SEasonal PErformance factor and MOnitoring for heat pump systems in the building sector
SEPEMO-Build

FINAL REPORT

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Summary

This report summarise the achievements of the IEE SEPEMO project, which have been conducted from June 2009 to May 2012.

The high level outcome from this project consists of a set of policy recommendations in support of the RES directive, especially Annex VII and Annex IV of the RES Directive.

The main body of work have included system boundary development for both hydronic systems and A/A systems. These system boundaries cover both heating and cooling mode. A measurement methodology for hydronic systems and A/A systems have also been developed. In order to compare performance, key indicators for HP efficiency benchmarking have been developed, including PER – primary energy ratio, Carnot Efficiency, Specific Energy Demand, DHWR - Domestic hot water ratio and HPSR - Heat pump energy supply ratio.

Field measurements have been carried out in a number of monitoring sites, and results from Austria, Germany, Greece, Netherlands, France and Sweden are presented.

Based on the monitoring results and on experiences from earlier made field monitorings, important factors for improvement of heat pump system performance and quality have been described.

An evaluation method for comparison of heat pump systems with conventional heating systems have also been developed, and a set of guiding principles for the development of installer guidelines have been developed.

Communication activities are reported, including project website, Heat Pump Best Practise Database and other dissemination activities in the project.

Given the large impact heat pumps could have in future European energy systems, the results from this project can be of vital importance for the correct evaluation of the RES contribution from heat pumps in European statistics. It can also serve as a basis for setting relevant requirements on heat pump systems in new and retrofit developments.

Borås, July, 2012

Roger Nordman
Coordinator of the SEPEMO project
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\[ SPF_{C_4} = \frac{Q_C + Q_{C_{BU}}}{E_{S_{fan/pump}} + E_{CU} + E_{W_{pump}} + E_{B_{fan/pump}} + E_{C_{BU}}} \] .......................................................... 22

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Introduction

Current development in the fields of the RES Directive, the EuP-Directive and the EPBD Directive can meaningfully be supported by the results of scientific projects.

In the European Eco-design of Energy using Products (EuP), the projects related to product groups (lots) lot 1 (Refrigerating and freezing equipment) and lot 10 (Air Conditioners and Fans used for comfort cooling) are presently discussing with CEN and with the heating industry what should be the EU reference climate and building conditions to characterize heat pump and other heating means seasonal performances and plan to use these reference values in order to classify different heating systems by order of merit and potentially to give strong signals to the EU heating market.

However, heat pump systems performances largely depend on the climate and quality of installation and not only on the product itself, which is not considered presently in EuP works. One of the outputs of this project has therefore been to supply relevant stakeholders with improved understanding od heat pumps seasonal performance.

There is presently very few data available to confirm that inverter driven units, particularly air to air units behave on field as in laboratory testing conditions because in the case of standard ratings (full or part load), frequency is pre-programmed by the manufacturers. Despite this problem, inverter air to air units are gaining more than 90 % of the market versus on-off cycling units. This project have aimed to diagnose possible differences between laboratory / field experience, findings of very high value for setting EuP implementing measures.

For the EuP Directive, the results from this project can serve as benchmark both for the methodology planned in the Directive to calculate the primary energy efficiency of heat pumps as well as for the setting of class boundaries (cf. www.ecoboiler.org and the suggested methodology and excel spreadsheet by VHK consultants).

This action is closely linked to RES directive , particularly annex VII B, because there is mentioned “No later than 1 January 2013, the Commission shall establish guidelines on how Member States shall estimate the values of $Q_{usable}$ and SPF for the different heat pump technologies and applications, taking into consideration differences in climatic conditions, especially very cold climates”.

The results from this project is a valuable input to the process of estimating SPF for the Annex VII B, and for the EUROSTAT statistics.

For the RES Directive it is important to understand the real performance of heat pumps in different climate zones of Europe. Such an understanding requires the definition and uniform application of systems boundaries, measurement and calculation methodology.

For the EPBD Directive, the results from this project illustrate the impact of changes in the energy demand of whole systems on the energy demand of the heating and hot water production.

The results of SEPEMO could lead to better insight in concepts and the differences in performance. This supports the RES-directive as these insights under the project will lead to guidelines for system quality, which can guarantee the performance of systems based upon SPF. Also it supports the possibility for certification of installers based upon system quality. The Sepemo approach to this has
been to have close collaboration with EHPA through the EUCERT Education Committee in order to expand the course curricula for the EUCERT certification to include deeper knowledge about system performance.

**Specific objective of the action**

The project have aimed at overcoming market barriers to a wider application of HPs, namely the lack of robust data on the conditions in real installations influencing reliability and seasonal efficiency, i.e. the SPF of Heat Pump systems in Europe. One key requirement to achieve awareness about real life performance is a universal methodology for field measurement of HP systems SPF. Such method requires a systems perspective including the efficiency of the HP unit and also the respective regional building standards and climate conditions. Such a method have been developed within this project. Connected to the development of this methodology the project sought to improve the understanding of key parameters influencing the reliability and efficiency of HP systems in residential buildings. By improving this knowledge, broader acceptance of HP systems and improved quality assurance for HP systems in the building sector can be expected.

The project has focused on all types of HPs (air, water and ground) in residential buildings except exhaust air heat pumps.

**Main body of work**

The main body of work conducted in this project has included:

- Collection and evaluation of past and present field measurements on HP systems.
- Evaluation of existing methods for field measurement and calculation of HP systems SPF.
- Development of a common methodology for field measurement of HP systems and calculation of SPF.
- Setting up new field measurements on HP systems using a common methodology, and monitoring for at least one year.
- Improve and extend existing guidelines to include all types of HPs, for installation of HP systems, taking into account regional constraints as well as the building standard.
- Information dissemination.

**Strategic objectives of the action:**

The knowledge about parameters influencing the efficiency of the HP is relatively high. It is a lack of information about real installations. The knowledge about how those parameters influence the design and installation in real systems needs to be improved. The aim has been to improve insight in, and better understand on how the system design and installation influence the parameters which are critical to achieve a high performance and reliability of Heat Pumps in heating and cooling systems.
Policy recommendations in support of the RES directive

Annex VII of the RES Directive

The RES Directive (2009/28/EU) sets out the measures and regulations concerning the use of renewable energy sources, including those used by heat pumps. Article 2 of this Directive defines what ‘renewable energy sources’ (RES) comprise, while article 5, in combination with Annex VII, describes how to calculate the share of energy from renewable sources, delivered by heat pumps. According to the Directive, the Commission is obliged to define a calculation method on how to estimate the renewable energy provided by heat pumps as well as guidelines on how the Member States are to perform data collection on renewable energy. In order to monitor renewable energy targets at EU and Member State level, statistics on the contribution of renewable energy from heat pumps must be made available. DG TREN requested EUROSTAT to develop the statistical system that will allow the identification of the contribution of heat pumps to the RE targets. This includes the preparation of guidelines on how MS will estimate the $Q_{usable}$ and the SPF. EUROSTAT requested input from the involved industry associations - including the EHPA - on the calculation procedure to properly record the renewables share of heat pumps in energy statistics.

While the RES Directive generally covers the use of renewable energy for heating and cooling (Article 5 §1b), it only covers produced heat from heat pumps (cf. Art. 5(4): “aerothermal, geothermal and hydrothermal heat energy […] shall be taken into account”). Thus, a calculation method is only presented for the determination of heat pumps RES share in heating mode (Annex VII):

\[ E_{RES} = Q_{usable} \times \left( \frac{1}{1-SPF} \right) \]

(1) \quad \text{where only heat pumps with SPF > 1,15 * 1/η shall be taken into account.}

In order to calculate the share of renewable energy sources used by heat pumps ($E_{RES}$), one has to have knowledge about both the estimated total usable heat delivered by heat pumps ($Q_{usable}$) and the annual efficiency of the heat pump expressed as Seasonal Performance Factor (SPF).

In most simple terms, the performance can be determined by

\[ SPF = \frac{\text{useful energy}}{\text{energy input}} \]

(3) putting the total energy production (heating and cooling) in relation to the total energy input.

How to determine the «missing» variables $Q_{usable}$ and SPF?

The RES Directive did define neither the SPF nor the $Q_{usable}$ which lead some Member States to the conclusion that the share of RES cannot be calculated until the European Commission and/or EUROSTAT come up with suggestions on which values to use.
While it is rather simple to determine the energy demand of an individual building as well as the efficiency of a heat pump installed (see paragraph 2), resulting data cannot simply be applied to the installed heat pump stock on MS or EU level. Unfortunately no quick and easy solution exists to overcome this issue, as data on the energy demand in the building stock as well as on the performance of heat generators used - including heat pumps - is poor. Most Member States’ statistics on the building stock are not detailed enough for this purpose and if energy statistics include heat pumps, efficiency is usually not documented.

In order to present a useful yet simple method on how to proceed, industry has proposed a first solution based on available data, Figure 1.

The useful thermal energy (Q usable | «heat») provided to buildings is determined by using

- the number of installed HP units per energy source (as documented in the EHPA heat pump statistics),
- an estimated average installed capacity per energy source (agreed upon by industry experts from the three climate zones), and
- the average operating hours (Qusablefactor), again agreed upon by industry experts).

With regard to the seasonal efficiency, the situation is more complex, as available approaches have different targets and choose different system boundaries. In general, seasonal efficiency can be measured in the real installation, or it can be calculated based on a variety of data, including lab tested performance for the individual unit/type.

Independent of the approach, the basic procedure always remains the same as outlined in the formula mentioned above (1). However, depending on the system boundaries, more or less components are included in the calculation/measurement. Even though the difference in results will most likely be marginal, it is important to keep in mind when applied to the existing and future stock of heat pumps.
Figure 2. Figure 2: Example scheme for the system boundaries of a heating system.

Table 1. Comparison of approaches in standards.

<table>
<thead>
<tr>
<th>Component</th>
<th>SPF H₁</th>
<th>SPF H₂</th>
<th>SPF H₃</th>
<th>SPF H₄</th>
<th>EN 14511:2011</th>
<th>EN 15316-4-2</th>
<th>EN 14825</th>
<th>EN 16147</th>
<th>EuP Lot 1-2012</th>
<th>EuP Lot 10-2012</th>
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<td>Compressor</td>
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<td>☒</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Brine fan/pump</td>
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<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>H.L*</td>
<td>H.L*</td>
<td>H.L*</td>
<td>H.L*</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buffer tank/pump</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>SHW fans/pumps</td>
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<td>H.L*</td>
<td>x*</td>
<td>H.L*</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Energetic basis: F=final; P=primary

*H.L = head losses

Table 1 shows a comparison of approaches to determine the seasonal performance of heat pump units. SPF_H₃-H₄ applies to field measurements of system performance in real installations and the system boundaries chosen to determine the impact of system components on efficiency. EN
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EN 16147:2012 and EN 14825:2012 apply to lab measurements of the heat pump unit performance under fixed conditions. EN 14511 is used for fixed speed, electric compression heat pumps. It is enhanced by part load conditions and climate data through EN 14825. EN 15316 does likewise, but much more complex, also integrating the building envelope. While these approaches are calculating the efficiency based on final energy, using primary energy as a basis is introduced by the implementing measures to EuP. This approach is as such not appropriate for the RES Directive, which is based on final energy performance.

**Solution & conclusion**

For the purpose of this Directive a compromise is necessary between applicability and accuracy. There are several options available:

1) Field surveys: Measuring a (large) number of installations could be done based on the SEPEMO methodology. They are however time-consuming and costly.

2) A combination of measurements and calculation: This approach is used in the EuP methodology for boilers, hot water production units and air conditioning units. It allows for comparison, yet it is based on primary energy and as such not usable for estimating the RES contribution.

3) Unit performance measured according to standards: For heat pumps, these standards are available to measure unit performance under lab conditions: EN 14511 and EN 15879 (heating mode), EN 16147 (domestic hot water production: based on a defined tapping cycle), EN 12309 (gas absorption units).

4) Calculated seasonal efficiency based on test data: EN14825 provides an Annex for the calculation of the Seasonal Coefficient of Performance (SCOPnet), based final energy and different climates, also integrating part load operation. It can be applied on existing measurement data.

In conclusion, the SPF in the context of the RES Directive should be understood as the SCOPnet according to EN14825 for the provision of heating and the unit COP according to EN 16147 for the provision of domestic hot water. They can be applied to calculate the renewables share based on the measured unit performance and climate data input/tapping cycle, thereby ignoring the multitude of other influencing factors from user behaviour to the building envelope. Data is available immediately and its precision is deemed sufficiently close to real life data to justify its use.

Using this approach is resulting in a sufficient approximation to reality. However it is not complete: There are heat pump types not covered by these standards, namely hybrids and large units. More work is necessary to fine-tune and extend the coverage of existing standards towards a more complete approach. Field surveys – based on a standard measurement approach and agreed upon system boundaries – will be necessary to support this work.

**Annex IV of the RES Directive**

**Quality and Certification**

The European Directive on Renewable Energy states that: “Member States shall ensure that certification schemes or equivalent qualification schemes become or are available by 31 December 2012 for installers of small-scale biomass boilers and stoves, solar photovoltaic and solar thermal systems, shallow geothermal systems and heat pumps. Those schemes may take into account
existing schemes and structures as appropriate, and shall be based on the criteria laid down in Annex IV. Each Member State shall recognise certification awarded by other Member States in accordance with those criteria.”

As heat pump systems consist of the energy source, heat pump and heat distribution and occur in various concepts it is not easy to develop a straightforward performance certification of systems. The optimal performance is dependent on:

- the quality of the heat pump itself;
- the heating and/or cooling distribution system in the building;
- the design of the heat pump system in relation to the quality of the building envelope;
- the quality of the source design;
- the quality of installation, and
- user characteristics and behaviour.

Figure 3. Heat pump system quality is a complex matter.

On top of the aforementioned, the designers of the heat pump and the heat source and the installer of the system are usually not the same persons. Often they do not even work in the same company. Figure 3 illustrates the complexity of the heat pump systems and different existing labels.

Legislative acts exist or are under construction that govern several aspects of the installation addressing both product performance as well as environmental and safety aspects (pressure vessels, F-gases, ground sources, Ecodesign). Some of them even require certified personnel already (F-Gas Directive, Requirements on maintenance for air conditioning systems under the EPBD).

In various countries legislation, certification and registration drilling of ground sources is being developed or existing. This is often mandatory certification as part of environmental legislation to protect ground water aquifers.
The installer (person and company) need to consider the requirements of the legal framework and the peculiarities of heat pump systems in order to provide quality systems in line with regulation.

It becomes obvious, that different training and competence requirements exist that need to be catered for by individual training programs. Today’s reality is, that at least six certification schemes exist throughout the EU. Certification can be done according to an identical scheme for all heat pump and small RES installers.

![Figure 4. Today, at least six different certification schemes for heat pumps exist on the EU market (Ulla Lindberg, SP, European heat pump summit, Nürnberg, Germany, November 2011).](image)

**System Quality and EUCERT**

The European Certified Heat Pump Installer programme (EUCERT) is the response of manufacturers and industry stakeholders to setting minimum requirements for heat pump installers that are necessary for high quality, efficient and reliable installations. It focuses on implementing a training program for heat pump installers, establishing a certification programme for this target group and disseminating the trademark “certified heat pump installer”.

Experience from the EUCERT program shows that the success of the programme strongly relies on support from the industry (manufacturers/heat pump associations offering a brand independent education scheme) and governments (certified installers as a prerequisite for subsidies, acknowledgement of an increasing share of RES systems in heating and cooling and appropriately adjusting the curricula of education and training). Agreement on one education system supported by relevant industry actors seems to be of particular importance, especially since the RES Directive asks for mutual acceptance of the certificate across Member States. A rapid uptake of education and training programmes, as well as of certification options in the workforce seems to strongly rely on the abovementioned elements.
As a lack of sufficiently educated installers can severely limit market development, it is in the interest of Member States as well as of industry to establish training and certification options at the same time encouraging (new) installers to enrol in them. The number of trainees is small compared the potential requirements in Europe.

The solution could be to make proof of training or even certification mandatory, due to cost and time constraints for the training of all installers. A pragmatic approach is needed to allow a fair number of installers to be trained without posing too big a burden on the installer trade.

The necessary next steps are:

- To establish understanding in the administration of Member States on the compliance of EUCERT with the requirements of Annex IV of the RES Directive and seek official acknowledgement of the programme as an option to fulfil the Directive’s requirements.
- To get the certification in line with the local building codes.
- Find partners in the remaining European Member States to execute the programme.
- Encourage more installers to participate in the training courses and in certification.
- Financial incentives and tax reduction schemes dependent on installations made by certified installers.
- Manufacturers, members of EHPA, or the various national manufacturers’ associations in the various counties, should only deliver to certified installers.

**Conclusions**

Proper training for the installation of heat pump systems is a complex task that is not handled uniformly across Europe. The same holds true for installer certification (both for the installer company and the installer personnel). European heat pump industry has taken up the challenge and operates the most refined scheme (of all RES sources) for installer training and certification. Several national approaches coexist and are up and running in a number of European countries, both for heat pump installation and for design and installation of ground sources. However, for a robust Europe-wide heat pump system quality the following needs to be put in place:

- Participation in EUCERT (and GEOTRAINET) and recognition of these schemes should be expanded to all European countries;
- EUCERT needs to be in line with national building codes and manufacturers’ training activities;
- EUCERT needs to be harmonised with other European standards and certification schemes on heat pump related topics.
- EUCERT should be recognized in each country and used to uniform the different labels in order to avoid confusion for customers as for authorities.
**Work description**

The project objectives have been achieved by the work in the 6 main Work Packages:

**WP 1: Management**

Co-ordination of activities: The project leader (PL) started with a preliminary phase, setting up of work plan, spreading of tasks in the project and definition of information needs. The co-ordinator was responsible for the overall steering of the project, co-ordinating the workflow and supervising overall scope of the WP’s and in so that the aimed overall project results were achieved. The PL developed a structure and a network under which the activities were co-ordinated.

**WP 2: Field measurement of air/water and ground/water based heat pumps**

In this WP, in depth information was gathered and analysed on existing projects with ground source and air source HPs in domestic buildings with hydronic distribution systems. The WPL together with the participants assessed and structured this information and made this information available. That information together with the information gained in the field measurements was used in WP4 and 5 as input for the development of a common methodology and guidelines. This WP ran as a follow up on IEA Annex 29 and GroundReach (the SEPEMO Build project widened the scope compared to GroundReach) and has strong connections with the work done under the EHPA labelling scheme and the EUCERT committee.

**WP 3: Field measurement of air/air based heat pumps**

In this WP, information was gathered and analysed on existing projects with air/air source HPs in domestic buildings. The WPL together with the participants assessed and structured this information and made this information available. That information together with the information gained in the field measurements was used in WP4 and 5 as input for the development of a common methodology and guidelines.

**WP 4: Development of monitoring methodology**

In this WP a methodology was developed as well as definitions for monitoring the Seasonal Performance Factor (SPF) of HP systems in buildings. A method to compare HPs with other heating sources was also be developed. This information serves as a source for creating a basis on international level for:

- Measurement methodologies
- New demonstration projects
- Increasing the performance of systems.

**WP 5: Development of basic heat pump system quality**

In this WP the findings of WP2, 3 and 4 were further analysed and translated into guidelines for the basic quality of high performance systems. These guidelines will be used for training installers and designers, making it able to use the experience for new demonstration projects and monitor the effects. This information serves as a source for creating amongst others a basis on international level for:
• Quality guidelines based upon system performance in line with Annex VII of the RES directive to fully exploit the potential of heat pump systems with high efficiency in the domestic sector.
• Guidelines for the certification of installers, in line with Annex IV of the RES directive, based upon quality guidelines

WP 6: Communication and Dissemination

Dissemination of all results, measured values, reports and guidelines were communicated in workshops and in standardisation committees, as well as in conferences and in meetings with EU policy makers and stakeholders. In addition, the field measurements can be followed from the project website, where also all deliverables are available for download.

Workshops with EU MEP’s and other policy makers as for example members of the commission and policy responsible in DG TREN and DG ENVIRONMENT were carried out to increase the awareness of the importance of correctly measured installations in order to reach the EU 20-20-20 targets.
System boundary development

General

For calculating the SPF for heating and cooling in heat pump systems, the system boundaries have to be set. Defining those boundaries directly impacts the measurement equipment needed to measure the required parameters for the calculation of the different SPF. This SPF-calculation method also facilitates the quantification of the impact of the auxiliary devices like brine pumps and fans on the performance of the heat pump system. Furthermore the quantity of renewable energy supplied by the heat pump system can be calculated and used for EUROSTAT statistics.

Figure 5. SEPIMO system boundary concept.

The definition of the system boundaries influences – in dependency on the impact of the auxiliary devices – also the results of the SPF. Therefore the SPF should be calculated according to different system boundaries. Since the units can operate in heating and/or cooling mode the system boundaries and the SPF-calculation methodology is separated into heating and cooling mode. According to the system boundaries, the SPF can be calculated for cooling, space heating and domestic hot water production. It also enables the comparison of heat pump system and other heating systems like oil or gas by allowing for the calculation of the CO2- and primary energy reduction potential.

For systems with an additional heating system other than an electrical back up heater (e.g. oil, gas or biomass) the quantity of heat and the energy content of the fuel demand have to be determined for the calculation of the SPF according to the system boundaries. For any additional (solar) thermal system, the electric auxiliary energy to run this system has to be measured.

The four defined SPF’s are:

- SPF\(_1\) includes only the heat pump unit itself. Thereby SPF\(_1\) is similar to the average COP for the measured period.

\[
SPF_1 = \frac{Q_{HP}}{W_{HP}}
\]

- SPF\(_2\) consist of the heat pump unit and the equipment needed to make the heat source available the heat pump.

\[
SPF_2 = \frac{Q_{HP}}{W_{HP} + W_{heat\_source\_pump}}
\]

16
SPF2 represents the heat pump system SPF. SPF2 includes the heat pump and the heat source pump as in SPF2, but also the back up heater.

\[ SPF_2 = \frac{Q_{HP} + Q_{\text{back up heater}}}{W_{HP} + W_{\text{heat source pump}} + W_{\text{back up heater}}} \]

SPF4 includes all parts related to SPF3, additionally SPF4 also includes the distribution of the heat.

\[ SPF_4 = \frac{Q_{HP} + Q_{\text{back up heater}}}{W_{HP} + W_{\text{heat source pump}} + W_{\text{back up heater}} + W_{\text{heat sink pump}}} \]

Figure 6. System boundaries for calculations of SPF.

The definitions of the system boundaries considered in the project SEPEMO are a general description for all different heating and cooling systems. Therefore the possibility to realise the measurement can be slightly different for the different systems, although it is possible to have correct comparisons within the different systems e.g. Air/Water with another Air/Water system.

There are different existing standards and regulations for calculating the SPF. These calculation methodologies are mainly based on input from the testing standard EN 14511. The system boundaries of testing standards are however focused on the heating or cooling unit itself. In comparing test results, the system integration is not taken into account. Therefore these standards do not include the entire energy consumption of the auxiliary drives on the heat sink and heat source side. Due to the different framework conditions, there are differences between field testing and testing on a test rig, which can’t be avoided due to reasons of practicability. Those differences shall be pointed out. The main difference in the evaluation methodologies originates from the evaluation subject. While testing on a test rig is focused on the unit, the field measurements are determined by the system. Hence, the system boundaries for testing and field measurements will be slightly different and therefore have to be considered when comparing calculated and field measured SPF. Within the project the following differences concerning the nomenclature of SPF, COP, EER, SCOP and SEER has been defined:

- SPF – evaluation of field measurement data according to the defined system boundaries
- COP/EER – measurements on test rigs according to certain standards or regulations e.g.: EN 15411, EHPA-Quality label
- SCOP/SEER - calculation out of testing results
Hydronic systems

System boundaries – heating mode:

SPFH1:
This system contains only the heat pump unit. SPFH1 evaluate the performance of the refrigeration cycle. The system boundaries are similar to COP defined in EN 14511 [1], except that the standard takes, in addition, a small part of the pump consumption to overcome head losses, and most part of fan consumption.

SPFH2:
This system contains of the heat pump unit and the equipment to make the source energy available for the heat pump. SPFH2 evaluate the performance of the HP operation, and this level of system boundary responds to SCOP\textsubscript{NET} in prEN 14825 [2] and the RES-Directive [3] requirements\textsuperscript{1}.

Note: COP in EN 14511 and SCOP\textsubscript{NET} in prEN 14825 are more or less between SPF\textsubscript{H1} and SPF\textsubscript{H2} (see table 1 at the end of the document)

SPFH3:
This system contains of the heat pump unit, the equipment to make the source energy available and the back up heater. SPF\textsubscript{H3} represents the heat pump system and thereby it can be used for comparison to conventional heating systems (e.g. oil, gas,...). This system boundary is similar to the SPF in VDI 4650-1 [4], EN 15316-4-2 [5] and the SCOP\textsubscript{ON} in prEN 14825. For monovalent\textsuperscript{2} heat pump systems SPF\textsubscript{H3} and SPF\textsubscript{H2} are identical.

SPFH4:
This system contains of the heat pump unit, the equipment to make the source energy available, the back up heater and all auxiliary drives including the auxiliary of the heat sink system. SPF\textsubscript{H4} represents the heat pump heating system including all auxiliary drives which are installed in the heating system.

SPF-calculcation – heating mode:
In this chapter the formulas for calculating the SPF for heating mode together with the energy flowcharts for the different system boundaries are described.

\textsuperscript{1} For compact heat pumps having built-in electric backup heaters, this would constitute a problem, since the SPF is normally attributed the product, and then SPF\textsubscript{H3} is easier to evaluate in praqctice..

\textsuperscript{2} Monovalent heat pumps are heat pumps without supplemental (backup) heating.
Figure 7. Energy flow chart for the heating mode.

\[ SPF_{H1} = \frac{Q_{H_{hp}} + Q_{W_{hp}}}{E_{HW_{hp}}} \]

\[ SPF_{H2} = \frac{Q_{H_{hp}} + Q_{W_{hp}}}{E_{S\_fan/pump} + E_{HW_{hp}}} \]

\[ SPF_{H3} = \frac{Q_{H_{hp}} + Q_{W_{hp}} + Q_{HW_{bu}}}{E_{S\_fan/pump} + E_{HW_{hp}} + E_{HW_{bu}}} \]
System boundaries – cooling mode:

SPF\textsubscript{C1}:

This system contains only the cooling unit. SPF\textsubscript{C1} evaluate the performance of the refrigeration cycle. The system boundaries are similar to EER defined in EN 14511 [1], except that the standard takes, in addition, a small part of the pump consumption to overcome head losses, and most part of fan consumption.

SPF\textsubscript{C2}:

This system contains the cooling unit and the equipment to dissipate the heat energy. The system boundaries compares to SEER\textsubscript{ON} in prEN 14825 [2].

Note: EER in EN 14511 and SEER\textsubscript{ON} in prEN 14825 are more or less between SPF\textsubscript{C1} and SPF\textsubscript{C2} (see table 1 at the end of the document)

SPF\textsubscript{C3}:

This system contains the cooling unit, the equipment to dissipate the heat energy and all auxiliary drives of the cooling system. SPF\textsubscript{C3} represents the cooling system including all auxiliary drives which are installed in the cooling system.

SPF\textsubscript{C4}:

This system contains the cooling studied cooling system and possible additional cooling systems. In this analysis it is assumed that additional, supplementary, cooling systems are autonomous from the studied system. This level corresponds to the total cooling system performance for a building.
**SPF calculation – cooling mode:**

In this section the formulas for calculating the SPF for cooling mode together with the energy flowcharts for the different system boundaries are described.

\[
SPF_{C1} = \frac{Q_c}{E_{CU}}
\]

\[
SPF_{C2} = \frac{Q_c}{E_{S,fan/pump} + E_{CU}}
\]

Figure 8. Energy flow chart for the cooling mode.
\[ SPF_{C3} = \frac{Q_C}{E_{S\_fan\_pump} + E_{CU} + E_{B\_pump} + E_{B\_fan\_pump}} \]

\[ SPF_{C4} = \frac{Q_C + Q_{C\_BU}}{E_{S\_fan\_pump} + E_{CU} + E_{B\_pump} + E_{B\_fan\_pump} + E_{C\_BU}} \]
**SPF calculation – simultaneous cooling and heating mode:**
For systems operating simultaneously in cooling and heating mode, e.g. for domestic hot water production, the fraction of heat delivered to the system has to be taken into account when calculating the different combined SPF according to the system boundaries.

**A/A systems**

**System boundary for heating mode**
Figure 3 shows the different system boundaries for heating mode described in an energy flowchart. The general formula for calculating the SPF in heating mode is defined as:

\[
SPF_H = \frac{\sum Q_H}{\sum E}
\]

![Figure 9. Energy flow chart for the heating mode.](image)

**System boundary for cooling mode**
Figure 4 shows the different system boundaries for cooling mode described in an energy flowchart. The general formula for calculating the SPF in cooling mode is defined as:

\[
SPF_C = \frac{\sum Q_C}{\sum E}
\]
Figure 10. Energy flow chart for the cooling mode.
Measurement methodology

General
In this project we have observed the “real” operation and if necessary or/and possible have used the information to improve the efficiency in the case of obvious problems in the system or heat pump. Such changes have always been documented Only this way we can learn how to make the operation of heat pumps better.

In order to implement a common system evaluation, it is not mandatory to use the same measurement equipment, but it is obligatory that during the measurements the same parameters have been recorded with comparable accuracy. The need for different measurement equipment derives from the different system boundaries. Therefore it is important to define what to measure in order to apply SPF calculations and to provide information about the measurement quality needed (accuracy, sampling intervals, measurement equipment quality (sensors), etc). Additionally proper equipment integration into the system is needed in order to gain accurate measurement data.

In deliverable D4.1 “guideline for heat pump field measurements” a methodology to provide comparable field monitoring data from different types of heat pump systems has been developed. The common monitoring procedure is based on three steps:

- Detailed test site specification and user/installer log about the non-measurable data
- Measuring of data by a data logger directly on site
- Evaluation of the system

![Figure 11. Monitoring procedure.](image-url)
Generally there are measurable and non-measurable data. For characterizing the building and the system the detailed test site specification gives additional information. Additionally a “log book” for the user and installer reports about different occurrences during the measurement season. This additional information makes the evaluation and interpretation of the measurement data easier. The measurable data define the operating behaviour and the efficiency of the system.

The logging interval depends on different approaches and measurement methods. For calculating mainly SPF, the logging interval can be less frequent e.g. 10 minutes like recommended by the “logging interval SEPEMO”. A/W and A/A systems need a smaller logging interval due to their short defrost cycles. If the main purpose of the monitoring is focused on different system operations, it is necessary to reduce the logging interval to e.g. 1 minute, to be able to record small changes in the system during operation.

Table 2. Measurement and logging intervals.

<table>
<thead>
<tr>
<th>Measuring interval</th>
<th>Logging interval SEPEMO</th>
<th>Logging interval operation interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/W and A/A</td>
<td>5 s</td>
<td>1 min.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 min.</td>
</tr>
<tr>
<td>DX/W</td>
<td>5 s</td>
<td>10 min.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 min.</td>
</tr>
<tr>
<td>B/W</td>
<td>5 s</td>
<td>10 min.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 min.</td>
</tr>
<tr>
<td>W/W</td>
<td>5 s</td>
<td>10 min.</td>
</tr>
</tbody>
</table>

In practice sensor accuracies need to be specified using a combination of prior knowledge of the accuracies of commonly available sensors and the analysis which will be applied to the data. The table below summarises the accuracies and resolutions required to provide useful information at a one or ten minute data recording interval.

Table 3. Measurement accuracy and resolution.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Accuracy</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity consumption compressor</td>
<td>±2%</td>
<td>1 imp/Wh</td>
</tr>
<tr>
<td>Electricity consumption auxiliary drives</td>
<td>±2%</td>
<td>10 imp/Wh</td>
</tr>
<tr>
<td>Heat output</td>
<td>±2%</td>
<td>1 imp/Wh</td>
</tr>
<tr>
<td>Fluid temperatures</td>
<td>±0.15°C</td>
<td>0.01°C</td>
</tr>
<tr>
<td>Internal air temperatures</td>
<td>±0.4°C</td>
<td>0.1°C</td>
</tr>
<tr>
<td>External air temperatures</td>
<td>±0.4°C</td>
<td>0.1°C</td>
</tr>
</tbody>
</table>

Hydronic systems
For a common monitoring evaluation the following “minimum results” should be mandatory, in order ensure the comparability of the different systems. It is important to get additional information to the SPF (e.g. average supply temperature, indoor temperature,...) to understand under which operating conditions the heat pump system was operated.
Table 4. Minimum required results from monitoring.

<table>
<thead>
<tr>
<th></th>
<th>A/W</th>
<th>DX/W</th>
<th>B/W</th>
<th>W/W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric energy input – total</td>
<td>kWh</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Electric energy input backup heater</td>
<td>kWh</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Electric energy input pumps/fans heat source side</td>
<td>kWh</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Electric energy input pumps/fans heat sink side</td>
<td>kWh</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Energy output heating / cooling</td>
<td>kWh</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Energy output DHW</td>
<td>kWh</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>SPF2</td>
<td>-</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>SPF3</td>
<td>-</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Average supply temperature heat sink*</td>
<td>°C</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Average return temperature heat sink*</td>
<td>°C</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Average supply temperature DHW*</td>
<td>°C</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Average return temperature DHW*</td>
<td>°C</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Average supply temperature heat source*</td>
<td>°C</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Average return temperature heat source*</td>
<td>°C</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Average outdoor temperature*</td>
<td>°C</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Average indoor temperature*</td>
<td>°C</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

*during operation of the unit

According to the different system boundaries, different requirements on the mandatory equipment are given. The mandatory measurement equipment can be separated into two parts: firstly the energy meters for calculating the SPF according to the system boundaries and secondly the temperature/humidity/pressure-sensors to gather information on the boundary conditions under which the system was operated during the measurement season.
The mandatory equipment is highlighted in green. The equipment marked light grey is optional to gather additional information on the system operation.

In some countries, in cooling mode it is mandatory to measure the heat released by the ground probe to the ground. This is not a necessary device for monitoring the SPF, but will give additional information about the system performance.

**A/A systems**

The measurement approach required consists of determining the heat delivered by, and electrical energy consumed by, the heat pump.

In the following Figure 7 the mandatory measurement sensors to analyse the system according to the different system boundaries are described for space heating and cooling.
Figure 13. Measurement sensors.

According to the different system boundaries different requirements on the mandatory equipment are given. The mandatory equipment in Figure 7 is highlighted in green. The equipment marked light grey is optional to get additional information about the system operation.

The mandatory measurement equipment can be separated into two parts, first the energy meters for calculating the SPF according to the system boundaries and second the temperature, humidity, and air flow rate sensors to get information about the boundary conditions under which the system was operating during the measurement season:

- **Energy meter:**
  - the electricity consumed by the heat pump compressor, controls and fans
  - the heat delivered to (or removed from) the indoor space: computed from the measurement of the enthalpy difference between the inlet and outlet air stream of the indoor unit and the air flow rate of the indoor unit

- **Physical performance measurements:**
  - outdoor air temperature
  - outdoor air humidity
  - potentially the indoor air temperature at temperature control location

For a common monitoring evaluation the following results (Table 5) should be mandatory, in order to be able to compare the different systems. It is important to get additional information to the SPF (e.g. average supply temperature, indoor temperature,...) to understand under which operating conditions the heat pump system was running.
Table 5. Required results A/A measurements.

<table>
<thead>
<tr>
<th>A/A</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric energy input - total</td>
<td>kWh x</td>
</tr>
<tr>
<td>Electric energy input backup heater</td>
<td>kWh x</td>
</tr>
<tr>
<td>Electric energy input fans heat source side</td>
<td>kWh</td>
</tr>
<tr>
<td>Electric energy input fans heat sink side</td>
<td>kWh</td>
</tr>
<tr>
<td>Energy output heating / cooling</td>
<td>kWh x</td>
</tr>
<tr>
<td>SPF according the system boundaries</td>
<td>- x</td>
</tr>
<tr>
<td>Average supply temperature heat sink*</td>
<td>°C x</td>
</tr>
<tr>
<td>Average return temperature heat sink*</td>
<td>°C x</td>
</tr>
<tr>
<td>Average supply temperature heat source* (outdoor temperature)</td>
<td>°C x</td>
</tr>
<tr>
<td>Average return temperature heat source*</td>
<td>°C</td>
</tr>
<tr>
<td>Average outdoor specific humidity*</td>
<td>g/kg</td>
</tr>
<tr>
<td>Average indoor temperature*</td>
<td>°C x</td>
</tr>
</tbody>
</table>

*during heating/cooling season (operating season)
Key indicators for HP efficiency benchmarking
The efficiency of heat pumps systems represented as SPF is mainly influenced by the operating conditions and the set system boundaries for calculating the SPF. Therefore it is important to define minimum results for field trials in order to get a hint under which conditions the heat pump was operated. Furthermore it is necessary to calculate the SPF according to different system boundaries display the impact of the auxiliaries integrated in the system. For a better interpretation of the heat pump performance, SPF does not give the whole picture. Additional parameters should be used to point out the operating conditions of the system:

- PER – primary energy ratio
- Specific Energy Demand
- Carnot Efficiency
- DHWR - Domestic hot water ratio
- HPSR - Heat pump energy supply ratio

The deliverable “D4.4 Benchmarking method of seasonal performance under consideration of boundary conditions” presents a methodology for benchmarking the seasonal performance under consideration of the boundary conditions the system is running.

PER – primary energy ratio
There are different characteristic factors for benchmarking the systems according to primary energy, final energy, usable energy, SPF, PEF and PER.
Figure 14. The PER points out how much usable energy can be generated per primary energy input.

\[
\text{PER} = \frac{\text{usable energy [kWh]}}{\text{primary energy [kWh]}}
\]

**Carnot Efficiency**

The Carnot efficiency is the relation between the efficiency under real conditions and the theoretically maximum reachable efficiency.

The theoretical performance of heat pumps is often referred to the COP\text{Carnot}. Together with the measured COP\text{real}, \( \varepsilon_{\text{Carnot}} \) can be calculated. This parameter enables benchmarking the system and analysing if the heat pump unit is operating properly.

\[
\text{COP}_{\text{Carnot}} = \frac{T_1}{T_1 - T_2}
\]

Equation 1

\[
\varepsilon_{\text{Carnot}} = \frac{\text{COP}_{\text{real}}}{\text{COP}_{\text{Carnot}}}
\]

Equation 2
The COP for an heat pump depends on the temperature lift between heat source and heat sink. The Carnot-efficiency varies from 0.3 to 0.5 for small electric heat pumps and 0.5 to 0.7 for large, very efficient electric heat pump systems.

![Carnot Efficiency](image)

*Figure 15. Carnot Efficiency.*

Modern heat pump units for single family houses should reach the following $\varepsilon_{\text{Carnot}}$ depending on the heat source:

- outside air: $\varepsilon_{\text{Carnot}} = 0.40$
- ground: $\varepsilon_{\text{Carnot}} = 0.45$
- ground water: $\varepsilon_{\text{Carnot}} = 0.50$

The calculation of the Carnot Efficiency based on SPF for analysing heat pumps systems has to be slightly adopted as the calculation parameters will change from COP to SPF. For the calculation the average temperatures measured during operation of the unit have to be considered.

$$\text{SPF}_{\text{Carnot}} = \frac{T_1}{T_1 - T_2}$$

* $T_1$: average supply temperature heat sink during heat pump operation
* $T_2$: average supply temperature heat source during heat pump operation
\[
\varepsilon_{\text{Carnot-SPF}} = \frac{\text{SPF}_{\text{H3/C3}}}{\text{SPF}_{\text{Carnot}}}
\]

The advantages of presenting the data of SPF_{H3/C3} in combination with the Carnot Efficiency are:

- showing the quality/efficiency of the heat pump unit during operation
- using \( \varepsilon_{\text{Carnot-SPF}} \) as characteristic factor for showing the performance of the heat pump unit
- proving the operating conditions without showing operating temperatures e.g.:
  - high SPF_{H3/C3} + average \( \varepsilon_{\text{Carnot-SPF}} \): average heat pump unit efficiency + good system integration
  - low SPF_{H3/C3} + average \( \varepsilon_{\text{Carnot-SPF}} \): average heat pump unit efficiency + poor operating conditions for the heat pump

**Specific Energy Demand**
The specific energy demand is based on the measured usable energy delivered by the heat pump system to the building, the final energy demand of the heat pump system and heated/cooled building area. Using specific values makes it possible to compare the energy demand of different system independently of the capacity of the system.

- specific heating demand \[\text{specific heating demand} = \frac{\text{usable energy [kWh]}}{\text{heated /cooled area [m}^2]\text{]}}\]

- specific electric energy demand \[\text{specific electric energy demand} = \frac{\text{final energy [kWh]}}{\text{heated /cooled area [m}^2]\text{]}}\]

**DHWR - Domestic hot water ratio**
Depending on the supply temperature for space heating, the DHW preparation will have an influence on the SPF. Therefore the domestic hot water ratio DHWR is calculated to shows how much of the useable energy is used for DHW.

\[\text{DHWR} \% = \frac{\text{usable energy}_{\text{DHW}} [\text{kWh}]}{\text{usable energy}_{\text{SH}} + \text{usable energy}_{\text{DHW}} [\text{kWh}]}\]
HPSR - Heat pump energy supply ratio

For bivalent heat pump systems the heat pump energy supply ratio HPESR shows how much of the usable energy is supplied by heat pump and the backup heater.

\[
\text{HPESR} \ [	ext{%}] = \frac{\text{usable energy}_{hp} \ [\text{kWh}]}{\text{usable energy}_{hp} + \text{usable energy}_{bu} \ [\text{kWh}]} 
\]
Field measurements

Monitoring sites
In total, 52 sites were monitored in the SEPEMO project. Out of these 52 sites, we were able to publish one-year monitoring results from about 44. The rest of the sites were not possible to report due to e.g. too high amount of data missing or end user unwillingness to show data. The sites geographical locations are shown in Figure 9. To zoom in on the locations, please refer to the SEPEMO website, www.sepemo.eu.

![Geographical location of SEPEMO monitored sites.](image)

Results
In the sepemo project, we have monitored and reported calculated SPF values for all system boundaries. However, for presentation purposes, we have decided to present SPF_H3 values for heating. This system boundary corresponds to the heating system except the heat distribution inside the building.

Out of the 44 sites where we could present final monitoring data, 8 sites recorded SPF values
below 2.6. Only four sites showed values between 2.6 – 3.0, and the remaining sites showed SPF values above 3.0. The site with the absolutely highest SPF value was a site having DX/water source and floor and wall heating system, with no DHW production. This site recorded an incredible 7.3 SPF. As can be seen in Figure 17, a large number of sites presented SPF H3 values of above 4. These sites have generally in common that they are designed for full heat pump coverage, i.e. they are designed to meet full demand without using electric backup heaters, and they generally have low temperature distribution systems, e.g. underfloor heating systems. This way the condensing temperature for the heat pump can be kept low, and correspondingly, COP’s during operation can be kept high.

![Figure 17. SPF values for monitored GSHP and ASHP in the project.](image)

Table 6 summarise the A2A heat pump test sites in the project. For each test site, more information can be found in the Fact sheets on the SEPEMO Build project website. When finalizing this report, part of the data was not yet available, namely sites SE1, SE7 and SE8. For the French test sites, numerous monitoring problems occurred. In cases of sites FR3, FR6 and FR8, data gathered cannot be used. For other sites, in most cases, part of the heating season is missing, from a few days only in some cases, to several weeks. However in these latter cases, it is still possible to compute a seasonal performance factor for part of the year.
Table 6. SEPEMO Build project field test sites for air-to-air heat pumps: description.

<table>
<thead>
<tr>
<th>Climate</th>
<th>SE1</th>
<th>SE7</th>
<th>SE8</th>
<th>FR3</th>
<th>FR5</th>
<th>FR6</th>
<th>FR7</th>
<th>FR8</th>
<th>FS11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year of construction / retrofit</td>
<td>Cold</td>
<td>Cold</td>
<td>Cold</td>
<td>Average</td>
<td>Average</td>
<td>Average</td>
<td>mildly Warm</td>
<td>Average</td>
<td>&gt; 1980 / 2000</td>
</tr>
<tr>
<td>Heated / cooled area</td>
<td>153</td>
<td>147 m²</td>
<td>135 m²</td>
<td>Unknown</td>
<td>141 m²</td>
<td>120-140 m²</td>
<td>~ 140 m²</td>
<td>~ 60 m²</td>
<td>~ 152 m²</td>
</tr>
<tr>
<td>Building type</td>
<td>House</td>
<td>House</td>
<td>House</td>
<td>House</td>
<td>House</td>
<td>House</td>
<td>House</td>
<td>Multi storey flat</td>
<td>House</td>
</tr>
<tr>
<td>A/A HP indoor units</td>
<td>Non ducted</td>
<td>Non ducted</td>
<td>Non ducted</td>
<td>Non ducted</td>
<td>Non ducted</td>
<td>Non ducted</td>
<td>Non ducted</td>
<td>Non ducted</td>
<td>Ducted</td>
</tr>
<tr>
<td>A/A HP indoor units</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>A/A HP outdoor units</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>A/A HP rated capacity</td>
<td>5 kW</td>
<td>3.6 kW</td>
<td>5.0 kW</td>
<td>10 kW (est.)</td>
<td>7.5 kW (est.)</td>
<td>16.2 kW</td>
<td>20 kW (est.)</td>
<td>4.2 kW (x2)</td>
<td>6.8 kW</td>
</tr>
<tr>
<td>A/A HP control</td>
<td>Inverter</td>
<td>Inverter</td>
<td>Inverter</td>
<td>Inverter</td>
<td>Inverter</td>
<td>Inverter</td>
<td>Inverter</td>
<td>Inverter</td>
<td>Inverter</td>
</tr>
<tr>
<td>A/A HP refrigerant</td>
<td>R410A</td>
<td>R410A</td>
<td>R410A</td>
<td>R410A</td>
<td>R410A</td>
<td>R410A</td>
<td>R410A</td>
<td>R410A</td>
<td>R410A</td>
</tr>
<tr>
<td>Complementary heating system</td>
<td>direct electric radiators</td>
<td>Wood stove, oil filled radiators, floor electrical heating (kitchen)</td>
<td>floor heating, direct electric radiators</td>
<td>Gas boiler</td>
<td>Wood stove</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>Gas boiler</td>
</tr>
<tr>
<td>Cooling</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

For the results below, it is important to notice that all measurement results analyzed are based on the proposed Armines method, which principle is detailed in SEPEMO deliverable 4.2 and synthetized in the chapter 3 of this report. Uncertainties with this method are relatively high, estimated to be smaller then +/- 15%. The main cause is linked to the necessity to measure the air flow continuously, as explained in the SEPEMO deliverable 4.2.

Although the high uncertainty of the reported values, all monitored A2A heat pumps show SPF H3 values well above 3. Even with a 15% error margin as depicted in Figure 18 the results are indeed good.
Figure 18. SPF values for monitored A2A HP's in the project.

Below, monitored values for each site is presented in more detail using the SEPEMO methodology. These results are in this report only summarised, so for a more detailed information on each site, the reader is referred to the sepemo website, section field test sites, [http://www.sepemo.eu/field-test-sites/](http://www.sepemo.eu/field-test-sites/), where all detailed information is reported.
Figure 19. SPF for all monitored SEPEMO sites. The dashed green line represent RES threshold value in 2010.
Results from Austria
Since AIT was the lead partner for the WP4 methodology development, a more detailed presentation of the results has been made, applying many of the developed methodologies.

In Austria 7 heat pump systems have been measured and evaluated according the SEPEMO methodology. All measured systems are integrated in single family houses with an capacity range of the heat pump units between 8,8 and 16 kW nominal heating capacity. The detailed site information and measurement results are available on the project website and in the fact sheets of the individual sites.

Table 7. Summary of Austrian monitoring sites.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<tr>
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<td>Puchenau</td>
<td>Öed</td>
<td>Nebelberg</td>
<td>Königstetten</td>
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<td>0411 - 0412</td>
<td>0911 - 0412</td>
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<td>0511 - 0412</td>
<td>1011 - 0412</td>
<td>0911 - 0412</td>
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<tr>
<td>HP Type</td>
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<td>A/W split</td>
<td>B/W</td>
<td>DX/W</td>
<td>W/W</td>
<td>B/W</td>
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<tr>
<td>nominal capacity</td>
<td>E4/W35 8,8 kW</td>
<td>L2/W35 11,6 kW</td>
<td>L2/W35 14 kW</td>
<td>B0/W35 12,1 kW</td>
<td>E4/W35 16 kW</td>
<td>W10/W35 9,7 kW</td>
<td>B0/W35 12 kW</td>
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<td>floor heating</td>
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<td>floor heating</td>
<td>floor heating</td>
<td>floor / radiators</td>
</tr>
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<td>n</td>
<td>n</td>
<td>n</td>
<td>n</td>
<td>y (passiv)</td>
</tr>
<tr>
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All the field sites have been set up for measurements in the beginning of 2011. Due to some technical difficulties the detailed data acquisition of 4 out of the 7 sites started in summer 2011.

The following diagram shows the evaluated SPF of the different heat pump systems calculated according to D4.2. Additionally the Carnot efficiency $\varepsilon_{\text{Carnot}}$ of the systems is shown according to D4.4. The SPF_H3 for ground coupled systems reached typical values higher than 4 and for outside air systems higher than 3. Also the evaluated $\varepsilon_{\text{Carnot}}$ gives results between 30 % and 60 %, which fits to average $\varepsilon_{\text{Carnot}}$ for modern heat pump units for single family houses according to D4.2. The really high SPF_H3 of site number 5 can be explained by perfect system integration, low heat sink temperatures and a modular capacity controlled heat pump unit.
The electric energy demand of the auxiliary drives in the heat pump system in combination with the different system boundaries shows the impact of the auxiliary drives on the SPF. For site number 6 the electric energy demand of the ground water pump has a big impact on the SPF which drops from SPF_H1 of 5,6 to SPF_H3 of 4,7, which means a reduction of 16 %. Taking all auxiliary drives into account SPF_H1 decreases by 28 % to SPF_H4 of 4,0.

According to D4.4 the PER of the systems are evaluated according to system boundary 2 and 3. As non of the systems have been operated with back up heaters PER_2 and PER_H3 show the same results. The calculated PER of the individual systems ins mainly influenced by the system efficiency SPF and the Primary energy factor $f_p$ as discussed in D4.4. The result of PER_H2 and PER_H3 of the different sites are between 1,01 and 2,20.
Figure 22. PER calculations for the monitored sites.

Based on D4.3, where the calculation of the CO₂-emissions is explained, the specific CO₂-emissions related to the heated area and the thermal usable energy delivered by the system are evaluated. The specific CO₂-emissions of the systems enable the comparison of different sites independet of the building size and the heat pump capacity. The results for the specific CO₂-emissions related to the heated area are between 5 and 24 kg CO₂/m². Taking the thermal usable energy delivered by the system as basis the specific CO₂-emissions are within a range of 0,08 and 0,19 kg CO₂/kWh.

Figure 23. Specific CO₂ emissions for the monitored sites.

The specific energy demand is based on the measured usable energy delivered by the heat pump system to the building, the final energy demand of the heat pump system and heated/cooled building area as described in D4.4. Using specific values makes it possible to compare the energy demand of different system independently of the capacity of the system. The specific heating...
The specific energy demand of the sites also represents the thermal building quality which is a range of 31 and 112 kWh/m².

Figure 24. Specific energy demand for the monitored buildings.

The domestic hot water ratio DHWR of the systems shows how much of the useable energy is used for DHW production. Only in the systems number 1, 4, 6 and 7 the heat pump was operating in space heating and DHW mode. The DHWR for these systems is in a range between 13 % and 26 %. Additionally for bivalent heat pump systems the heat pump energy supply ratio HPESR is calculated to show how much of the usable energy is supplied by heat pump and the backup heater. As all seven site have not been operated with back up heaters the HPESR is allways 100 %.

Figure 25. Domestic hot water ration and Energy supply ratio.

The systems under investigstion showed representable results concerning the SPF. Especially site number 7 showed a very high efficiency. It seems that the most simple site, without a buffer tank and
no buffer tank pump, could reach the best performance. Further important factors are a capacity controlled heat pump and the low heat sink temperatures.

Generally the experience about reliability of the systems was very good as no malfunction of the systems occurred during the measurement season. There were only some minor problems with the control strategies e.g.:

- the heat pump system for heating and active cooling changed the operation mode from cooling to heating in summer and from heating to cooling during winter. This might have been caused by an suboptimal control algorithm. It is recommended to check / readjust the system to prevent the operation in cooling mode during winter and heating mode in summer for optimization of the behavior and efficiency of the system.
- when the air to water systems changed to defrost mode, the circulation pump of the heating circuit sometimes was in operation. The thermal energy for defrost was partially provided by the heating circuit itself and not exclusively by the buffer tank.

Results from Germany

One-family house, Düsseldorf
The GSHP system consists of one ground source heat pump coupled to three vertical drillings (32m each, 96m in total). The system provides heating/cooling and domestic hot water to a single family building in Düsseldorf, Germany. The heat pump is equipped with a capacity modulating brine pump. The heat distribution system consists of a floor heating system with decreased pipe distance (max 15cm, 7,5cm in bathrooms). There is no storage tank for the heating system and no individual room thermostats. Temperature in each room can be adjusted by the flow rate of the floor heating. For hot water, the system has a 362l tank. For remote control and maintenance, the heat pump is equipped with a web-server and connected to the internet via DSL link. The controls unit itself has an RJ 45 interface and a USB port.

The system is not equipped with any additional measurement devices. It is a standard heat pump that is using sensor valves to determine the pressure differences and refrigerant flow in the unit to deduct the heat produced by the refrigerant cycle. The heat produced is the energy produced by the refrigeration cycle. Electricity consumption is measured via a separate electric meter. This meter is also a requirement to benefit from a special heat pump tariff. This set-up is typical for heat pumps sold in Germany.

The Seasonal Performance Factor (SPF) is calculated based on meter readings and the thermal energy produced by the heat pump itself. In the SEPETO system, it is an SPF3 for heating and cooling. The graph shows the development of these reading since the heating system was first switched on in fall 2009. The average efficiency since 30 October 2009 is 4.27.
One-family house, Allmendingen

The air source heat pump (ASHP) is installed in a new building with a low energy demand. The heat pump is installed outside and provides both, space heating and domestic hot water (DHW). An additional electrical back-up heater is installed in the DHW-storage and in the buffer storage, however, both operated according to an individually adjusted control strategy. The heat transfer is realized by floor heating which allows for low inlet temperatures. The buffer storage which is installed in series improves the operation time in the transitional period and ensures the defrosting mode.

This object is monitored as part of the “WP Monitor” project which started in 2009. “WP Monitor” is a German monitoring project run by the Fraunhofer ISE in Freiburg. The aim of the project is to collect real performance data of various buildings equipped with different heat pumps. The monitoring project “WP Effizienz” which ended in 2010 serves as a good basis for the present project as the knowledge gained about the measurement is useful for the classifications of the presently measured heat pumps. Here ASHPs reached an average SPF of 2.9 (2.3...3.4). The energy share for space heating amounts to 82% whereas the average temperature was 36°C (DHW: 52°C).
One-family house, Bedburg-Hau
The heating system is installed in a new building with a low energy demand. The system consists of one heat pump for each operation mode. A ground source heat pump (GSHP) provides energy for space heating and is coupled with a heat source system consisting of three vertical borehole heat exchangers with an overall length of 120 m. The heat pump for domestic hot water (DHW) uses the return flow of the space heating circuit as heat source. The GSHP also includes an electrical back-up heater which operates according to the adjusted control strategy. The heat transfer is realized by floor heating which allows for low inlet temperatures in the heating circuit. Additional buffer storage is not installed.

This object is monitored as part of the “WP Monitor” project which started in 2009. “WP Monitor” is a German monitoring project run by the Fraunhofer ISE in Freiburg. The aim of the project is to collect real performance data of various buildings equipped with different heat pumps. The monitoring project “WP Effizienz” which ended in 2010 serves as a good basis for the present project as the knowledge gained about the measurement is useful for the classifications of the presently measured heat pumps. Here GSHPs reached an average SPF of 3.9 (3.1...5.1). The energy share for space heating amounts to 82% whereas the average temperature was 36 °C (DHW: 52°C). The average brine inlet temperature of borehole systems amounts to 7.1 °C.
One-family house, Buchenbach

The heating system is installed in a new building with a low energy demand. The system primarily consists of one heat pump for each operation mode. Space heating energy is provided by an air source heat pump (ASHP) installed outside. A separate heat pump uses the exhaust air of the building to generate domestic hot water (DHW). Each heat pump includes an electrical back-up heater which operates according to an individually adjusted control strategy. The heat transfer is realized by floor heating which allows for low inlet temperatures. The buffer storage which is installed parallel improves the operation time in the transitional period and ensures the defrosting mode.

This object is monitored as part of the “WP Monitor” project which started in 2009. “WP Monitor” is a German monitoring project run by the Fraunhofer ISE in Freiburg. The project’s aim is to collect real performance data of various buildings equipped with different heat pumps. The monitoring project “WP Effizienz” which ended in 2010 serves as a good basis for the present project as the knowledge gained about the measurement is useful for the classifications of the presently measured heat pumps. Here ASHPs reached an average SPF of 2.9 (2.3...3.4). The energy share for space heating amounts to 82% whereas the average temperature was 36 °C (DHW: 52°C).

During the evaluation period from April 2011 to April 2012 the measured heat pump reached a SPF of 3.22 and thus shows an improvement compared to the results of the “WP-Effizienz”-project. The SPF of the heat pump in charge of heating amounts to 3.30. The separate DHW heat pump has an SPF of 3.10. The SPF of the heat pump in charge of heating is positively influenced by the low inlet temperature for the heating circuit which varies around 34°C. The energy share of 8% for DHW is clearly below average and positively influences the total SPF value. The electrical back-up heater
operated for one month only (very cold February 2012) and influenced the SPF value only slightly in a negative way. The yearly operation time of the heat pump in charge of heating amounted to 2,210 hours in 2010.

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**Figure 28. Monthly SPF H3 values.**

**One-family house, Gengenbach**

The ground source heat pump (GSHP) is installed in a building with a rather low heat demand compared to other buildings in building stock. The heat pump is coupled with a heat source system consisting of one vertical borehole heat exchanger with a length of 300 m. The extreme length of this probe allows for the use of water as heat transfer medium since frost problems can be excluded. The heat pump also includes an electrical back-up heater which operates according to the adjusted control strategy. The heat pump provides space heating and domestic hot water (DHW). The heat transfer is realized by floor heating which allows for low inlet temperatures. Additional buffer storage is not installed. During the evaluation period from April 2011 to April 2012 the measured heat pump reached a SPF of 5.13 and thus shows a remarkable improvement compared to the results of the “WP-Effizienz”-project. The SPF of this heat pump is mainly influenced by two factors: the high heat source temperature and the energy share for space heating. As the vertical heat exchanger is 300 meter long and equipped with water as heat medium, the temperatures vary between 9.4 and 16.3°C. The inlet temperature for the heating circuit varies around 38°C, the temperature for DHW around 48°C. Significant in the context of high SPF values is the low share of energy for DHW which amounts to 7%. The electrical back-up heater did not operate, so the SPF was not influenced negatively. The annual operation time amounted to 2,830 hours in 2010.
One-family house, Merzig

The air source heat pump (ASHP) is installed in a new building with a low energy demand. The heat pump is installed outside and provides both, space heating and domestic hot water (DHW). An additional electrical back-up heater is installed in the heat pump and operates according to an individually adjusted control strategy. The heat transfer is realized by floor heating which allows for low inlet temperatures. Additional buffer storage is not installed. During the evaluation period from April 2011 to April 2012 the measured heat pump reached a SPF of 3.50 and thus shows a significant improvement compared to the results of the “WP-Effizienz”-project. The SPF of this heat pump is mainly influenced by the low inlet temperature for the heating circle which varies around 33°C. The energy share for DHW with 23% is slightly above average, however, does not influence the SPF strongly due to the low DHW temperatures of 45°C on average. The operation of the electrical back-up heater was not significant (6 kWh) for the SPF, thus it was not influenced in a negative way. The yearly operation time amounted to 2060 hours in 2010.
One-family house, Mittenwalde
The ground source heat pump (GSHP) is installed in a new building with a low energy demand. The heat pump is coupled with a heat source system consisting of two vertical borehole heat exchangers with an overall length of 160 m. The heat pump also includes an electrical back-up heater which operates according to the adjusted control strategy. The heat pump provides space heating and domestic hot water (DHW). As a so-called compact system, heat pump and DHW storage are located in one casing. The heating circuit consists of floor heating which allows for low inlet temperatures. The buffer storage is installed in series. There is an additional feature in form of a passive cooling system. During the evaluation period from April 2011 to April 2012 the measured heat pump reached a SPF of 3.90 and thus meets the average result of the “WP-Effizienz”-project. The SPF is mainly influenced by the system temperatures. The brine inlet temperature varies between 5.5 and 12.8°C. The inlet temperature for the heating circuit is around 39°C which is a relatively high value as floor heating is installed. The low share of energy for DHW only amounts to 13%. Thus, the average loading temperature for DHW of 48°C did not influence the SPF immensely. The operation time of the electrical back-up heater was insignificantly small, thus the SPF was not influenced negatively. The annual operation time amounts to 1820 hours in 2010.
One-family house, Remagen

The ground source heat pump (GSHP) is installed in a new building with a low energy demand. The heat pump is coupled with a heat source system consisting of one vertical borehole heat exchanger of 96 meter length. The heat pump also includes an electrical back-up heater which operates according to the adjusted control strategy. The heat pump provides space heating and domestic hot water (DHW). The heat transfer is realized by floor heating and concrete core activation which allows for low inlet temperatures. Additional buffer storage is not installed. During the evaluation period from April 2011 to April 2012 the measured heat pump reached a SPF of 4.56 and thus shows an improvement compared to the results of the “WP-Effizienz”-project. The SPF of this heat pump is mainly influenced by the system temperatures as average monthly heat source inlet temperatures vary between 5.2 and 9.9 °C during the main heating period. Particularly the inlet temperature of around 32°C for the heating circuit positively contributes to the SPF. This influence increases since the energy share for DHW only amounts to 2% (51°C). The electrical back-up heater did not affect the SPF negatively. The annual operation time amounted to notable high 4010 hours in 2010.
One-family house, Ruhpolding

The ground source heat pump (GSHP) is installed in a new building with a low energy demand. The heat pump is coupled with a heat source system consisting of vertical borehole heat exchangers. The heat pump also includes an electrical back-up heater which operates according to the adjusted control strategy. The heat pump provides space heating and domestic hot water (DHW). The heat transfer is realized by floor heating which allows for low inlet temperatures for the heating circuit. Additional buffer storage is not installed. During the evaluation period from April 2011 to April 2012 the measured heat pump reached a SPF of 4.00 and thus shows a slight improvement compared to the results of the “WP-Effizienz”-project. The SPF of this heat pump is mainly influenced by the system temperatures. The average monthly heat source inlet temperatures vary between 5.9 and 11.8°C. The inlet temperature for the heating circuit which varies around 34°C also positively contributes to the SPF. The low share of energy for DHW which amounts to 12% is remarkable. Thus the average loading temperature for DHW of 55°C did not influence the SPF immensely. The electrical back-up heater did not operate and thus the SPF was not influenced negatively. The annual operation time amounted to relatively low 1430 hours in 2010.
Results from Greece

Office building, Keratea

The central building and the geothermal energy hub of the Park of Energy Awareness (PENA) is heated and cooled by a geothermal heat pump system. The main components of the system are five borehole heat exchangers and a heat pump. The heating/cooling distribution system consists of four (4) fan-coil units (floor standing type).

The monitoring of the office building started on the 1st of April 2011. The heat pump operates in the heating mode from the 1st of October till the 30th of April and in the cooling mode from the 1st of May till the 30th of September.
Figure 34. Distribution of heating (red) and cooling (blue) demands over the year.

Figure 35. Monthly SPF H3/C3 values.
Office Building, Pikermi

The bioclimatic and low-energy consuming office building (total net area 428 m²) of CRES was designed and constructed as a demonstration building which use various RES technologies and energy saving techniques. Among RES technologies used in the building, the geothermal water-to-water heat pump operates in bivalent mode and covers about 21% of heating and 15% of cooling loads of the building. The unit uses the thermal energy content of the stored water of the existing well which is 80m deep, located 10 m north of the building. After use the water is poured into the same well it was pumped from. The monitoring of the office building started on the 1st of April 2011. The heat pump operates in the heating mode from the 1st of October till the 30th of April and in the cooling mode from the 1st of May till the 30th of September.

![Figure 36. Distribution of heating (red) and cooling (blue) demands over the year.](image-url)
Two-family House, Pikermi

The 180 m² Residence in Pikermi is heated and cooled by a geothermal heat pump system. The main components of the system are one groundwater supplying well and one reinjection well, one electrical water source heat pump in serial connection with the under-floor system of the house. In addition, there is a direct expansion small electrical heat pump attached to a 300lt hot water tank, producing sanitary hot water by using as a source the return pipe of the floor system, extracting energy from the circulating water. The monitoring of the house started on the 1st of April 2011. The heat pump operates in the heating mode from the 1st of October till the 30th of April and in the cooling mode from the 1st of May till the 30th of September.
Figure 38. Distribution of heating (red) and cooling (blue) demands over the year.

Figure 39. Monthly SPF H3/C3 values.
Two-family House, Pikermi (2)
The 180 m² Residence in Pikermi is heated by a geothermal heat pump system. The main components of the system are one 3 bore-hole heat exchangers of 65m depth each one, one electrical water source heat pump in serial connection with the radiators of the house. The heat pump also heats up a 300 lt hot water tank, equipped with a large heat exchange solenoid especially for use with heat pumps. The monitoring of the house started on the 1st of April 2011. The heat pump operates only in heating mode from the 1st of October till the 31st of March.

Two-family House, Markopoulo
The 350 m² Residence in Markopoulo, Attiki, is heated and cooled by a combined system of geothermal heat pump and solar thermal. The main components of the geothermal system is one ground source heat pump coupled to horizontal collectors with a total length of 1100meters. The heating/cooling distribution system consists of floor heating system and 3 fun coil units. The monitoring of the house started on the 1st of April 2011. The heat pump operates in the heating mode from the 1st of October till the 30th of April and in the cooling mode from the 1st of May till the 30th of September.
Figure 41. Distribution of heating (red) and cooling (blue) demands over the year.

Figure 42. Monthly SPF H3/C3 values.
Results from Netherlands

New housing estate Oosterheem ‘Heemburgh’, Zoetermeer

Oosterheem ‘Heemburgh’ is part of a new housing estate project in Zoetermeer. The total project consists of 8800 family dwellings together with schools and commercial buildings. The monitored part of the project consists of 158 apartments. For this part of the project, space heating and cooling is provided by a collective heat and cold storage system and heat pumps. The project also includes 57 single-family dwellings which use individual heat pumps. After the use of the system had started, the need for continuous monitoring arose, due to unexpectedly low energy efficiencies of the collective heat pumps. Over 2011, the heat pumps operate at 1500 running hours per year (equivalent full load). The supply performance of the heatpump is 49% of the total (heat and hotwater), the backup gas condensing boilers 51%. Distribution heat losses are 30% (space heating system) and 50% (hot water system), together 39%.

SPF2 = 2.0 and SPF3=1.33. The PER of the total system including the distribution losses is 0.54.
Figure 43. Distribution of energy for heat pump operation (brown) and back up heater (black).

Figure 44. Distribution between heating and DHW.
**Apartment block “Intermezzo”, Tilburg**

In the city of Tilburg, the “Intermezzo” apartment block with commercial space and apartments in various sizes and designs has been realised in 2009. The energy system consists of a collective bivalent heat pump for space heating and offers cooling via the aquifer heat source. A gas-fired boiler serves as back-up and supplies hotwater. The apartment block includes 131 privately-owned apartments, 422 small apartments for students, and furthermore commercial space. Gasboiler is not monitored apart for space heating or DHW. Gasboiler (m3 gas) is only monitored for m3 input, not for GJ-output.

Domestic hotwater (DHW) is not monitored apart, but calculated (cold water input). The monitoring shows an average demand of 78% for space heating and 22% (approximately) for DHW. The heat distribution losses (space heating, DHW) are 10,4%, incl. flue gas losses of the gas condensing boiler, this is relatively very low.

The heat pump is having a relatively high number (5000, approximately) of hours per year (equivalent full load).

The SPF1-SPF2-SPF3-SPF4-PER results are quite satisfying, but some attention points show up in the results.

The monitoring shows two winter months with a far to low HP production and a far to high Backup production. Possible reason was shortage of energy buffered in the aquifer/wells and shut-off of the heat pump.

The HP produced 62% of the space heating demand, 38% (approximately) by the gas condensing boiler, but 75% / 25% seems reasonably possible.

The electricity demand of the distribution pumps in the building system (space heating, cooling, DHW) is rather high, possibly other electric consumers in the building are included. The well pumps demand is only 4%.
Figure 46. Distribution of energy for heat pump operation (brown) and back up heater (black).

Figure 47. Monthly SPF H3 values.
Multifamily residence ‘Stoker en Brander’, Groningen

By lack of a heat meter on the heat supply of the heat pump, some additional assumptions had to be made, to estimate the heat supply data for the heat pump in accordance with warm source data, therefore the accuracy of the SPF2 information (heat pump only) and PER is limited. However, for the estimation of SPF3 and SPF4, this accuracy problem did not exist. Conclusions concerning the kWh-demand of the HP pumps, HP compressor and heating-cooling-DHW pumps are difficult to draw, since only the total electricity of the installation room and the HP compressor are monitored. Of the total space heating + DHW supply, 54% is supplied by the HP, 46% by the gas condensing boiler. The resulting total heat losses are calculated at approximately 30% (10% flue gas losses, 20% building distribution system).

Figure 48. Distribution of energy for heat pump operation (brown) and back up heater (black).
Figure 49. Monthly SPF H3 values.

**Multifamily residence, Nijmegen**

In 2008, the multifamily residence ‘Waterstraat’ with 24 existing apartments was renovated with a renewable energy system. The new heating system consists of a heat pump for base load space heating, solar collectors for domestic hot water (DHW) and gas fired condensing boilers as back-up for heating and for DHW. The heat source of the heat pump consists of 12 single U-tube ground heat exchangers. Monitoring period: 2010 (January - December).

Heat pump 40.3kW, 2 x 85kW gas condensing boilers. No cooling is possible with the radiators.

Design value COP 3.0, measured value 2.7. The monitoring shows an average demand per apartment of 10.660 kWh/y (38.4 GJ/y) for space heating and 2.037 kWh/y (7.3 GJ/y) for DHW including 52% DHW distribution losses. Below +6°C, the heat demand exceeds the HP capacity and the gas boiler serves as backup. The HP produced nearly 80% of the space heating demand (80% was planned).

DHW: in summer months the DHW demand is met by the solar collector (40%), in winter months mainly by the gas boiler, in total the solar collector contribution 17% of the DHW, or 3% of the heating plus DHW.
Figure 50. Distribution of energy for heat pump operation (brown), circulation pumps (grey) and back up heater (black).

Figure 51. Monthly SPF H3 values.
**One-family house, Schiermonnikoog**
The farm style house is located on the island of Schiermonnikoog. A heat pump is installed by Thercon (Belgium), who presents (online) the monitoring results of two air-to-water heat pump projects in the Netherlands including the Schiermonnikoog house and seven projects in Belgium on their website (www.liveheat.be).

![Figure 52. Monthly SPF H3 values.](image)

**One-family house, Berkelland**
The one-family house was renovated in 2010. The heat pump is installed by Thercon (Belgium), who presents (online) the monitoring results of two air/water heat pump projects in the Netherlands including the Berkelland house and seven projects in Belgium on the website (www.liveheat.be).
One-family house, Ootmarsum

The first existing home in the Netherlands, which is converted to a “zero energy” home. The electricity is generated by (15.5 kWp) Kyocera solar panels (50% facing east and 50% facing west) and converted to 230V AC through SMA inverters (yield 10500 kWh/year). Heating and hot water are provided by an air-to-water electric heat pump (Mitsubishi Zubadan, 11.2 kW heat). The house was already fully equipped with radiant floor heating. Detailed energy monitoring all year round: graphics available with kWh’s heating in 1C bins.

Graphics show a lower COP in summer, while 52C hot water demand only. Average SPF2 for heating and hot water is 3.54.

Performance monitoring in summertime can be less accurate on day basis, because compressor electricity is counted in 100 pulses/kWh, while heat is counted in only 1 pulse/kWh.
**Commercial building, Groot-Ammers**

The GSHP system consists of a ground source heat pump coupled to mono-source system (aquifer). The system provides heating and free cooling to the Kwakernaak workshop with office building in Groot-Ammers. The heating/cooling hydronic distribution system in the building is coupled with floor heating/cooling. This application represents a common geothermal heat pump solution in the building sector in the Netherlands. The building is using free cooling, drawn from aquifer. The free cooling system was not yet 100% started up in this period, influencing the heating and cooling performance in the first year. The aquifer source will be in better balance after more summer/winter cycling.
Figure 55. Distribution of energy for heat pump operation (brown), circulation pumps (grey) and back up heater (black).

Figure 56. Monthly SPF H3 values.
Commercial building “Gulden Winkelplantsoen”, Amsterdam
The electricity demand of the aquifer/wells pumps is very high in the last two winter months (2010). The specific electricity demand (21%) of these pumps can be reduced to 15% or less after optimisation.

Housing project Meerpolder, Berkel en Rodenrijs
The housing project Meerwijk in Berkel en Rodenrijs consists of 129 single family terraced (row-) houses, type low-energy. A number of 118 houses are monitored and reported. This housing project was completely monitored to obtain extra operation experiences. All Itho Daalderop heatpump systems are monitored. In all 129 houses the same heat pump system was installed with individual ground loop sources.

Figure 57. Monthly SPF H3 values.
A privately owned traditionally built terraced house in a row of four houses built in 1976, has been installed in 2011 with an air source heat pump in bivalent mode supported by a gas-fired condensing boiler. In peak load conditions with lower outside temperatures the gas-fired boiler takes over the space heating. During the monitoring in the first season the capacity of the 4 kW heat pump was not sufficient to comfortably heat the living areas. The house was not insulated in the first year. Insulation was applied later on in the cavity walls and under the floor decreasing the energy demand. Heating is provided by traditional high temperature radiators in all rooms with a temperature heating level at 35 °C. Domestic hot water is supplied by the gas-fired boiler only as an instantaneous water heater. In the first phase of this experimental set up the heat pump has not been able to cover the demand for the space heating system sufficiently. This is a similar experience to that of an Essent project with ELGA. A larger capacity heat pump could have been installed but as the house will be insulated in 2011 this was not considered further. Also the first hand-taken measurements of the COP were not higher than 2.2 - 2.7, which is well below expectation. A valve with a wrong setpoint did not give the right flow through the heat exchangers. Also the room thermostat as central sensor system was not equipped for the heat pump causing much on/off switching. Dutch Heat Pump Solutions solved this by an update of the software for control system and by changing the hydraulic scheme. The monitoring period is 1 April 2011 - 1 April 2012. The condensing gas boiler also runs at a rather low performance with an efficiency of 84% in higher heating value for space heating. For DHW-heating the efficiency is well below 50%.
Figure 59. Distribution of energy for heat pump operation (brown) and back up heater (black).

Figure 60. Monthly SPF H3 values.
Results from France

One family house, Marck (1)
The GSHP system consists of heat pump, one vertical borehole of 100 m depth and a floor heating system. The system provides space heating only. This single family house is located in the North of France. The building has been constructed in 2009 and the heat pump operates since September 2010.

The geothermal heat pump shows very good performances with an average seasonal performance factor (SPF2) of 4.61. The building is a low energy building (label BBC in France) and the heat produced is 53 kWh/m² heated floor area. These performances can be explained by an oversized heat pump and the vertical borehole related to the availability of heat pumps with lower nominal heating power. The average supply temperature to the floor heating system over the whole period is 33.5°C. The average source temperature (inlet of the heat pump on the evaporator side) is 9°C.

![Figure 61. Monthly SPF H3 values.](image)

One family house, Marck (2)
The GSHP system consists of heat pump, one vertical borehole of 100 m depth and a floor heating system. The system provides space heating only. This single family house is located in the North of France. The building has been constructed in 2009 and the heat pump operates since September 2010.

The geothermal heat pump shows very good performances with an average seasonal performance factor (SPF2) of 5.0. The building is a low energy building (label BBC in France) and the heat produced is 60 kWh/m² heated floor area. These performances can be explained by an oversized heat pump and the vertical borehole related to the availability of heat pumps with lower nominal heating power.
The average supply temperature to the floor heating system over the whole period is 29.9 °C. The average source temperature (inlet of the heat pump on the evaporator side) is 9.3 °C.

Lessons learned/ suggestions for improvement

Although presenting very good performances, the seasonal performances could be highly improved by allowing the heat pump controller to switch off the circulation pump on the building side when the compressor is not operating. This effect cannot be observed for SPF1-3, but is visible in SPF4 where the overall performances including building side is considered. Also, the efficiency of the circulation pumps are poor with a nominal power of 140-150 W which is very high. The SPF4 is thus very low only related to the choice of the circulation pump and its control, compared to the very good performance of the heat pump itself (thermodynamic cycle).

![Figure 62. Monthly SPF H3.](image)

**One family house, Villecerf**

This field site is a one-family house, single floor, in Villecerf built in 1971 and refurbished (double-glass windows, floor and glass-wool in attic). The system consists of a split system: with one outdoor unit and three indoor units. The heat pump system was installed after 2000-2005 and operates well since than. The tap water is produced by thermal solar panels and some photovoltaic panels have been installed in 2010.

The field measurement has been operated from May 14th 2011 till May 13th 2012. Data for April 2011 are consequently not displayed. The heat pump did not operated in cooling mode because the family doesn’t want to, the heat pump is shut down at the end of heating season. For some days,
communication of acquisition system was stopped and consequently the days when this occurred have been removed from the dataset (some non consecutive period). The final measured seasonal coefficient of performance (SPF 2, 3 or 4 because of no backup heater and non ducted unit) in heating mode is close to 3.8. Because of the lack of some data days, the measurements were operating on 1225 total heating degree days instead of 2123 on the heating period. The measurement uncertainty relative to the method is +/- 15 %.

![Figure 63. Monthly SPF H3.](image)

**One family house, Maslives**

This field site is a one-family house, single floor, in Maslives built in 1800 and 1900, and refurbished (double-glass windows, etc.) in 1992. The system consists of two split systems: with two outdoor units and seven indoor units. The heat pump system was installed after 2000-2005 and operates well since then.

The field measurement has been operated from May 31th 2011 till May 13th 2012. Data for April 2011 and May 2011 are consequently not displayed. The heat pump did not operate in cooling mode because of poor summer weather. The heating period started late because of very nice autumn, the winter was quite sweet except a very cold period in February. For some days, communication of acquisition system was stopped and consequently the days when this occurred have been removed from the dataset (some non consecutive period). The final measured seasonal coefficient of performance (SPF 2, 3 or 4 because of no backup heater and non ducted unit) in heating mode is close to 3.4. Because of the lack of some data days, the measurements were operating on 1261 total heating degree days instead of 2040 on the heating period. The ambient sensor broke down during the tests, the outdoor temperatures reported are the one from the close weather station of Blois. The measurement uncertainty relative to the method is +/- 15 % for SPF.
Medical practice, Le Cannet
This field site is a medical practice installed in a flat of a multi-family building built in 1970. The flat is located on the first floor. Each of the rooms, the consultation room and the waiting room, are equipped with a heat pump. Both heat pumps are identical. These are recent air source single reversible split air conditioner. There is no alternative heating system.

The measurements are displayed only for the heat pump located in the consultation room, with a surface of about 35 m2. The field measurement was operated from April 21th 2011 till May 13th 2012. Data for April 2011 are consequently not displayed. During summer, the heat pump operated in cooling mode and data is not reported. The outdoor temperature sensor was probably influenced by sun exposition part of the time so outdoor temperatures measured at the close station of Cannes are reported. For some days, the sensors stopped operating or communication was stopped and consequently days when this occurred have been removed from the dataset. The final measured seasonal coefficient of performance (SPF2, 3 or 4 as no backup heater and non ducted) in heating mode is close to 4.3 (weighted average, versus 3.77 the average of monthly COP values). With the measurement uncertainty relative to the method +/- 15 % and given the fact the heat pump operated in a relatively hot climate with weighted average operating temperatures for heating slightly higher than 10 °C, these results appear to be close with the nominal performance of 3.8.
One family house, Mougins

The air/water heat pump system consists of a monobloc air to water heat pump coupled to a floor heating system. The system provides space heating only. This single family house is located in the South of France. The building has been constructed in 2000 and the heat pump operates since September 2008. Initially the building was heated by a gas boiler with annual operation costs of about 2500-3000€/year. The air/water heat pump is for heating only and connected to an outdoor unit.

The air/water heat pump shows poor performances with an average seasonal performance factor (SPF2) of 2.5. The building is has a high energy consumption for heating with a heat production of 84 kWh/m² heated floor area. Although the heat pump is installed in a warm climate (close to Nice), the performances a poor, mainly to the use of an existing floor heating system asking for high supply temperatures in order to allow space heating at an acceptable comfort level. The average supply temperature to the floor heating system over the whole period is 41.6 °C. The average source temperature (inlet of the heat pump on the evaporator side, the external air in this case) is 11.1 °C. During the whole period, no defaults have been reported and the heat pump operated as expected.
Nursery, Savigneux

The GSHP system consists of heat pump, two vertical boreholes of 100 m depth each and a floor heating system. The system provides space heating and cooling. The nursery is located in the Center of France. The building has been constructed in 2009 and the heat pump operates since 2010.

The geothermal heat pump shows acceptable performances with an average seasonal performance factor (SPF2) of 4.1. The building is a low energy building (label BBC in France) and the heat produced is 107.7 kWh/m² heated floor area. The specific consumptions do not agree with the BBC label since the nursery is located at the northern facade of the building without passive solar energy gains. In addition, the nursery asking for quite high temperatures in order to guarantee comfort for the children, the necessary floor temperature is rather high. The average supply temperature to the floor heating system over the whole period is 35.4 °C. The average source temperature (inlet of the heat pump on the evaporator side) is 10.9 °C.
One family house, Rogny
This field site concerns a one-family house, single floor, in Rogny. The house has been built in 1980 and refurbished in 2006, insulated and air to air heat pump. The heat pump has been replaced in 2009 for a model with Inverter compressor. The system consists in a monosplit air to air centralized ducted system.

The field measurement has been operated from March 2011 till April 30th 2012. The heat pump did not operate in cooling mode because of poor summer weather. The heating period started late (17th of October) because of very nice autumn, the winter was quite sweet except a very cold period in February. The final measured seasonal coefficient of performance (SPF 4 , it is a ducted unit) in heating mode is close to 3.3. The back-up heater did not run. The kitchen and the bathroom are not heated by heat pump but by an electric radiator which energy consumption is not included in the SPF calculation; this area is not included in the HP heated area. No ambient temperature sensor was installed so the outdoor temperatures reported are the one from the close weather station of Auxerre. The measurement uncertainty relative to the method is +/- 10 % for SPF.
Results from Sweden

**One-family house in Onsala**

The ASHP system consists of an outdoor unit, an accumulator tank, and a coupled solar thermal system. The system provides heating and domestic hot water. The heating distribution is by underfloor heating in both floors. This application represents one of the most common applications of air to water heat pumps in Sweden. However, the accumulator tank is quite novel, with very precise stratification, thus the system could be expected to be in the higher end of performance.

The measurements has been ongoing since 2009 to 2011, and here, the results from the heating season of 2010 is reported (September 2009-May 2010. This year was exceptionally cold in this part of Sweden, and there was much snow until late April. The snow can have an insulating effect on the house, but is can also disturb the air flow pattern for the outdoor unit.
One-family terraced house in Mölndal
The ASHP system consists of an air source heat pump. The system provides heating and domestic hot water. The heating distribution is by circulating water to radiators. Domestic hot water is also circulated with a separate circulator.

In addition to the heat pump, there is a wood stove installed, but it is mainly used for cozyness.

The measurements has been ongoing since 2009 to 2011, and here, the results from the heating season of 2010 is reported (September 2009-May 2010). This year was exceptionally cold in this part of Sweden, and there was much snow until late April.

The house’s DHW circulation pump is operating constantly, which clearly decreases the SPF H4.
One-family House in Mölnlycke

The building is a one storey house with 240 m² heated area and 30 m² bi-area. The original house was built in 1961, about ten years later an extension building was built. The house has relatively large window areas with two glass windows. A wood stove that is used for coziness is located in the living room. The heating system was originally an oil boiler.

The heat pump has an 11 kW nominal effect and was installed in the latter 1997. The year after the installation, two additional circulation pumps was installed, one for the original part of the house and one for the extension. There is a separate tank for sanitary hot water. The heat pump alternates between sanitary hot water production and space heating. A three way valve is used to control the operation. A back up heater is placed right after the heat pump, before the three-way-valve. The borehole is about 110 m deep drilled in grey mountain. The cold heat transfer media is around 28% ethanol based brinole. The measurements has been ongoing since 2009 to 2011, and here, the results from the heating season of 2010 is reported (September 2009-May 2010). This year was exceptionally cold in this part of Sweden, and there was much snow until late April.
One-family House in Brämhult

The house was built in 1946 as a 1 ½ storey building, now after extension it can be counted as a 2 storey house. The house is poorly insulated, but supplementary insulation of the roof is made. The windows are 3-glass. The heating of the house was probably handled by an oil boiler before the heat pump installation was made in 2005. A 4.5 kW ground source heat pump is heating the house via floor and radiator heating. The heat pump is also used to the preparation of sanitary hot water together with a 6.6 m² solar collector installed in 2008. The size of the sanitary hot water tank is 270 liters. The heat pump has an electric backup heater of 8.8 kW installed. The measurements has been ongoing since 2009 to 2011, and here, the results from the heating season of 2010 is reported (September 2009-May 2010). This year was exceptionally cold in this part of Sweden, and there was much snow until late April.
Figure 72. Monthly SPF H1-H4 for the site. In the summer months, the heat pump is not operating, and all energy is provided by the solar heat.

One-family House in Mölnlycke
The house is built in 1982. The house is a split level house with a wooden framed top floor and a mortar bottom floor. Most windows are three glasses A 6kW ground source heat pump was installed in 2004. In addition to the heat from the heat pump electric underfloor heating is installed in the hall. The volume of the hot water tank is 165 litres. The borehole is 120 meter deep with an outer bottom diameter of 114 mm. The ground water flow is measured to 180l/h. The cold heat transfer medium is 75Thermo Multi Bioethanol 30%. The heat pump has a 6kW immersion heater that is used as a backup. The heat sink is radiators (around 3dm high aluminium radiators). The house has mechanical ventilation with heat exchange for supply and exhaust air. Exhaust air is ducted from the kitchen and wet areas, while the supply air is led into sleeping rooms and living room. The measurements has been ongoing since 2009 to 2011, and here, the results from the heating season of 2010 is reported (September 2009-May 2010). This year was exceptionally cold in this part of Sweden, and there was much snow until late April.
Figure 73. Monthly SPF H1-H4 for the site.
Important factors for improvement of heat pump system performance and quality

A significant opportunity for improving heat pump operating performance (capacity, efficiency, etc.) is related to how well the equipment is actually designed, installed and subsequently maintained in the field.

As this a wide range of parameters can influence the performance of heat pumps the focus of this project was structured in four main topics:

- Design and calculation of heat pump system

The proper design of a heat pump system seems complex. Besides proper sizing of the heat pump itself also the design of the source system, especially with ground source systems but also with air sources, and the low temperature heating system is crucial. In the housing market there is a clear split between new buildings and retrofit for existing buildings. In general as observed the performance of heat pump systems often fall short of their expectations as in the design phase the capacity is over dimensioned.

**Over dimensioning** is not a shortcoming for heat pumps only, however the performance of the heat pump is more influenced by this as the heat pump is more sensitive to this than traditional gas or oil fired boilers. For heat pumps over dimensioning results in frequent on/off switching of the heat pump, high supply temperatures, high costs and shorter life time. Over capacity in heat pumps thus can dramatically reduce the overall SPF of the system.

Over sizing is one problem, **under sizing** can be another one. In the design phase often optimistic assumptions made for the sources based upon theory. Especially with individual and collective ground sources this is the problem

- Installation quality of heat pump systems and components

A **start up protocol** that shall be filled out by the installer is a good way to assure quality. After installation the heat pump and heating system (for example heat transfer medium flow) should be balanced in order to fit the requirements of the house. The installer should also ensure that the heating demand in all places of the house is met in a sufficient way. Another development is that of installers towards **integral consulting and quality management** from design to maintenance of a finalised project as also installers are confronted with installation and performance problems with heat pump systems.

- Quality of the house envelope and the building process

Optimised heat pump systems require a high level of building quality because by their small capacity and slow heating up speed, they are sensitive for peak demands. The envelope of the building will therefore have to be checked on sufficient, careful and precise applied insulation, window glazing, thermal bridges and air tightness.

The main conclusion is that if in the design of the building the heating system has not been an integral part of the building process, concessions have to be made towards an optimal solution. Instead of thinking of individual measures a building should be designed as a set of coherent interrelated measures and concepts.
Completion and Maintenance of the system

Problems arise in all phases of the construction, but are visible (sensible) in the operational phase with the end user with the comfort and reliability at issue. For the end user it is also a question of operational management with high energy costs, connection fees and rental at issue. The issues range from technical failures to comfort questions by sizing errors or poor construction quality.

At the completion of a home the energy system is insufficiently tested on their functioning and their performance. The installer with a little attention this is motivated by competitive pressures to provide low cost (EURO counts each).
Evaluation method for comparison of heat pump systems with conventional heating systems

The deliverable “D4.3 Concept for evaluation of CO₂-reduction potential” contains information on how to compare heat pump systems with conventional technologies like coal, oil or gas heating systems. By this comparison it is possible to calculate the CO₂e-emission and PE reduction potential from different heat pump systems compared to other heating systems. The evaluation method for comparing the heat pump system with conventional heating systems will be focused on the following three parameters:

- CO₂e-emissions
- Primary Energy (PE) demand
- TEWI (Total Equivalent Warming Impact)

In all three methods, the effect over the lifetime of the product is chose, even if the CO₂e-emissions and PE requirements of course also can be expressed per year. The comparison of the different systems is focused on the PE demand and the global warming impact (Figure 13).

Figure 74. Comparison of the systems.

---

3 CO₂e, Carbon dioxide equivalent is a quantity that describes, for a given mixture and amount of greenhouse gas, the amount of CO₂ that would have the same global warming potential (GWP), when measured over a specified timescale (generally, 100 years). The carbon dioxide equivalency for a gas is obtained by multiplying the mass and the GWP of the gas.
In Figure 14 a schematic picture of the life cycle of a heat pump is shown, from the production to the end of life phase. The production phase has not been analyzed in the curse of the SEPEMO project. Other studies have shown that the emissions related to the production of the heating equipment as well as the end of life phase is small compared to the emissions during the user phase, including the fuel production for the impact categories included in this study. Therefore the focus is on the user phase concerning the CO2e-emissions and the primary energy (PE) demand. Additionally the TEWI method is used for calculations of the emissions of CO2-eqvialents during the whole operating time of the system, including the recycling of the refrigerant at the end of life phase.

**Figure 75. Heat pump life cycle.**

**Validation process for heating systems**

The validation process for heating systems describes how to get from the measured usable energy over the final energy to the PE demand and the CO2e-emissions. The heat pump systems will be compared regarding to these specifics with common heating systems. In the graph below the usable energy is supposed to be the same for all compared heating systems.

In Figure 15 the validation process is visualized and it can be seen that in order to calculate values for the final energy, the PE and CO2e-emissions there is a need for an input of different factors, coefficients and efficiencies related the system.
The starting point for each calculation will be the measured usable energy. For other heating systems than heat pumps, the AE of boiler systems should account for electricity consumption which participates to lower the AE (fan of the gas burner, pump, electronics ...). A description of such effects can be found in e.g. Ecodesign ENER Lot 1
Installer guidelines

During the discussions of the project an important focal point was the question *how to ensure that you deliver what you promise*.

The question on delivering what you promise involves more than just energy. It should also apply to the other benefits that are promised in the sales brochures, including: healthy indoor climate, comfort, quality being robustness and reliability, economy on investments and running costs. The property value in all this is at stake. DEPW partners, i.e. building companies, project developers and energy companies, could structurally measure and monitor their projects on these topics. Understanding successes and shortcomings are the basis for improving and scaling up and are the basis not to miss in a market switch towards even more renewable energy in innovating concepts.

In order to ensure that the residents/occupants in the long run are satisfied with the heat pump system, it is thus advisable to offer a maintenance contract and at least come back after half a year and one year to fine tune the operation of the system and to verify whether the inhabitants properly understand the operation of the system. If there are symptoms, these can often simply be remedied.

In the course of the project, two set of guidelines were set up, one set of Easy to understand guidelines for installation of reliable and energy efficient heat pump systems as a basis for courses and certification of installers, and one set of guidelines for installation of reliable and energy efficient heat pump systems for architects/planners.

The guidelines are based upon lessons learned from both a majority of successful and a minority of failing projects. We have been working from an optimistic point of view, which is quite important, because prominent stories in the media about failing heat pump projects obviously have an impact that goes far beyond the real significance of the problem in detail. So we don’t say: “One small leak
and the complete tyre is flat”. We prefer the statement “If we know how to prevent the leak, the complete tyre will function as it should.”

With this project we tried to contribute to the establishment of successful heat pump concepts for various applications in the domestic sector by presenting guidelines for a clever approach and preventive measures.
Communication activities

As the development of the HP market in Europe is complex and not solely dependent on one market group the project has targeted several groups. A top-down approach has been chosen in this project. Focus has been to disseminate project results to policy makers and public authorities, architects/planners/project developers and installers.

EHPA, the European heat pump association communicated the outcome from the project to all members through different information channels.

Project website

At the Kick-off meeting in Boras, June 2009 a decision was made on the structure of the project website. The programming work was carried out by the subcontractor bwise GmbH, Karlsruhe using the web content management framework TYPO3. The website comprises a public section and a password protected partner area. Online operation started end of July 2009 with the registered domain www.sepemo.eu. Regular maintenance and update of the website was carried out by FIZ.
In the course of the project information on all 52 field test sites including describing texts and display of measurement results were published country by country. From each field test site links were set to the Heat Pump Best Practice Database, to the fact sheets in English (Error! Reference source not found. below) and the respective national language as well as to two Google maps (SEPEMO projects, Heat Pump Best Practice Database).

All documents, deliverables and publications produced in the course of the project were published on the website as downloadable files. Links to external sources of information like events, publications, websites and other projects related to SEPEMO were installed. In total 74 news articles were posted on the website, 28 of them informing about the project progress and results.
The quarterly updated website statistics indicate a continuously increasing interest in the progress and results of the project. The number of page requests to the project website stepped up from 2,637 in the third quarter of 2009 to 19,435 in the first quarter of 2012. At the end of the project in total nearly 156,000 page requests and more than 30,000 downloads of deliverables and other project documents were registered.

Figure 80. www.sepemo.eu website statistics.

Covering the period January 2010 until May 2012 the website statistics provide detailed page request figures per website topic and per quarter, an internal page ranking, a list of most downloaded PDF files and a list of downloads per deliverable.

Table 8. Website page ranking.

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Table 9. Website breakdown of statistics 2010.

Website statistics: SEPEMO-Build (January 2010 - May 2012)

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Σ page requests: 35,624
Table 10. Website breakdown of statistics 2011.

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Σ page requests: 53,045
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Σ page requests 28,150

Heat Pump Best Practise Database

The “Ground Source Heat Pump Best Practice Database” was developed within the framework of the IEE project GROUND-REACH. At the end of the project in December 2008 at all 52 case studies from 15 countries had been compiled in the database.

In the course of the GROUND-MED project (7FP) eight demonstration projects from seven countries were added to the database. Results from an extensive monitoring programme shall be made available in the database too.

At the beginning of the SEPEMO-Build project the structure of the database was extended to include also air source heat pumps. Consequently, the name of the database was changed to "Heat Pump Best Practice Database". Further 52 case studies arising from the European-wide field test carried out in the framework of the SEPEMO-Build project have been added to the database. Recently, in total the database includes 113 case studies from 18 countries.
Figure 81. Heat Pump Best Practise Database.

The database provides all available information on the 52 field test sites. Links to the measurement result display on the project website and to the fact sheets were set. A comfortable search engine enables an extended search for specific case studies.

Other dissemination activities in the project
A number of meetings have been identified to present the findings from this project.

In the letter of July 25, the P.O has asked for the number of bilateral meetings with DG ENER and DG ESTAT. This has not generally been easy to monitor, but the responsible from the project, Mr. Nowak says that he meets with e.g Mr. Vessia and Dr. Rubig in different occasions on a weekly basis. These meetings are both by invitation and spontaneous meetings. In addition, meetings with MEP’s have been conducted, also not possible to tabulate.

Articles have presented the system boundary concept developed, and it has gained large attention. Meetings have been carried out targeting both policy makers (MEP Debate) and professionals (installer, architects, planners (EUSEW workshop, national workshops).
Meetings with presentations presented on the SEPEMO website include:

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<td>Brussels, BE</td>
<td>Does it really count? Contribution of renewable energy from heat pumps in the EU energy statistics</td>
<td>21</td>
</tr>
</tbody>
</table>

**Total** 988

Twelve issues of the newsletter have been produced during project. Email notifications were sent to about 150 recipients, who in turn distribute the information about the newsletter further. The newsletter has also been promoted on the EHPA and SEPEMO websites.
Evaluation of Performance Indicators
In the Sepemo project, performance and impact indicators were set up according to Table 10 and Table 11. Text in italic comments on the outcomes from the Sepemo project for each individual indicator.

Table 12. Sepemo result indicators.

<table>
<thead>
<tr>
<th>Specific Objectives</th>
<th>Result Indicators:</th>
<th>Quantification of success:</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Well designed, reliable and efficient heat pump systems</td>
<td>▪ Proposal for harmonised EU field measurement method for reliable information about “real installations” is presented to CEN committees. <em>Two meetings have been held, and email communication with relevant CEN groups is on-going. The concept of developing a standard for performing field monitoring projects is attractive, but other heating devices than heat pumps (oil, gas boilers) should also be targeted using the same, or a similar, methodology as was developed in the Sepemo project (D4.2).</em></td>
<td>CEN commits to start a working group on this topic, and use this proposal as a basis. <em>Jaap Hogeling, chair of CEN TC 228 has commented the ambitions to establish a CEN standard on field monitoring: “Based on this information I tabled this item at the CENTC228 meeting last week. Given that one of the aims of the project is standardisation I ask you on behalf of CENTC228 if a liaison could be established. To produce a standard on a standardised monitoring protocol for HP installations in buildings is within the scope of CENTC228. I expect, given the partners in SEPEMO, that experts handling such a liaison could easily be found. As your project has the common 36 months period I assume it will be possible to start working on a report that could be the basis of a CEN standard.”</em></td>
</tr>
<tr>
<td>▪ Improved quality assurance of heat pump systems</td>
<td>▪ Guidelines for setting up, and evaluating SPF field measurements for all types of heat pump systems are widely used, giving comparable results between different field measurements. <em>The Sepemo methodology has been used by the IEA HPP Annex 34 and Annex 3. It has been co-developed with the Groundmed project, and has been set as standard in the IEA HPP Annex 37 on good examples. The Swedish Energy agency use SPF H3 in one of their on-going monitoring projects. In the Netherlands, project developers are taking up 1000 downloads of each of the guidelines from the project website.</em></td>
<td>1000 downloads of each of the guidelines from the project website. <em>More than 2 500 individual downloads of the methodologies have occurred during the project period.</em></td>
</tr>
<tr>
<td>▪ Increased acceptance and increase the market share for heat pumps</td>
<td>▪</td>
<td>EHPA distributes SPF guidelines to all 61 members. <em>EHPA has distributed SPF guidelines to all 98 members.</em></td>
</tr>
<tr>
<td>▪ Increased energy savings with heat pumps</td>
<td>▪</td>
<td></td>
</tr>
<tr>
<td>▪ Increased use of renewable energy with heat pumps</td>
<td>▪</td>
<td></td>
</tr>
</tbody>
</table>
monitoring according to SEPEMO as a requirement for giving long term performance guarantees to customers. The Energy saving trust in the UK make reference to the Sepemo system boundaries in their monitoring project and the Fraunhofer monitoring project

| Good examples for all types of heat pumps demonstrated in the project. | At least 5 good examples communicated through national workshops in 12 occasions (500 installers, manufacturers), 5 articles describing the good examples. (air-air, air-water with floor or radiator heating, GSHP with floor or radiator heating )

In total, ten national workshops were held in the project. German held workshops were replaced by Fraunhofer participation with field sites in the project. A total of 52 field sites are presented in the best practise database, and more than 40 sites are reported with performance data. |

| Results disseminated and presented to policy makers, installers and other target groups | 400 policy makers (national and EU level) have received information about the project results. In total, 966 attendees have participated in SEPEMO events, whereof 276 in policy and installers and manufacturer targeted events in Brussels and Milano. Also the national events were targeted towards these groups. | 400 policy makers (national and EU level) have received information about the project results. In total, 966 attendees have participated in SEPEMO events, whereof 276 in policy and installers and manufacturer targeted events in Brussels and Milano. Also the national events were targeted towards these groups. |

Policy makers promotes the use of project results for Annex VII in the RES-directive

It is likely that the COMMISSION DECISION on guidelines for Member States on calculating renewable energy from heat pumps for the purpose of Article 5 of Directive 2009/28/EC will include SEPEMO references. |
Guidelines for improving heat pump system quality, reliability and energy performance for the system for all types of heat pump systems

- EHPA distributes guidelines to all 61 members
- EHPA has distributed SPF guidelines to all 98 members.

1000 downloads of the guidelines from the project website.

995 downloads of WP5 deliverables until the end of the project were counted.

EHPA commit to incorporate and promote the method in the EUCERT certification scheme.

EUCERT have decided to use results from the SEPEMO project in their installer certification training.

Table 13. Sepemo impact indicators.

<table>
<thead>
<tr>
<th>Strategic Objectives</th>
<th>Impact Indicators:</th>
<th>Quantification of success:</th>
</tr>
</thead>
</table>
| ▪ Harmonised standard for field measurements and SPF definition | ▪ Proposal for field measurements presented to CEN committees | CEN accept standard for field measurements based on project results
  
  Work is on-going in a positive direction, including all types of heating devices. |
| ▪ Mature market for heat pumps in Europe | ▪ Guidelines included in European/national quality assurance systems
  
  ▪ Guidelines for field measurement implemented and used for reliable EUROSTAT heating statistics. | At least 20% increased deployment of certified heat pump systems on the market.
  
  This indicator has not been possible to evaluate through the project. The Energy Related Products’ performance limits have not yet been voted, so those numbers are unavailable. For the EHPA Q label, Belgium and France joined in 2010, which makes a total of 10 participating countries. The EHPA database currently holds 3223 certified heat pump models. |
| ▪ Increase the energy savings with heat pumps by at least 50% | | Heat pumps’ heating output is correctly described in national and EU statistics.
  
  The proposed Eurostat statistics |
method includes conclusions from the Sepemo project, and will, when it comes into force describe the heating output from heat pumps in a uniform way.

EHPA includes training on field measurement in the EUCERT certification scheme. EHPA have trained 3000 installers with the material developed in this project three years after project is finished. Still to be evaluated.
Success stories

**SPF included in Dutch legislation**
During the monitoring of field sites in the Netherlands the insight that open source aquifers for domestic buildings is not a good solution. Based upon the monitoring results, closed loop ground sources are superior, hence Etten Leur becoming European Heat Pump City of the Year. As a consequence of this SPF 0 was developed and is taken up as a performance requirement for ground sources in the legislation and permit requirements for ground sources. It is taken up also in the mandatory certification for ground sources. The project developers are taking up monitoring according to SEPEMO as a requirement for giving long term performance guarantees to customers. And Dutch heat pump manufacturers are building in monitoring as a requirement for maintenance and performance guarantees. In order to be able to get a clear level of performance for ground sources as well as to get a comparable standard the SEPEMO project gets a follow up closely followed by policy makers in order to know at which level the hurdle should be raised. Existing Dutch guide lines for the installation of heat pump systems will be updated with the SEPEMO defined SPF methodology. It is further expected that for competing heating technologies the same type of definitions for performance will be developed. A parallel running set of field tests is now running for 6 months already on High Efficiency Gas boilers, Micro CHP and Solar Heating Systems. It is also expected that District Heating will be measured along the same type of yardstick on real performance. The National Heat Pump Platform (NPW) is streamlining the certification procedures for heat pump installers and is considering to 'export' their knowledge to EUCERT in order to get EUCERT at the same level/structure.

**SPF methodology included in proposal to EUROSTAT statistical method**
The IEE SEPEMO project provides a holistic approach by determining the boundary conditions for the RES calculation in heating and cooling mode (see deliverables D2.4 and D3.4 on www.sepemo.eu/deliverables). The methodology proposed by industry, supported by Sepemo, addresses the issues that arise from the use of the rather undefined variables in the RES directive’s calculation formula and it presents one possible approach to determine the RES contribution from heat pumps on the EU-27 level.

**SEPEMO results are taken up by EUCERT**
After discussions with the EUCERT committee, it was agreed to add the following topics in the updated EUCERT course materials:

- System boundary concept
- Monitoring of HP for proof of performance
- Monitoring concepts and quality monitoring
- Benchmarking other HP key numbers for better understanding
- Environmental aspects
- Experience of performance


Lessons learned & Further work

Monitoring is expensive and time consuming

However, very valuable insights about heating system performance can be acquired. In this project, it has been shown that the biggest improvements in existing heat pump systems can be made in the heat distribution system. For a realistic evaluation of the RES contribution from heat pumps, field monitoring are necessary, since they reveal many oddities that lab testing does not foresee.

Inspire and educate installers!

Although much of the improvement is in the heat distribution system, installers should not be blamed. There is little information on whole system design available in training material, and a holistic view is seldom taken. This project has delivered knowledge on how this can be overcome to the EUCERT certification. Since the closing of the project, Denmark and Poland have joined the EUCERT which now includes 14 member states.

Dissemination to key stakeholders is difficult but valuable!

In this project, the aim was to reach out to policy makers, industry (manufacturers, project developers, architects) and installers. The dissemination key messages have been limited to a few in order to reach out (System boundaries, comparability, installer training, RES contribution). Although we have organized a number of high level meetings and workshops, the number of policy makers could have been even higher. Industry interest in the project has been good, since the main issues of the project were actual and very important for industry’s development.

However, throughout the project, we have had very good contacts with relevant stakeholders of the industry and policy, and we feel that there has been great interest in what we have done. Therefore, it can very well be a good idea to focus on a smaller target group and massage that group more intense.

Further work

The implementation of the SPF methodology for RES calculation from heat pumps is further addressed in close collaboration between EHPA and other relevant stakeholders.

○ It is essential that the RES contribution from heat pumps is reflected in an objective and transparent way in national statistics. Therefore the final calculation methodology needs to reflect real performance as good as possible.

○ Since cooling was not included in the RES directive, we believe that this needs to be addressed. We have in the project already treated cooling in a similar way that heating and DHW, therefore a methodology exist when RES cooling will be lifted on the political agenda’s.

After the project ends, EHPA follows the development of the RES contribution from heat pumps, and how this is taken up by the MS in their national NREAP’s.

○ The impact from this activity will be very important for manufacturers and other industry partners in order to assess the market development.
Guidelines, system boundary methodology and other key measures to study heat pump and heat pump system performance will be integrated in the EUCERT training material.

- Given a sharp increase of the heat pump market development; there is the risk that many heat pumps will be installed by unqualified installers. It is therefore of outmost importance that the certification of installers is highlighted, maybe even made a necessity for even be on the market. EUCERT is already adopted in ten MS’s, and many more have shown great interest. Therefore we suggest that the EUCERT is made a mandatory training for heat pump installers. In order to not unbalance the market, similar requirements should be put on installers of other heating equipment.

Already started discussions with CEN on a standard for field monitoring of heating systems will be followed-up with the aim to develop a standard for monitoring of heating equipment. It is important that the methodology is transparent and technology neutral, so the inclusion of other heating technologies will be essential. SP, Armines, CRES, CSTB and AIT are all strongly involved in standardisation on national or European level, so these organisations will be deeply involved.
Seasonal performance factor and monitoring for heat pump systems in the building sector

The project aims at developing:

- Recommendation for a harmonised methodology for field measurement which can be incorporated in CEN standardisation.
- A database on heat pump system SPF based on a common methodology.
- A set of quality criteria for field measurement and calculation of SPF including all types of heat sources (air, water and ground).
- Recommendation for a standard method to estimate the performance of heat pump systems, to be used with the RES directive, Annex VII.
- “Easy to understand” guidelines for installation of reliable and energy efficient heat pump systems taking into account both building standard and regional constraints, to be used as a basis courses for certification of installers with RES directive, Annex IV.
- A set of guiding principles to develop quality schemes for heat pump systems based upon an SPF for certification of installers with RES directive, Annex IV.
- A reference guide describing presently available system concepts with their applications and users experience with a set of standardized high performance concepts as a basis for quality assurance of heat pump systems.

Objective
Broader acceptance of heat pumps systems, and improved quality assurance for heat pump systems in the building sector, by harmonised monitoring methods and guidelines.

Benefits
- Better knowledge of factors influencing heat pump SPF
- New harmonised field measurement method for heat pumps
- New field measurements data on SPF
- New and improved installer guidelines

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