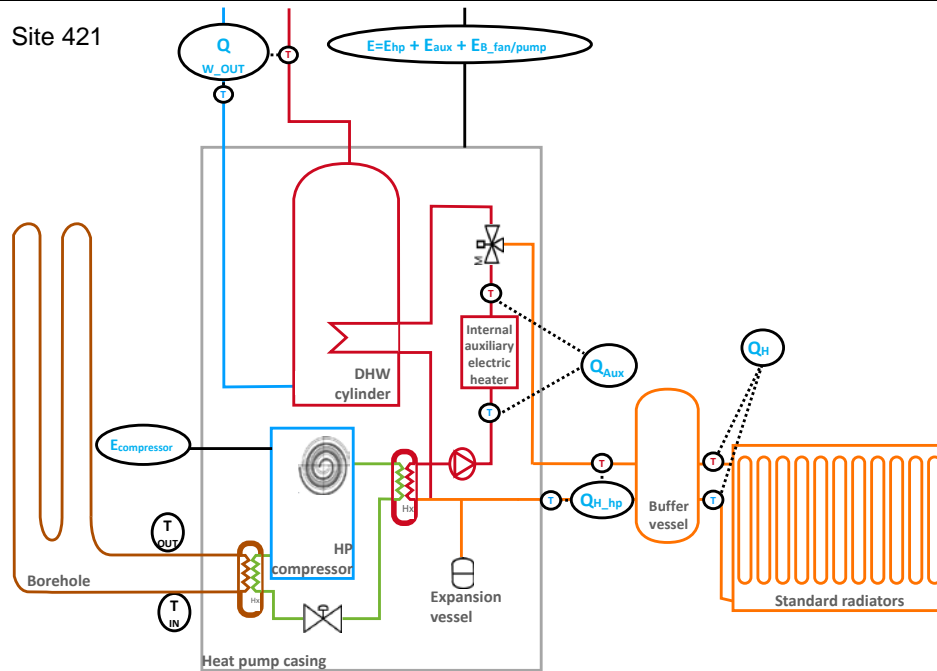
➤ Heating system features

- Year of installation : 2011
- Rated heating output power : 8kW
- Heat source : ☒ vertical borehole
- Use of heat : ☒ space heating and domestic hot water
- Heat distribution: ☒ standard radiators
- Heating provision: ☒ heat pump alone without backup

➤ Operational benefits

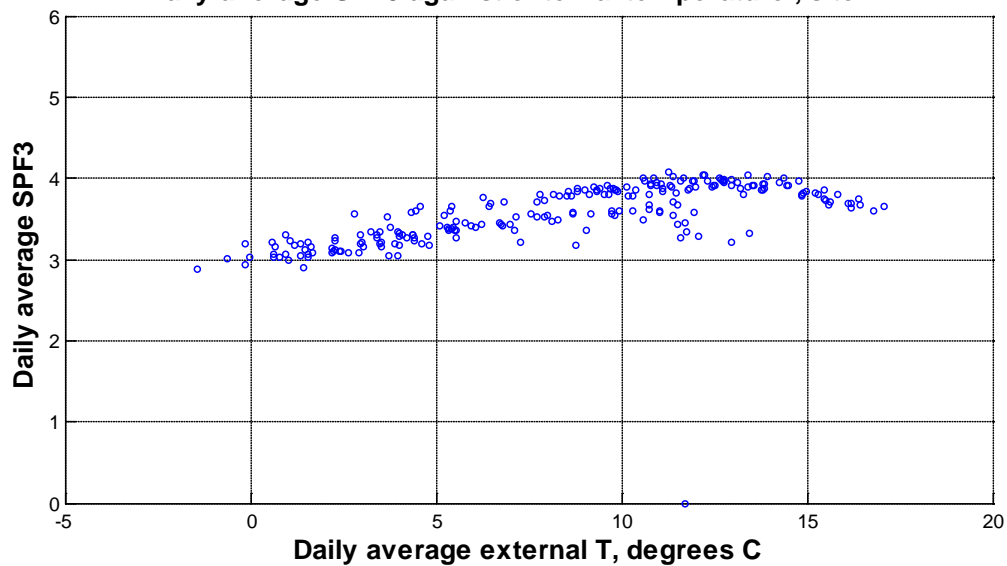


➤ System's schematic

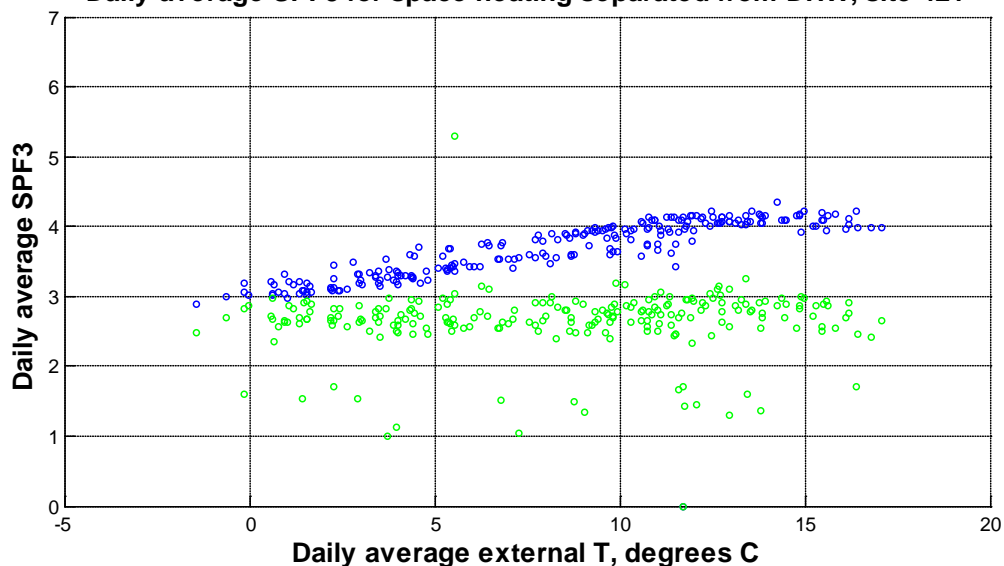


➤ Heat pump performance

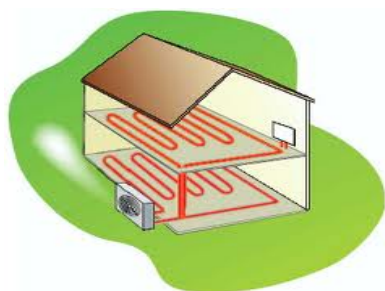
Daily average SPF3 against external temperature , site 421



Daily average SPF3 for space heating separated from DHW, site 421



Heat pump air/water – Scotland, UK



City : Aberdeen

Altitude : 66 m

Region :
Aberdeenshire

Average yearly temp : 7.1°C

Country : UK

Measurement period : from
(22/02/2011) to (31/03/2012)

➤ Building type

- Heated surface : 73 m²
- Construction year : 1992
- Number of occupants : Retired person
- Construction : ☒ renovation
- Energy rating: ☒ Energy Performance Certificate : 49 E rating ☒ SAP rating : 48

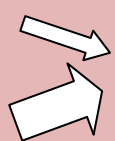
➤ Heating system features

- Year of installation : 2011
- Rated heating output power : 5kW
- Heat source : ☒ air
- Use of heat : ☒ space heating and domestic hot water
- Heat distribution: ☒ standard radiators
- Heating provision: ☒ heat pump alone without backup

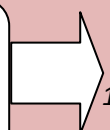
➤ Operational benefits

Electricity
4,000 kWh/year

Renewable energy
9,300 kWh/year

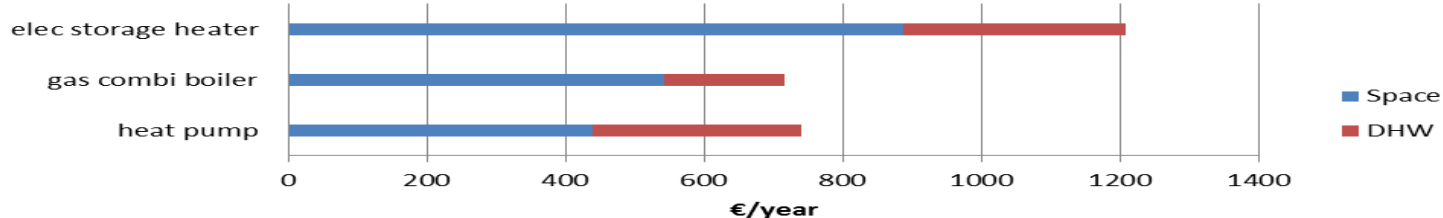
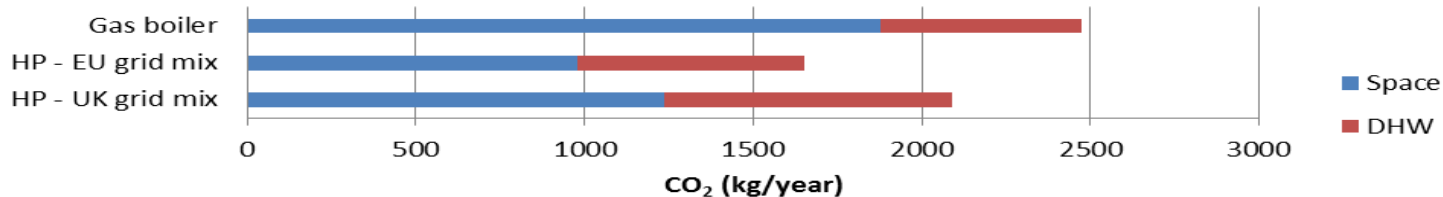


Heat pump

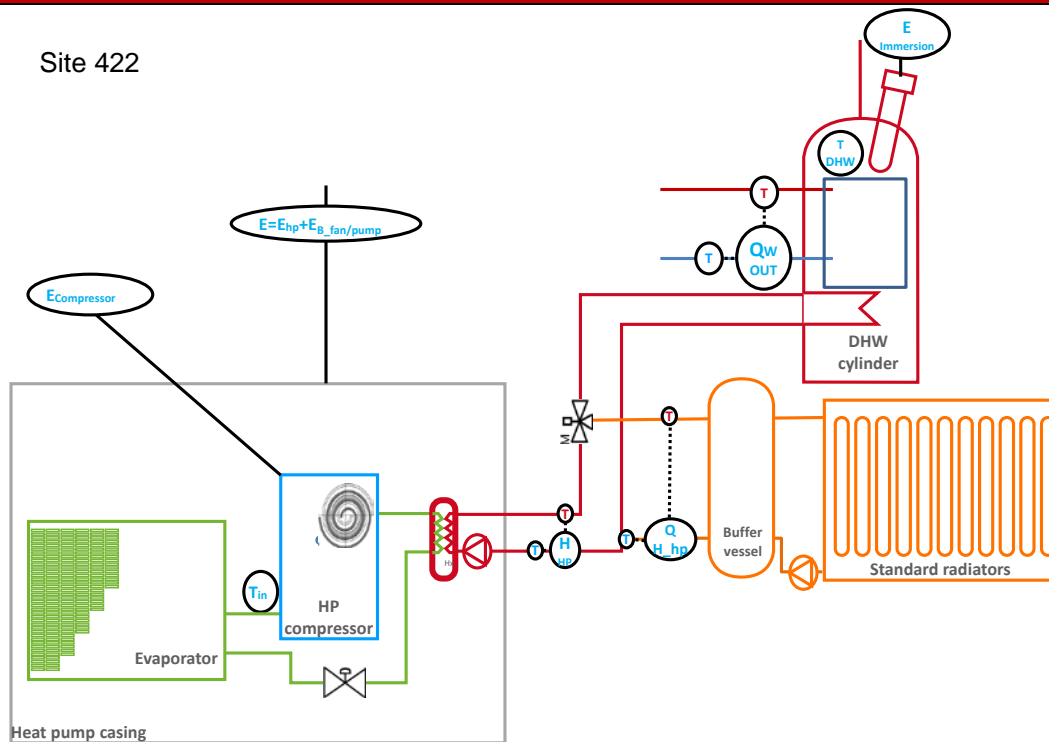


Heat
13,300 kWh/year

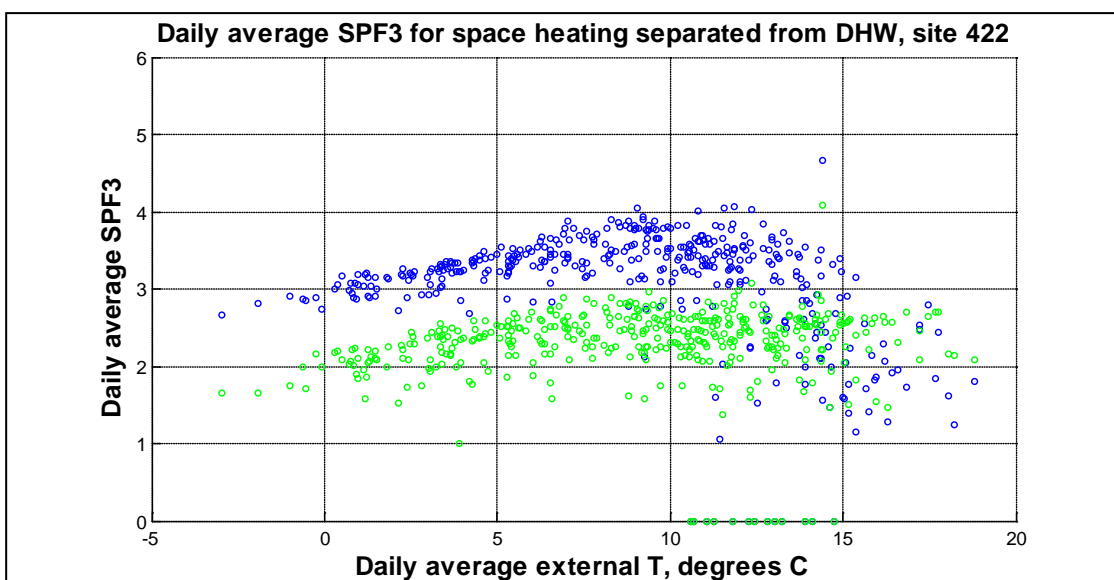
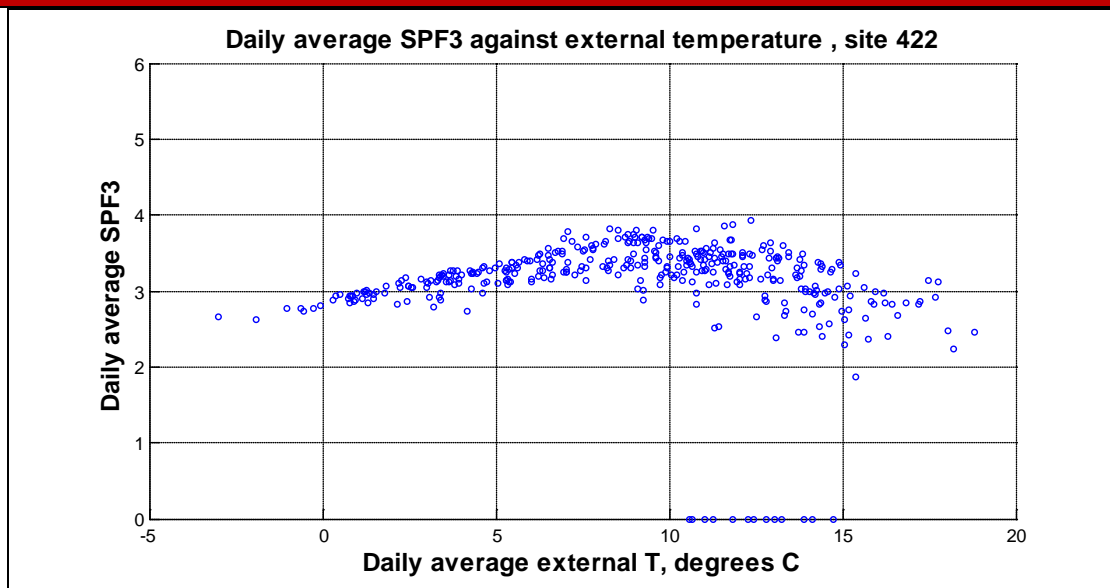
Out of 1kWh electricity the heat pump produces 3.3 kWh useful heat (yearly average or SPF3)



➤ System's schematic



➤ Heat pump performance





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