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European Heat Pump NEWS

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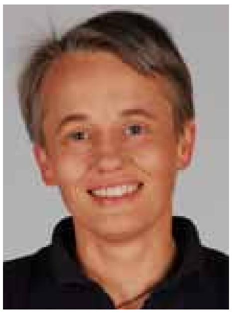
heat pump association

editorial

The impact of component choice on more efficient heat pumps


Dina Koepke (Member of EHPA's Executive committee)

Different countries provide different frameworks (MAP in Germany, tax credits in France) to help end-customers evaluate renewable energy solutions for heating. For heat pumps, many of these frameworks are linked to achieving a specified minimum seasonal efficiency performance. As a result, work on the efficient use of renewable energy is a never ending endeavor for all industry stakeholders, particularly members of the EHPA, who have embraced the responsibility to develop ever more efficient and reliable products.

Even though seasonal performance measurement is based on standards like prEN14825, actual seasonal performance of an installation is influenced by many factors including (but not limited to) local climate, heating demand of the building, water temperature profile, design and installation quality, domestic hot water demand and the behavior of the inhabitants.

This newsletter focuses on the impact of component choice on heat pump performance, and how the right selections form the basis for products that fulfill and exceed the long term expectations of the building owner.

Nothing is worse for the reputation of heat pumps than a product design or an installation that does not meet promised performance, or the minimum performance levels specified in the frameworks discussed above. As all of us know – an unhappy customer tells a negative story to seven times more people than a positive one!

The most influential components are the compressor, the evaporator (and in case of air/water always in connection with the fan), condenser, expansion valves, pumps, thermostats, measuring devices and system controller. All of these have to be specified during the product design of the heat pump with a view to system impact and their influence on efficiency. Exergy losses have to be avoided and only a very careful choice of components will result in long lasting and efficient heat pumps, which will in turn contribute to the reputation of heat pumps as a mature renewable energy technology.

At this year's ISH exhibition in Frankfurt , the Lucerne School of Engineering and Architecture, will present its work in the field of heat pumps (EHPA booth: Hall 9.0 FOY 05). They will present results from a project aimed at the development of universally valid design and planning criteria ("guidance") for the realization of efficient, reliable and economic air/water heat pumps with continuous capacity control.

Their investigations show that the optimal control strategy and efficiency of capacity controlled heat pumps is strongly dependent upon the partial load efficiencies of the compressor and the fan. Their experiments further show that continuous capacity control can increase the seasonal performance factor by approximately 20 – 50% compared to air/water heat pumps with on/off control. On this basis, seasonal performance factors can even be as high as those of brine/water heat pumps, a fact that could be proven in a prototype which will be shown at the booth.

This type of research supports the future developments of industry players to ensure even further growth and better energy efficiency of heat pumps – in order to help achieve the 20-20-20 target set by the European Union.

We look forward to seeing you at the ISH in Frankfurt!

content

The role of efficient components in heat pump systems

The Coefficient of Performance, COP, of a heat pump, and also the Seasonal Performance Factor, SPF, of a heat pump system depends on the heat pump unit and the heat source and heat sink distribution system. In order to achieve highly efficient systems, both the heat pump unit and the system in which it will operate in must be designed in an optimal way.

What is considered optimal is not always obvious. For the manufacturer of heat pumps, optimal could be a tradeoff between performance and manufacturing cost. The optimization would then be to minimize the manufacturing cost for a specific performance. For a house owner, the optimal performing heating product is one that minimizes the life cycle cost, LCC, for satisfying the heating demand of the house. In this case, the investment price and the operating cost for the heat pump system become important factors. Investing in costlier, but better performing components can result in higher investment costs, but lowered operating costs. The choice of components and the design of the heat distribution and control system can thus substantially impact the total heat pump system efficiency, and thus the LCC for the house owner.

Theoretical and practical limitations

The theoretical performance of heat pumps is often referred to by the Carnot COP:

$$COP_{Carnot} = \frac{T_1}{T_1 - T_2}$$

The Carnot COP represents a box in the T-s diagram where T_1 represents the condensation temperature (heat sink system) and T_2 the temperature of the heat source, but for many practical reasons, this box is never realized. The Carnot COP does not represent realistic conditions; instead the real heat pump cycle can be represented as Figure 1 depicts. Normally, one can expect that the COP is lowered by e.g. the need for a few degrees of superheating before entering the compressor. The deviation from the ideal Carnot COP is defined as the Carnot efficiency:

$$\pi_{Carnot} = \frac{COP_{Real}}{COP_{Carnot}}$$

Getting closer to the Carnot efficiency is one task that can be accomplished by better components. An interesting visualization of this was shown by Kopp [3], see Figure 2. In this Figure, it can be seen that given a specific source temperature, the effective cycle COP depends on the sink temperature and the Carnot efficiency.

In order to achieve Carnot efficiencies of 1, heat exchangers should have no pressure drop, the compressor should be able to compress refrigerant in the two-phase region, and then perform an isentropic compression. The expansion should also be isentropic. This cannot be achieved in practice, but could be a target to work against. The $COP_{effecitve}$ values along the line of $\pi_{Carnot} = 1$ then represent the theoretical maximum that can be achieved.

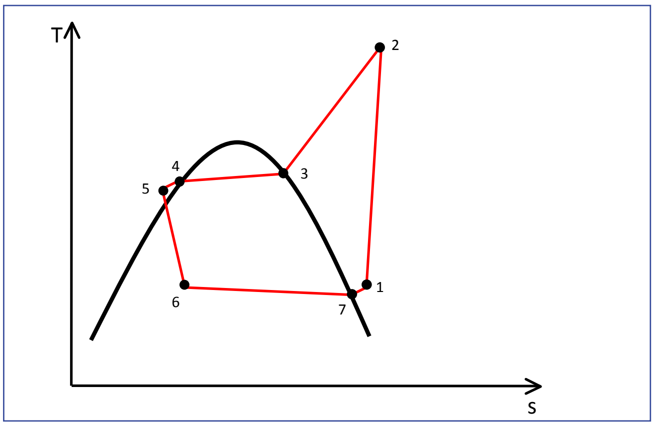


Figure 1: Real heat pump cycle in T-s diagram

SEPEMO system boundaries

In the IEE project SEPEMO-Build, a proposal for system boundaries and corresponding SPF calculation models for heating and cooling of heat pump systems for the use in field measurements has been developed [1].
For calculating the SPF for heating and cooling in heat pump systems, the system boundaries have been set to fulfill different

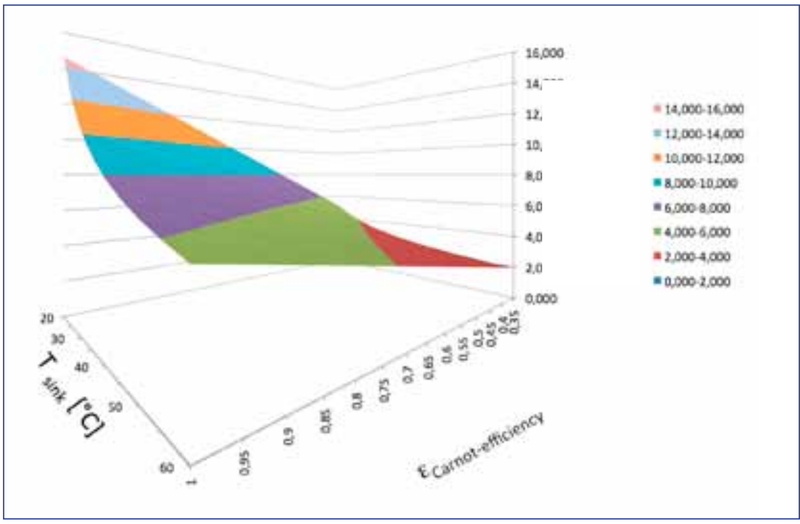


Figure 2: $COP_{effective} = f(T_{sink}, \pi_{Carnot-efficiency}, T_{source} = 0\ °C)$ [3].

needs. 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 (Figure 3).

This SPF-calculation method facilitates the quantification of the impact of the auxiliary devices like brine pumps and fans on the performance of the heat pump system. For the SPF of the whole heating system, also the "parasitic" processes such as fans, pumps, heating devices (e.g. oil sump heater) and control system energy use in the heat pumps should be considered. The SEPEMO project has defined the heating system SPF as

$$SPF_{H4} = \frac{Q_{H\_hp} + Q_{W\_hp} + Q_{HW\_bu} + Q_{DHW\_bu}}{E_{S\_fan/pump} + E_{HW\_hp} + E_{bt\_pump} + E_{HW\_bu} + E_{B\_fan/pump}}$$

Here it becomes clear that the energy used by pumps and fans to make the source available, as well as the pumps or fans in the heat distribution system influence the system performance. Even if the heat pump unit is very efficient, the system SPF can be low if the auxiliary components are low-efficient. It is therefore important to have the system design in mind also as a manufacturer of heat pumps, since a poor designed distribution will spill back on the heat pump performance.

Tiljander [2] made this analysis on a weekly basis for a field measurement in Sweden, reporting the system boundaries as "weekly Performance Factor (PF)" values since the evaluated time period was too short to call it SPF (Figure 5). In this figure, it is interesting to study the impact of certain components on the PF's. For example, it becomes apparent that the brine pump represents a PF drop of about 0.2–0.3 on a heat pump PF of between 4–5, corresponding to about 5 %.

Measures to increase the performance of heat pumps and heat pump systems

Figure 6 illustrates temperature level in a heat pump system for room heating. In order to maximise the heat pump performance the temperature difference in all heat exchangers between the source and the room temperature should be minimized. This includes the borehole heat exchanger (if GSHP – Ground Source Heat Pump), the evaporator, condenser and possible intermediate circuit exchangers. This can be achieved by either larger heat transfer surfaces, or more efficient heat exchanger types. In Annex 33 of the IEA Heat pump centre final report, a good summary of possible compact heat exchanger options is available [4].

Another important issue to remember is that the source temperature and the heat distribution temperature can change according to season and the heat demand by the house. Especially for ASHP (Domestic Air-Source Heat Pumps), this is the case for the source temperature. Regarding tThe condensing temperature, this can generally be lowered by lowering the heat distribution temperature. This can be done by installing enough heat transfer surface in the distribution system, either as radiators, fan coils or under floor heating systems. The heat pump control system should be able to adjust the condensing and evaporating temperatures for the heat pump efficiently, so that a higher condensing temperature than necessary is not used. For quick control, electronic expansion devices are preferred before thermostatic expansion devices. The control should also be able to manage capacity control, and eventually online optimisation optimization of the performance.

Pumps and fans, as well as electric motors to drive them and the compressor should be of high quality. In principle, PM motors (Permanent Magnet motors) should be used in all instances where they are available. The European Ecodesign directive [5] will ban motors, pumps and fans that are of very low quality, thus raising the "floor" of possible options for heat pump manufacturers.

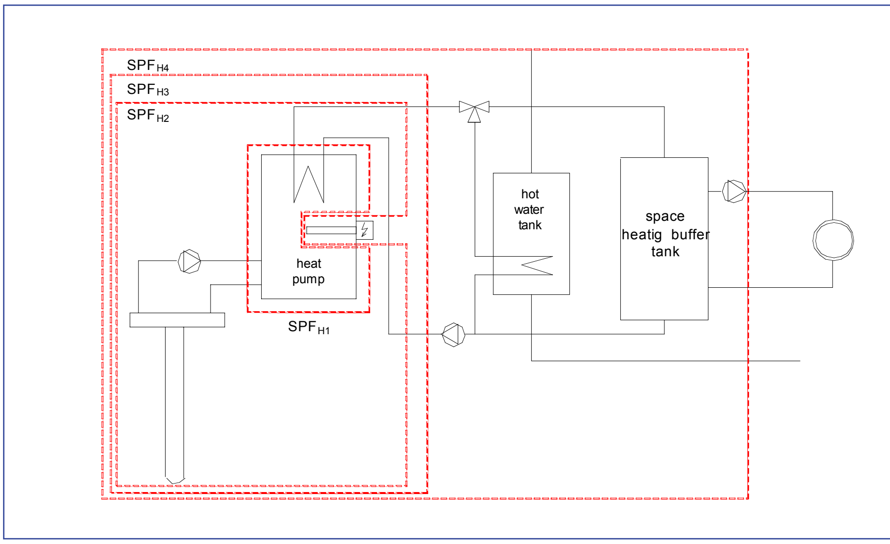


Figure 3. System boundaries for heating with a heat pump [1].

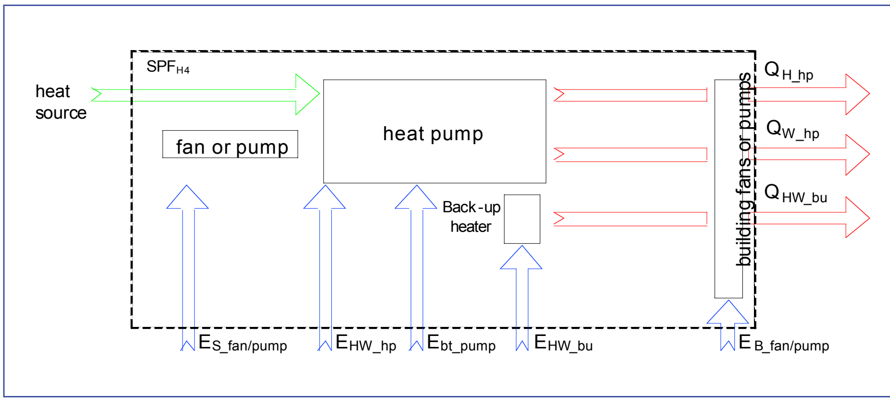


Figure 4. Energy use form different components to be considered in the system SPF.

In products including hot water accumulators, these should be well insulated, so that the heat pump doesn't heat water that later is lost through bad insulation.

System optimization

Although there are many options to improve different components in heat pump, it is of outmost importance to not to forget the total system optimization. There is an obvious tradeoff between the design of the heat exchangers and the installed pump or fan capacity. The heat exchanger design

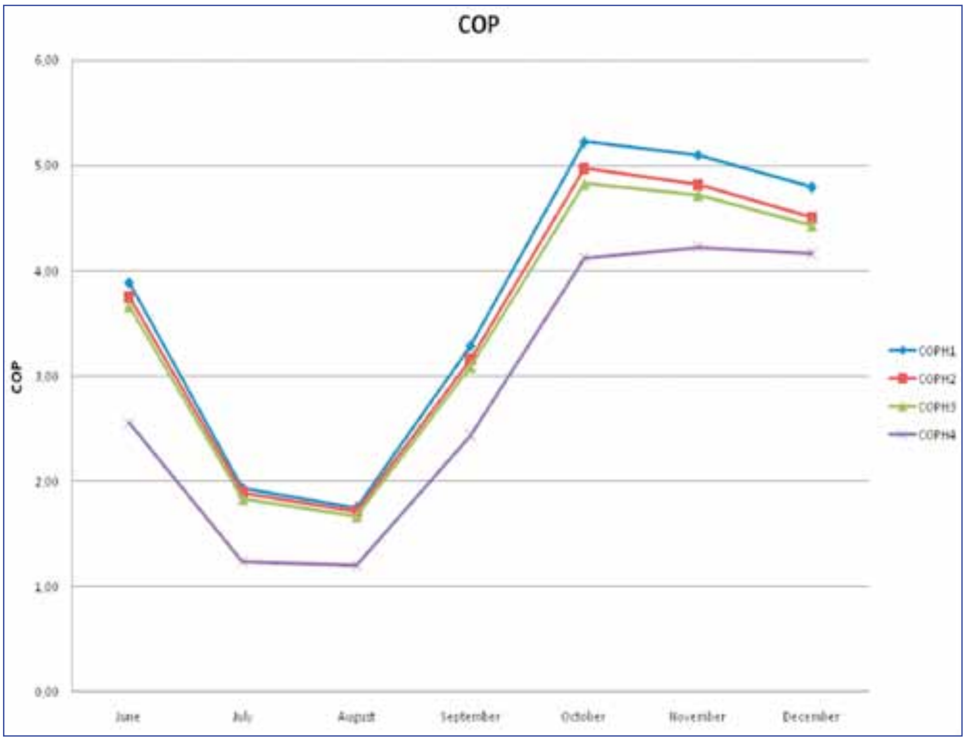


Figure 5. Monthly mean values of PF for a heat pump system according to the four system boundaries defined in SEPEMO-build [2].

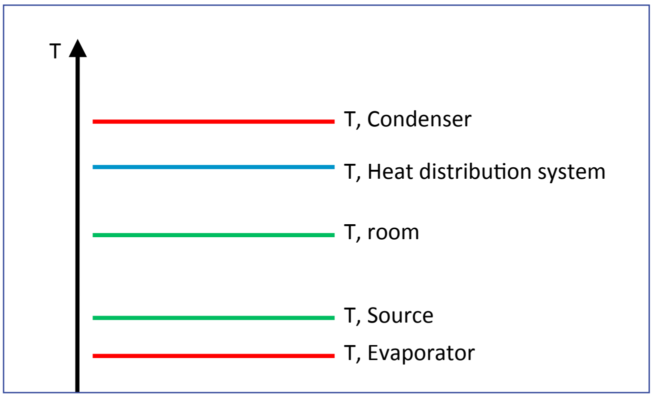


Figure 6. Temperature levels in a heat pump system.

must be designed so that the ΔT is kept low, while at the same time as the pressure drop shouldn't increase, since this would increase the electricity consumption, and thus lower the system SPF. An LCC optimization design could therefore be used to minimize the total cost for the end user. One challenge for the manufacturing industry with LCC optimization may be that the energy prices for the electricity used by the heat pump can be priced very differently throughout the market countries.

Conclusions

Rising energy prices will in the future motivate heat pump systems with high SPF, and thus investment in more efficient components . Better SPF can be achieved by:

- Low temperature distribution systems
- Large, efficient heat exchangers in all heat transfer processes (including radiators, floor systems and fan convectors)
- Efficient expansion devices and compressors
- Efficient motors, including variable speed control
- Control systems with adaptive optimization routines

The improvements of products must of course be made in such a way that the products still are still attractive on the market. For manufacturers of heat pumps it is therefore important to analyze the LCC of the product. This in turn makes it necessary to have a systems perspective on the heating system even if the core business is the heating product.

The implementation of the ecodesign directive will lead to a raised efficiency of components in the low end of the efficiency window. Besides, efficient components may also be important to have the high efficiency required to get product quality/efficiency labels such as e.g. the EHPA Quality label.

Roger Nordman, SP Technical Research Institute of Sweden, Andreas Zottl, Austrian Institute of Technology

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[3] Kopp T., Swiss Federal Office of Energy and University of Applied Sciences Rapperswil, Switzerland, presentation in the National Team Meeting 2009 of IEA Heat Pump Programme, Borås Sweden, 2009

[4] Reay, D., Compact Heat Exchangers in Heat Pumping Equipment, HPP-AN33-1, 2010

[5] DIRECTIVE 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products

High efficient air/water heat pumps with continuous capacity control

The use of air/water heat pumps (A/W-HP) as heating systems for residential buildings has rapidly grown over the last decade. A/W-HPs require only low investments, are easy to install and reliable in their operation. However, one of the most important prerequisites for the further proliferation of heat pumps is the substantial increase in their efficiency.

Introduction

The aim of the actual Swiss Federal Office of Energy (SFOE) research project is to develop universally valid design and planning criteria for the realisation of efficient, reliable and economic A/W-HPs with continuous capacity control.

With increasing ambient temperature, the heating capacity required by the building decreases. The behaviour of common A/W-HPs, whose compressor is operated at constant rotational speed, is exactly the opposite: the lower the heating capacity and heating temperature required, the higher the heating capacity and the discrepancy between heating temperature actually generated and required.

This behavior results in common HPs working in intermittent mode (on/off control) running at constant rotational speed of the compressor and is the reason for losses on efficiency of common A/W-HPs with on/off control. With increasing ambient temperature, the Coefficient of Performance (COP) of such heat pumps does indeed increase. In contrast to this, the exergetic efficiency decreases, see figure 1. The thermodynamics of heating would ge-nerally enable the exergetic efficiency to increase.

The increasing discrepancy between required and generated heating capacity and temperature has the effect of causing temperature gradients for heat transfer in the evaporator and condenser to increase as well. The actual temperature lift generated decreases less significantly in comparison with the ideal temperature lift. As a result the exergetic efficiency itself is considerably reduced.

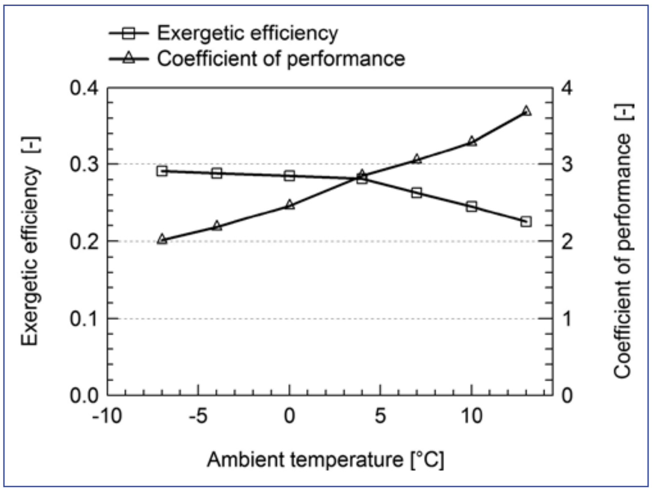
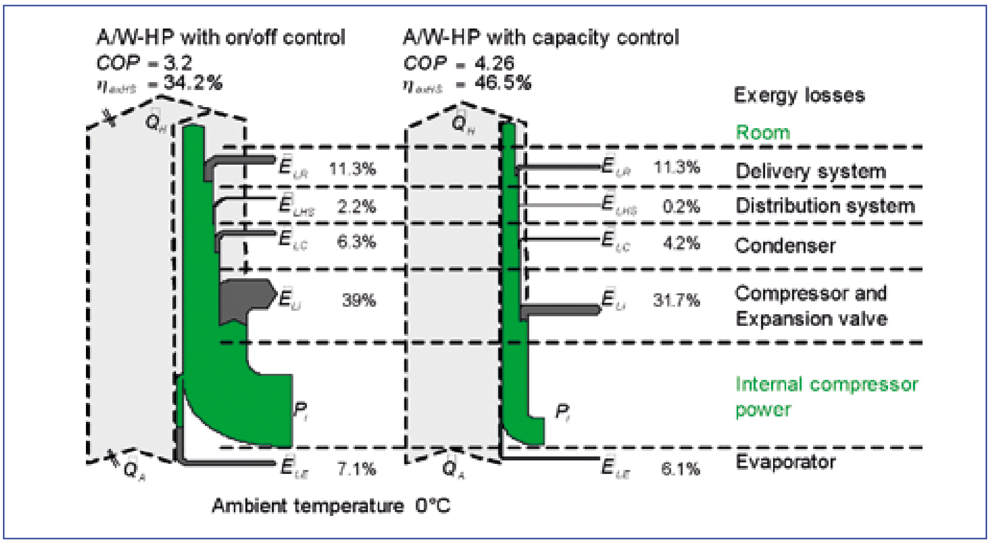


Figure 1: Exergetic efficiency and COP of real A/W-HP with on/off control (measurements)

Figure 2 (left) shows the energy/exergy flow diagrams including the exergy loss ratios for the entire heating system with an A/W-HP with on/off control. The exergy loss ratios, i. e. the exergy loss flow with reference to the internal compressor power, show directly the subtractive effect of the exergy losses on the exergetic efficiency.

The best efficiency, see figure 2 (right), can be achieved by

Figure 2: Energy and exergy flow diagram for the entire heating system with on/off controlled (left) and continuous capacity controlled (right) A/W-HP



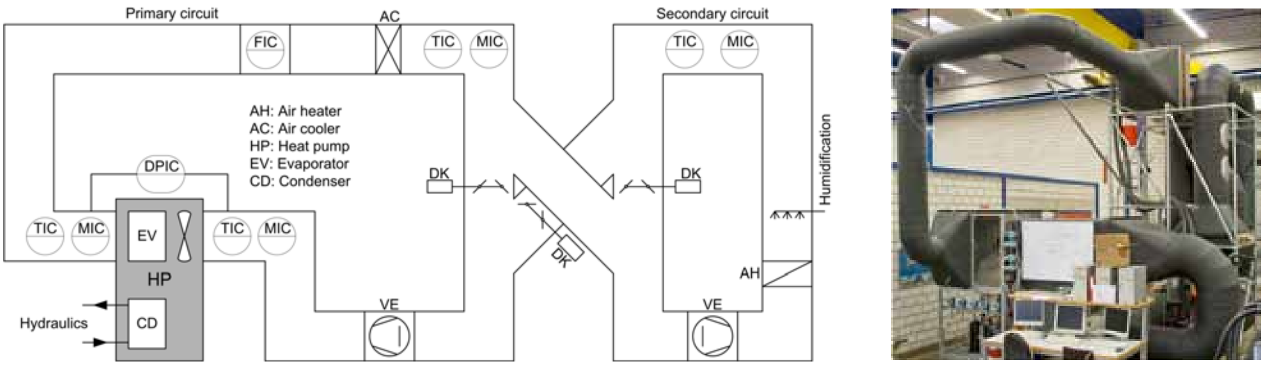


Figure 3: Left: Schematic diagram of the heat pump test rig. Right: Photograph of the heat pump test rig and the heat pump prototype

using continuous capacity control of the compressor and the fan. Detailed investigations show that, in the case of a continuous capacity controlled A/W-HP, the part load efficiencies of the fan and especially of the compressor have a significant effect on the SPF and the annual average exergetic efficiency.

Experiments

To verify the theoretical findings and to investigate different control strategies a heat pump test rig as well as heat pump prototypes with continuous capacity control at the design criterion –10°C ambient temperature for monovalent operation have been realized.

Figure 3 (left) shows the schematic diagram of the heat pump test rig. The test rig consists of two air circuits, a primary and a secondary. This design allows a high dynamic of the air conditioning and stable test conditions, which is necessary for the defrosting processes. The resulting deviations from the target values are significantly lower than those specified in the EN 14511. The built-up heat pump test rig is shown in figure 3 (right).

The A/W-HP prototypes were equipped with two variable speed compressors, identified as 1st Gen and 2nd Gen that enable continuous capacity control over a wide range of the part load ratio (f = 25–100%). The 2nd Gen compressor had been optimized for HP applications and was equipped with a vapour injection system.

In the design and layout stage of all prototypes, it was decided that each prototype had to be built as simple as possible. From this basis all additional components not totally necessary were excluded from the prototype. The design of the evaporator had to be made in conjunction with the selection of the fan. Also, to minimize the fan power consumption, the air side pressure drop was kept as low as possible across the evaporator and the fan was maintained at maximum efficiency. The A/W-HP prototypes and test rig were equipped with extensive measurement devices, so that all relevant process variables could be measured.

Results

The experiments were carried out for two different heating curves. The first one is a typical heating curve of a building based on the “Minergie” standard (Swiss standard for low energy buildings, www.minergie.ch) with low heating temperature requirements and a low heating limit, see figure 4 (left). The second one is a heating curve of a reconstructed old building that required higher heating water temperatures and a higher heating limit, see figure 4 (right).

The achieved COP values, including the fan, based on a "Minergie" heating curve as a function of ambient temperature are shown in figure 5 (left) for both A/W-HP prototypes. The resulting COPs for the variable speed compressor of the 2nd Gen above an ambient temperature of –2°C were found to be lower than those for the compressor of the 1st Gen. For ambient temperatures below -2°C, the COP of the compressor of the 2nd

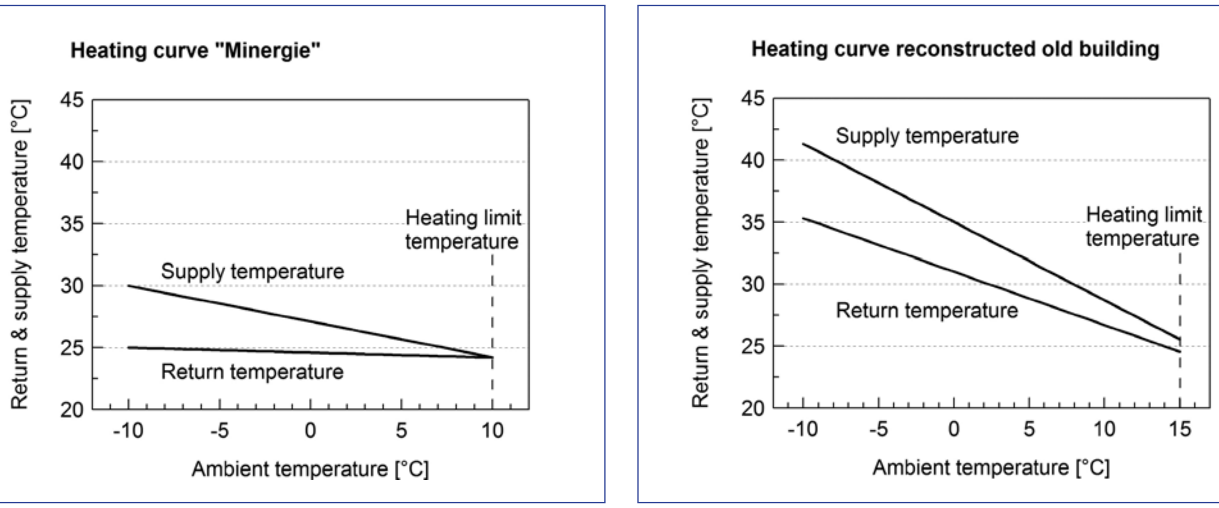


Figure 4: Left: Heating curve of a “Minergie” building. Right: Heating curve of a reconstructed old building

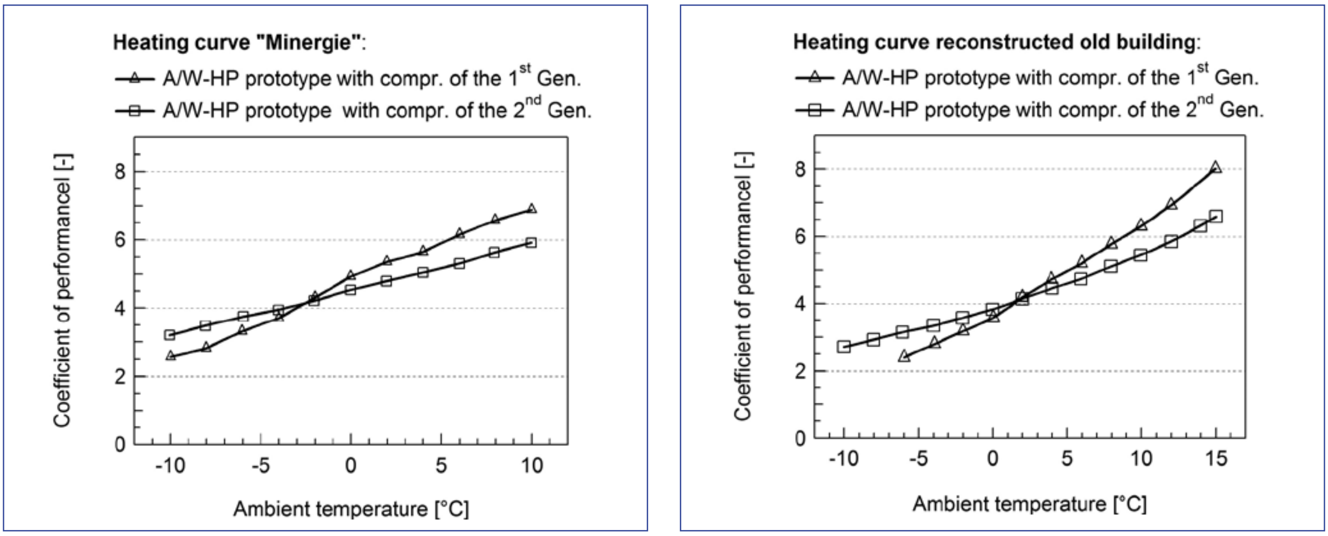


Figure 5: Left: COP based on a heating curve of a "Minergie" building. Right: COP based on a heating curve of a reconstructed old building

Gen was higher. This result shows that the compressor of the 2nd Gen, which had been optimized specifically for HP application, has the best performance in the case of higher temperature lifts.

The resulting COPs, including the fan, for the heating curve of a reconstructed old building are shown in figure 5 (right). It was found that below ambient temperatures of 2°C higher COPs were obtained when using the compressor of the 2nd Gen compared to the 1st Gen compressor. The resulting COPs for ambient temperatures above 2°C were found to be below the values of the compressor of the 1st Gen.

Table 1 shows the Seasonal Performance Factor (SPF), including the fan, of the capacity controlled A/W-HP prototypes for the "Minergie" heating curve and for the reconstructed old building. For this calculation method the defrosting processes are not taken into account. However, the SPF based on the heating curve for the reconstructed old building and compressor of the 1st Gen at 10°C ambient temperature was extrapolated since the maximum torque of the compressor had been reached at –6°C ambient temperature.

Heating curve	Minergie		Reconstructed old building	
Heat pump prototype	1st Gen	2nd Gen	1st Gen	2nd Gen
SPF	5.0	4.6	4.9	4.5

Table 1: SPF, including the fan, for the capacity controlled A/W-HP prototypes for the "Minergie" heating curve and for the reconstructed old building

The compressor of the 2nd Gen allows efficient operation at low ambient temperatures, i.e. high temperature lifts. Table 1 shows that the SPFs for the compressor of the 2nd Gen are slightly lower, since the distribution of the cumulative frequency at higher ambient temperatures in Zurich were more strongly weighted. The COP of the compressor of the 2nd Gen rises less significantly at higher ambient temperatures compared to the compressor of the 1st Gen, see figure 5. The capacity controlled A/W-HP prototypes with the compressors of both the 1st and 2nd Gen achieved SPFs well above the values of standard A/W-HPs running with on/off control. Today, typical SPF values for A/W-HPs are in the range of 3 to 3.5.

Conclusions

The reason for the comparatively moderate efficiency of common A/W-HPs with on/off control is due to the unfavourable operating characteristic, which results from the use of a constant speed compressor. However, through the continuous adjustment of the generated to the required heating capacity the efficiency of A/W-HPs can be increased considerably. A necessary prerequisite for achieving efficient A/W-HPs with continuous capacity control is the use of compressors and fans with a wide control range and high part load efficiencies.

Additional potential for an increased efficiency of A/W-HPs can be achieved by defrosting with continued ventilation. The key to defrosting with continued ventilation is the state of the ambient air. In addition to the air`s temperature, the air humidity must be considered mandatory.

Acknowledgements

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Energy-saving fans for air/water heat pumps

ebmpapst

Protecting the climate and securing our energy supply requires using innovative technologies as comprehensively as possible. At the same time, the heat supplies of new buildings today demand concepts that use renewable energies instead of fossil fuels

With air/water heat pumps, renewable aerothermal (energy from outside air) can be used for heating buildings and for preparing hot water. State-of-the-art EC fans substantially contribute to this, enabling today's heat pumps to operate very efficiently and thus cost-effectively.

Today, air/water heat pumps are available on the market in two versions, configured to use either indoor or outdoor installations (see Fig. 1a, b).

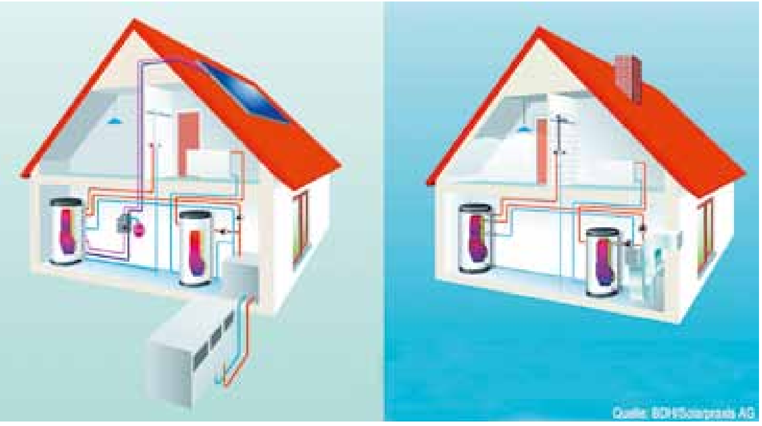

Figure 1a and b: There are air/water heat pumps for either outdoor installation (a) or indoor installation (b) (image source: BDH/Solarpraxis AG)

Each places different requirements on the fans used. With the indoor configuration, the external air is drawn in through one duct and blown out through another. Centrifugal fans lend themselves to this application area, since they are generally suited for a high pressure build-up. The fact that they are highly compact also proves beneficial for the air/water heat pumps installed indoors, since in this case available space is limited space. Space requirements are usually less of a problem for outdoor configurations. Here, the evaporator is attached as an offset exterior unit with a refrigerant pipe leading inwards. Another possibility is to exchange the heat outside using a brine heat exchanger and to integrate the refrigerant circuit completely on the inside. Such installations usually use axial fans.

Axial and radial fans in all sizes

In order to offer the right fan solution for every air/water heat pump, the motor and fan specialist ebm-papst Mulfingen offers both axial and centrifugal fans in different sizes: In the area of heat pumps, centrifugal fans of a diameter up to 630mm and axial fans of a diameter up to 910mm are mainly used, with which air performance levels of up to 30,000 m^3/h can be achieved. These fans are powered by modern EC motors, which are available in various sizes, depending on the power output required. In each case, the user benefits from the advantages of ebm-papst's GreenTech EC technology in several ways:

Air/water heat pumps must deal with the issue of noise development. Both the compressor and the fan used are relevant sources of noise, and should work as quietly as possible. An important basis for quiet operation of the fans is provided by the harmonious interaction of the fan impellers or blades with the motor and electronics. The HyBlade® axial fans and the RadiCal® centrifugal fans with GreenTech EC technology benefit from the latest insights in aerodynamics (Figure 2). The geometry of the blades and impellers was optimised to achieve significant improvements in terms of efficiency and noise behaviour. The noise behaviour is particularly important during the night hours indoors, but also outdoors when the limit values of DIN 18005 and German Technical Instructions on Noise Abatement (TA Lärm) must be complied with. An additional advantage results from easy to control EC motors whose speed (influencing the noise emission) can be reduced at night. If the speed of the sample fan is reduced by merely 100 rpm, a noise reduction of more than fifty percent can be achieved (Figure 3). In addition, the continuously adjustable fans can simplify the defrosting of the evaporator that has to be carried out from time to time. During the defrosting process, the fan continues to run at low speed without pumping large volumes of air. This avoids the possibility of the fan freezing, and may eliminate the need for vent heating, depending on the design and construction of the heat pump. If defrosting is not conducted regularly, but rather according to requirements, the current speed value of the fan can be used for monitoring. A drop in speed indicates a possibility of icing.

Compact energy savers

As part of the ErP Directive, legislation in Europe has specified minimum requirements for fans. Fans with asynchronous

Figure 2: The HyBlade® axial fan (left) and RadiCal® centrifugal fan (right) with GreenTech EC technology for use in heat pumps (image source: ebm-papst)

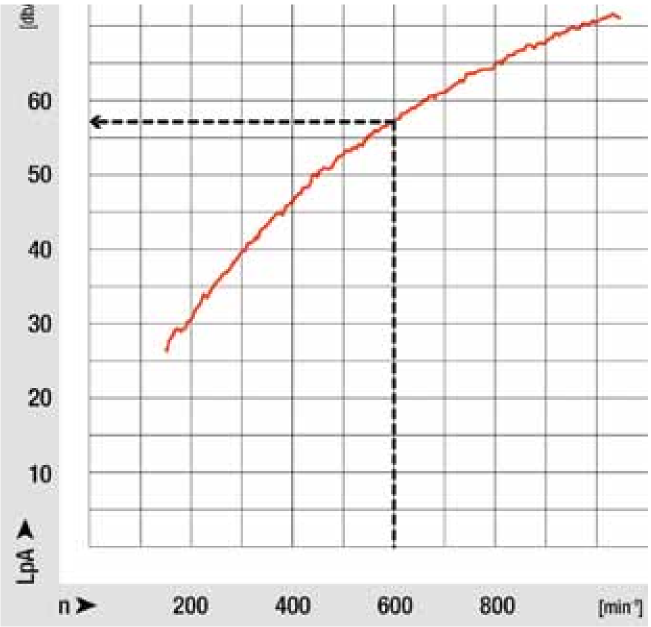

Figure 3: Dependency of the sound pressure on the speed for a centrifugal fan of size 630. If the speed is reduced by only 100 rpm, the noise can be reduced by more than 50 percent (image source: ebm-papst).

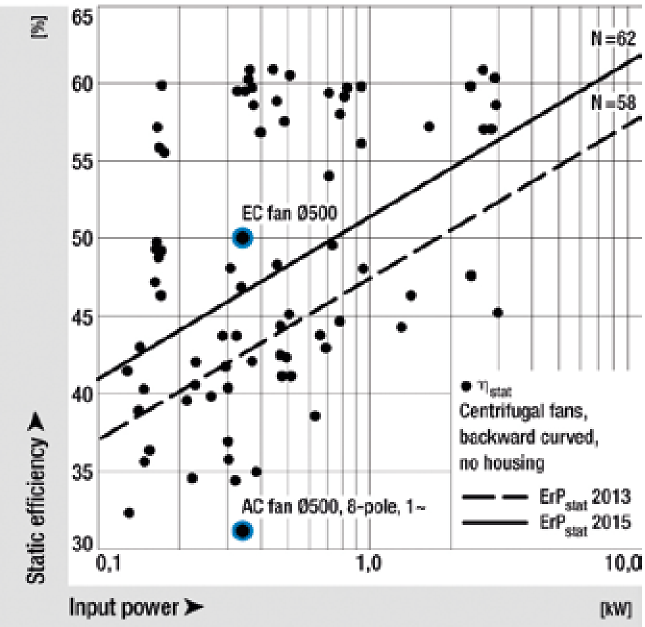

Figure 4: ErP minimum requirements for centrifugal fans without a scroll housing and efficiencies of centrifugal fans common in the market. The example shows a centrifugal fan of size 500, once equipped with an asynchronous motor and once equipped with a GreenTech EC motor.

motors still used today often do not achieve the set limits and will have to be replaced with more efficient fans as of 2013 or 2015 at the latest.

In terms of their efficiency, the "RadiCal" and HyBlade® fans with GreenTech EC technology far exceed the soon-to-be-required ErP minimum level of efficiency even today. The compressor for a heat pump consumes much more electricity than the fan. However, it still pays for itself if the fan works with maximum efficiency. Compared to conventional AC fans, they consume up to 50% less energy. These are many reasons explaining the increasing use of fans with GreenTech EC technology in air/water heat pumps. A trend that will surely intensify in the future.

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Heat pump city of the year: Interested communities invited to register

The race is on! Europe's climate protection and energy savings targets are demanding. It requires immediate action on all political levels to achieve meaningful results by 2020 already. Heat pumps are an available, reliable, efficient and cost effective solution in this quest. Unfortunately the technolog is often very well hidden in basements and technic-rooms of buildings.

The European Heat Pump Association has taken this as a challenge decided to inaugurate a new award: "The heat pump city of the year".
The trophy will be given to that very city that has shown the biggest effort in integrating heat pumps into its energy infrastructure (measured as additional heat pump installations per 10 000 inhabitants. The winner will be selected by an expert jury from the heat pump industry and from Eurocities, a head-organization of European cities representations in Brussels. If you are interested, mail us at info@ehpa.org!

The award will be handed out to the winner at the Sustainable Energy Week Europe on 14.04.2011 (Charlemagne Building).

Improving heat pump performance with a Brazed Plate Heat Exchanger

With a market incessantly demanding increasing efficiency from heat pumps, all components of the heat pump must be smartly designed to contribute to energy savings. SWEP's brazed plate heat exchangers (BPHEs) are key components in many heat pumps, both Air-to-Water (A-W) and Ground Source / Brine to water (B-W). They are designed to increase energy efficiency through their asymmetric plate pattern and optimized distribution system.

BPHEs can be used as evaporators or condensers in ground-source heat pumps, and as condensers in air-source heat pumps. In this article, we will focus on how BPHEs can increase the energy efficiency of both evaporators and condensers.

Energy efficiency is measured as the COP (Coefficient of Performance). A heat exchanger can influence the COP of a heat pump in two ways: by reducing the compressor pressure gap and by improving the evaporation temperature.

Benefits of reducing the compressor pressure gap

The compressor compresses the refrigerant gas from point 1 (PEvap) to point 2 (PCond), as shown in Figure 1. The smaller the pressure gap, the less electrical energy is needed to operate the compressor. A higher evaporation temperature and a lower condensing temperature (shown as blue arrows in figure 1) will improve the COP of the system, because the pressure gap to be bridged by the compressor is smaller.

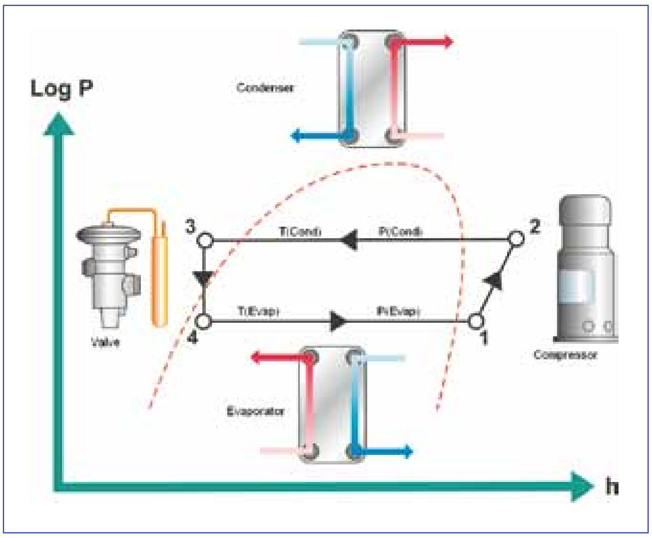
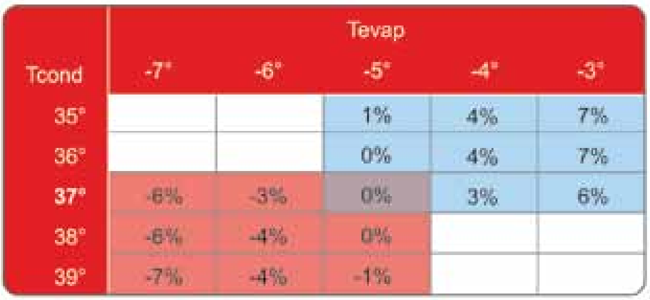


Figure 1: Heat pump system showing key components and definitions

Benefits of improving the evaporation temperature

The BPHE can further influence energy efficiency in a heat pump by improving the evaporation temperature. A BPHE designed for use as an evaporator or condenser can improve the saturation temperatures TEvap and TCond by several degrees centigrade, substantially improving the COP.

Furthermore, improving TEvap gives a better payback than corresponding efforts to improve TCond. Compressors have a fixed displacement volume, i.e. the swept volume compressed on each rotation of the shaft. If the evaporation pressure is increased, yielding a higher TEvap, the density of the gas increases. This means that for the same swept volume, the resulting mass flow of refrigerant will be larger. This higher mass flow will yield in more available useful energy for heating the building. The benefits of improving TEvap are double those of improving TCond.



	Tevap				
Tcond	-7°	-6°	-5°	-4°	-3°
35°			1%	4%	7%
36°			0%	4%	7%
37°	-6%	-3%	0%	3%	6%
38°	-6%	-4%	0%		
39°	-7%	-4%	-1%		

Figure 2: Impact of an improved TEvap on the available heat load in a condenser.

Designing a BPHE for high-efficiency heat pumps

The performance of a BPHE can be influenced via three design parameters. The thermal length of the BPHE influences how efficiently heat is transferred between the refrigerant and the water. A low pressure drop on the water/brine side enables a smaller pump to be used, consuming less energy. Finally, an even distribution of the refrigerant in the evaporator guarantees that all surfaces are used efficiently.

Finding a balance between thermal length and pressure drop

Heat transfer in the BPHE is based on complex plate patterns whose convoluted channels minimize film resistance by inducing turbulence. High turbulence reduces the film coefficient, resulting in very efficient heat transfer even at low fluid velocities. As a result, a BPHE achieves optimal turbulence at a fraction of the flow required in a shell & tube heat exchanger.

However, the turbulence will be excessive if the channel is too complex and narrow, which can dramatically increase the pressure drop on the water/brine side. In this case a more powerful pump is required to circulate the water or brine. This will consume more energy, reduce the COP and require a larger, more expensive heat pump.

The solution lies in the BPHE's plate pattern design, and in particular in asymmetric technology, where the refrigerant and secondary sides have different plate patterns. AsyMatrix™ BPHEs, developed by SWEP, successfully combine extended thermal length with low pressure drop.

Increased heat capacity enables the evaporator to be equipped with more plates, increasing the number of parallel channels for the fluid to pass through. However, this increases the risk of the refrigerant mixture being distributed unevenly at the inlet of the evaporator. This effect is commonly known as maldistribution. It is triggered by pressure differences inside the evaporator, caused by refrigerant that has turned into gas and expanded in volume. The gas therefore tends to take short-cuts that distribute the refrigerant unevenly over the different parallel channels.

Maldistribution causes two problems. First, the BPHE is not utilized efficiently, because some channels are filled with gas rather than liquid. Second, the amount of superheat required to reach system stability must be increased because the channels filled with liquid will not achieve 100 % evaporation.

SWEP has addressed the problem of maldistribution with distribution rings or distribution pipes optimized for the operating conditions in heat pumps. Small holes in the distribution rings create a high pressure drop at the entrance of the evaporator. This overcomes the problems of the dynamic pressure difference inside the evaporator because the shortcuts are eliminated. All the liquid refrigerant becomes evenly distributed over the BPHE channels, giving extremely efficient evaporation.

A BPHE with a distribution system optimized for heat pumps can easily operate with an evaporation temperature 2–3 K higher, using the same surface area.

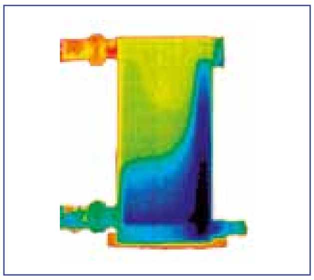


Figure 3: Maldistribution of the refrigerant mixture in the evaporator inlet. Green channels are filled with gas; blue channels are filled with liquid. Heat cannot be transferred efficiently in the green, gas-filled areas.

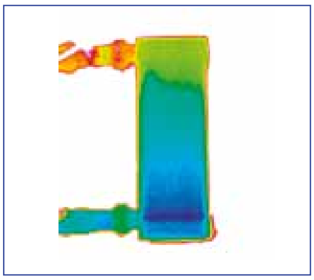


Figure 4: Maldistribution is eliminated through distribution rings that distribute the refrigerant evenly over the BPHE channels. The blue areas show the even liquid distribution.

In summary, BHPEs offer many ways to increase heat pump efficiency, with particular benefits from reducing the compressor pressure gap and improving the evaporation temperature. BPHEs are designed to deliver maximum efficiency in heat pumps by finding a balance between thermal length and pressure drop and by providing solutions to overcome the drawbacks of maldistribution.

Adam Dahlquist M.Sc
Segment Manager Heat Pumps | SWEP International AB

WILO

Impact of circulators components on heat pump efficiency

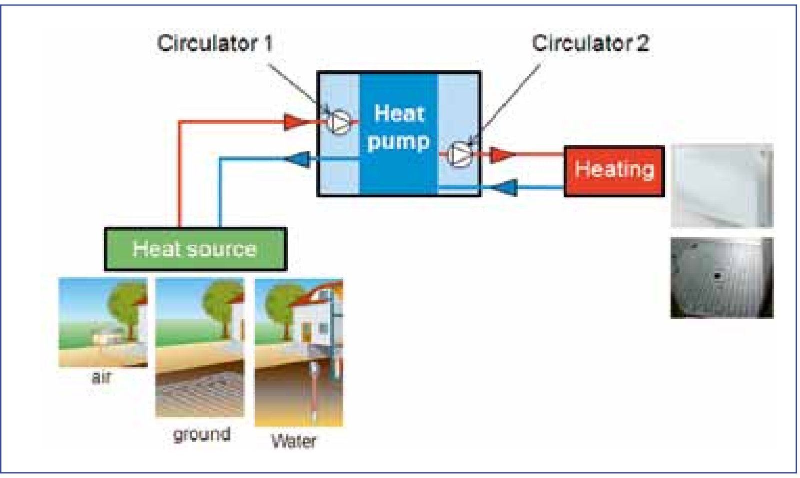


Figure 1: typical heat pumps systems incl. pumps

Typically, two circulators are part of a heat pump. Circulator 1 for the heat source circuit and circulator 2 for the heating circuit (figure 1).

The electrical energy demand for the circulators is part of the total demand of electrical energy for the operation of the heat pump. Hence the circulator's efficiency directly influences the coefficient of performance (COP) of the heat pump.

A modern "High efficiency circulator" (figure 2) with an EC-motor can reduce the power consumption up to 70 % in comparison to standard circulators with an asynchronous motor. Example calculations – based on European EN-standards – have shown that the COP value increases by 0,2...0,3 points if "High efficiency circulators" are installed in the heat pump.

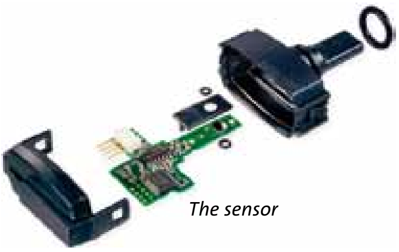
Figure 2: Stratos Para high efficiency pump

An additional aspect is, that a "COP"-improvement based on a higher circulator's efficiency achieves a very good cost / benefit relation in comparison to other technical modifications.

This aspect has been recognized by the European Commission which declared high efficiency circulators the future standard in its legislation for circulators (Regulation EC/641/2009). This Regulation establishes ecodesign requirements for the placing on the market of glandless standalone circulators and glandless circulators integrated in products. The core of the legislation is the Energy Efficiency Index (EEI), which is an indicator for the efficiency of the circulator. It sets two target dates for increasing the efficiency requirements: 1 January 2013 and 1 August 2015. The measurement methods are also described in the regulation. The required EEI values are not reachable by "old" standard circulators (Asynchronous motor).
In todays heat pump systems, most manufacturers have made the stop towards more efficient circulators already.

Ingo Fabricius | Wilo AG

Monitoring of heat pumps using direct sensors


The sensor

In recent years heat pumps have been accepted as an important solution for reducing the dependency on fossil fuels in the European energy system. As they provide renewable energy to households, commercial buildings, industrial processes etc. this seems to be a sound and natural development.

As the technology is getting more important in the European energy policy this will inevitably lead to higher demands on heat pumps in the future. Manufacturers need to address product quality (compared to replacing well proven designs of wall hung gas boilers), price and energy efficiency. This leads to a demand for cost effective solutions, which allows the manufacturer to monitor, control and display the energy efficiency of the systems.

Energy efficiency

When talking about efficiency of heat pumps, the coefficient of performance (COP) is a well-known parameter, which provides the ratio between electricity consumption and the production of heat under given sets of conditions. However the customers and governments providing subsidies to heat pump solutions are much more interested in the actual seasonal performance factor (SPF), which provides the performance over a season and thereby the actual saving of energy. The SPF also gives the customer the opportunity to document the renewable energy extracted from the ambient environment.

The expected value can be approached via calculations according to standards using temperature bins. But for the individual system, monitoring the actual electricity being consumed and heat produced gives a more correct and reliable value, and gives the opportunity to follow the efficiency over time. This enables a continual optimization of the heat pump operation.

When for instance installing a ground source heat pump, the overall efficiency will depend amongst others on the correct installation and dimensioning of the collector system in the ground, and similar with other types of heat pumps on the choice of heat pump compared to heat consumption in the building and correct servicing of the system.

SPF is also a measure, which is completely blind to the ways that the heat pump manufacturer has chosen to design and control his system. This therefore supports a fair and transparent market for the manufacturers, consumers and governments providing subsidies in the transition towards a less fossil dependent society.

The Sensors

Today, Grundfos Direct Sensors™ can supply cost-effective sensors for measuring flow or pressure combined with temperature. These sensors have been specially developed to meet the demands of OEM producers of heat pumps with regard to flow, pressure and temperature ranges. The sensors provide reliable, accurate and affordable solutions for the continuous monitoring of flow, pressure and temperatures in both the heat distribution system (drinking water and for heating), as well as in a ground source system.

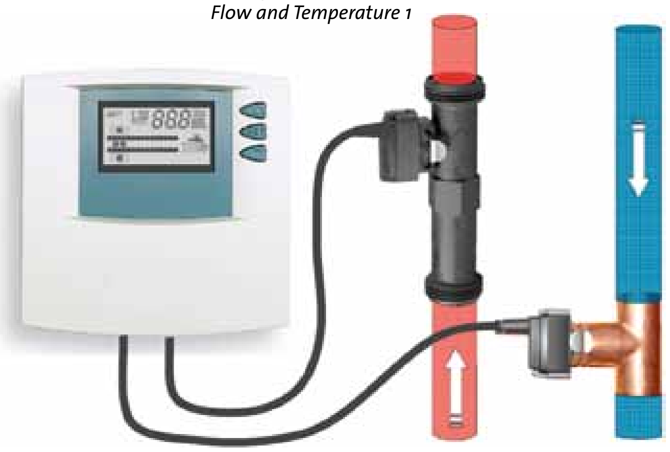
As an extra possibility, Grundfos Direct Sensors™ have developed complete heat meter solutions, where the sensors work together with the estimator, which allows the customer to read out a number of relevant data of the system - including the heat production of the system and the SPF value, if an electricity-meter is incorporated. These solutions have been developed together with suppliers of electronic controls and integrated specifically for and in heat pumps.

The sensors have been developed within the Grundfos Group since 1994. The sensor takes the advantages of a patented and cost effective metal-glass alloy coating that protects the silicon sensing element and gives high accuracy in aggressive media. It makes it possible to place the sensor element in direct contact with a medium giving fast response times. Regarding the signals, the flow signal is updated every 462 ms and the temperature signal is updated every 154 ms. Furthermore the sensor is a 2in1 sensor, meaning that a flow- or pressure sensor will always have a temperature measurement included. Therefore it is possible to do heat metering using only a flow and a pressure sensor, keeping it simple.
Before, a multitude of sensors were needed, adding complexity and thereby quality overhead plus extra cost of manufacturing.

Using sensors signals actively

Reading the SPF value is a way to see if the system is running properly with the expected energy efficiency over a given time (season). In addition, as the sensors are installed and often integrated directly in the controller of the heat pump, it

Grundfos VFS to measure:
Flow and Temperature 1



Grundfos RPS to measure:
Pressure and Temperature 2

provides the extra opportunity to use the signals more actively to improve energy efficiency in the given operation situation (COP) and to help secure liability of operation.

COP. Comparing the currently COP value with the given temperature levels in the ground loop and in the domestic loop gives a real time picture of the performance, and allows comparison of COP on a regular basis to detect any potential decrease in efficiency.

T control. Makes it possible to measure and control the heat pump according to the temperatures in the ground loop and in the distribution system.

Delta T control. Measuring temperature differences makes it possible to keep a constant temperature difference between inlet and outlet of the secondary cooling media at the evaporator.

Min. Pressure control. Monitoring of the pressure in the ground loop.

Min. Flow control. Utilizing a flow sensor gives the opportunity to ensure that there is a minimum flow in the loops before the heat pump is started up securing that the heat pump does not trigger pressure switches.

Ongoing activities

The sensors are currently undergoing a test program according to the standard EN 1434 at The Danish Technological Institute in order to allow Grundfos Direct Sensors™ to document for their costumers, that the sensors meet the demands in the standard.

Also recently Grundfos Direct Sensors™ have been supplied to Energinet.dk, the TSO of Denmark, with sensors for monitoring heat production of heat pumps in 300 households, where the heat pumps will be used actively to balance the grid. This test will provide valuable knowledge about the use of heat pumps in the intelligent electricity grid, and how to facilitate a fast changing energy mix.

At GRUNDFOS, we call it "FUTURE NOW", as the technologies and products already exist to generate a more sustainable future.

Grundfos Direct Sensors™
Klaus Frederiksen, B. Sc. Mech. Eng | Per Andersen, Physicist, Ph.D.
Klaus K. D. Kattenhøj, M.Sc. Economics

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Energy saving on ground source heat pumps with brushless DC compressor (BLDC) and electronic expansion valve

Inverters are commonly used in air-water heat pumps. This article provides evidence on the fact that they can also beneficially be employed in water-water units.

CAREL uses the pCO platform controller to manage the inverter driven compressor, with the focus on both protecting the compressor and optimizing management of the overall unit. The overall aim of the controller is to guarantee a stable condenser or evaporator water inlet or outlet temperature.

To do this, however, the compressor must be protected during the start-up phase, respecting the speed ramps provided by the manufacturer, while maintaining operation within the envisaged pressure range (envelope management). This is achieved by the controller, which manages the compressor as well as the electronic expansion valve and the system pumps. Electronic expansion valves replace traditional thermostatic expansion valves which would not be able to respond to the dynamics of the compressor. In this way, the operation of the various components can be actively coordinated.

The inverter manages all electrical and mechanical parameters for the BLDC compressor. It also contains the firmware with the default values provided by the manufacturer for managing the acceleration and deceleration ramps (figure 1). These ramps are used to manage the start-up procedure and control the speed at which the inverter varies the compressor frequency so as to protect it against mechanical or electrical damage.

Integration with the electronic valve allows procedures that exploit the information supplied by the compressor controller:

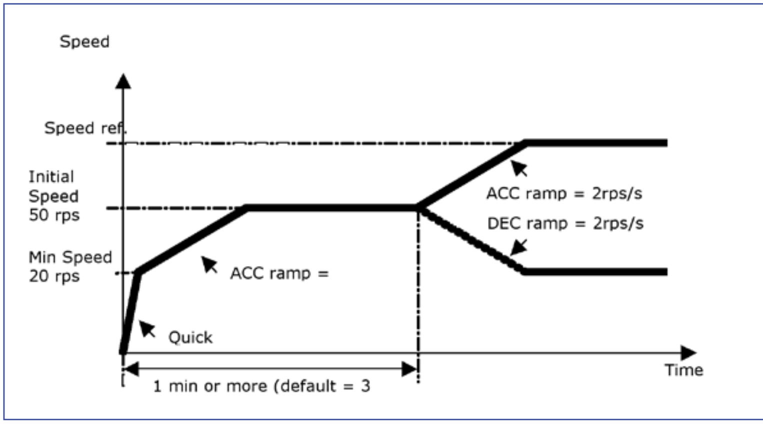

Figure 1: Acceleration and deceleration ramps for SIAM ANB33 compressor

the valve can therefore anticipate changes in capacity, completing pre-positioning movements based on the change in the operating conditions of the compressor.

The envelope provided by the manufacturer is divided into three parts (see figure 2):

- Area no. 2 represents normal compressor operation. This has no speed limits (in this case, from 20–120 rps) and the discharge temperature must remain below 120 °C.
- In area no. 1, operation again covers the entire speed range (20–120 rps), however the discharge temperature limit is reduced to 110 °C.
- In area no. 3, the speed range is reduced (20–90 rps) while the discharge temperature must remain below 120 °C.

When the evaporation and condensing pressure approach the envelope limits, the controller responds dynamically limiting the units operation to the operating boundaries.. This objective is achieved not only by controlling the compressor speed, but also the speed of the pumps and opening of the expansion valve. The result is a compromise between temperature control and compressor protection, represented by the envelope, while also trying to maximize energy efficiency.

The data acquisition system (based on LABVIEW) dynamically monitors all system parameters and visualizes them in three main graphs (compressor temp., Mollier chart and envelope).

Comparison of fixed to variable speed solutions

The main objective of the comparative tests was to evaluate the effective energy saving that can be achieved using the variable speed solution in part load conditions. In this condition a compressor operating with a differential band will be inefficient due to the repeated on/off cycles resulting in a reduction in overall COP. In addition, AC Inverter and BLDC Inverter technology were compared.

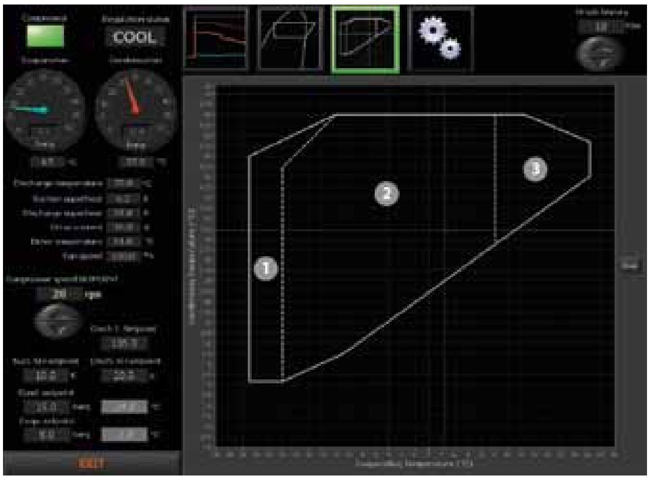

Figure 2: Compressor envelope

On-off operation was set for the unit to start at 27 °C and stop when reaching 29 °C, the average water outlet temperature was 34 °C. In operation with the inverter, the set point was set at 28 °C, maintaining the conditions in the climate chamber, the water flow-rate to the heat exchangers and the condensing temperature constant at all times.

The definition tests of the AC variable speed compressor showed an efficiency maximum between 65 and 80 Hz. The BLDC compressor achieved its maximum efficiency at around 50 % of its speed range (60 rps); in addition, at the limits of the range, there is a lower decline in COP compared to the AC compressor.

The trend in the efficiency of the traditional compressor depends on the time it remains on, with a longer “on-time” resulting in more stable conditions, and a shorter “on-time” resulting in inefficiencies due to on-off switching of the unit.

The observations from the definition tests were confirmed by the results of the comparison: when the load means temperature, control can stabilize within the range of frequencies relating to maximum efficiency of the variable speed compressor. Energy saving, calculated as higher power consumption of the on-off compressor compared to the inverter unit, is also maximized.

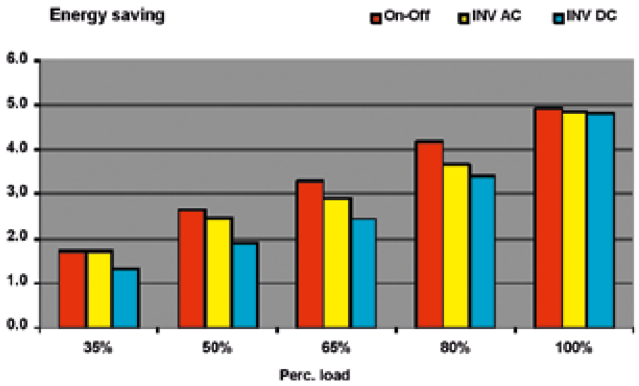

Figure 3. Power consumption in relation to percentage of load

The AC compressor therefore has maximum savings at 75 % load, while the BLDC compressor offers best savings at around 50 % load. In addition, it can be seen that BLDC technology always brings greater savings compared to AC motors, due to the lower heat loss of the permanent magnet rotor compared to the heat loss from windings or cage rotors on AC motors. Moreover, the smaller dimensions and lower heat loss mean further advantages from an energy point of view. The sensorless vector control used on the BLDC compressor optimises management of the torque/current ratio more effectively than the V/f scalar control used with the AC compressor.

Conclusions

The similarity in performance of the three systems at 100 % load can be explained by considering that the efficiency of the three compressors is very similar, and that under maximum load conditions the on-off compressor remains on at all times. At very low part loads, the AC inverter system loses its advantages over the traditional solution as a result of electrical and mechanical inefficiencies that exceed the advantages of a favourable thermodynamic cycle and more stable control.

Energy analysis can be performed based on the Integrated Part Load Value criterion: considering the COP extrapolated from the comparative test data and calculated accounting for the power consumption of the inverter, average savings can be determined.

Table 1: Percentages of savings for each technology:

Technology	Saving
INV AC vs. On-Off	8.60 %
INV DC vs. On-Off	25.30 %
INV DC vs. INV AC	15.40 %

To calculate the IPLV, the following formula was used, which considers the time the unit operates at different part loads:

$$0.01 \cdot COP_{100\%} + 0.42 \cdot COP_{75\%} + 0.45 \cdot COP_{50\%} + 0.12 \cdot COP_{25\%}$$

When analyzing these data, it must be remembered that this is a simple comparison between different technologies and compressors used in a laboratory on a quite simple water-water unit. This can be used to estimate the efficiency in different real commercial, industrial or residential applications.

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Ground source heat pump (GSHP) efficient engineering design

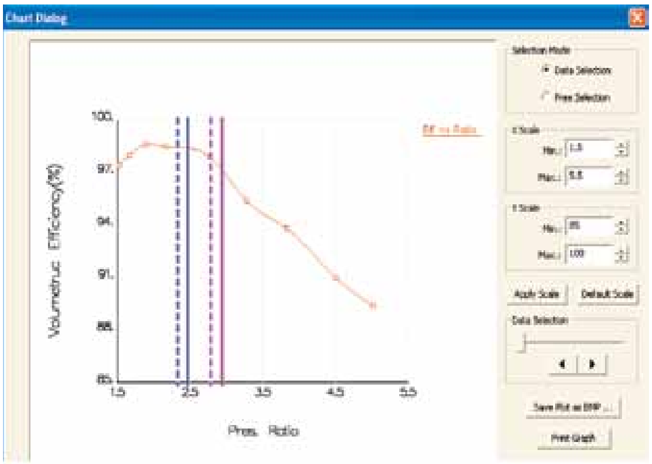
Geothermal energy is becoming one of the most interesting sources of renewable energy for heating and cooling by ground coupled heat pumps in most Europe. The EU Ground-Med project aims at demonstrating the sustainability of heat pump technology for heating and cooling of buildings in Mediterranean climate. Within the framework of this project, eight ground source heat pump systems are under construction and will be monitored, with heating capacities spanning from 14 to 75 kW. The main objective of Ground-Med is to demonstrate that a measured seasonal performance (SPF) higher than 5 can be obtained. As the SPF is determined not only by the heat pump unit, but also by its operating conditions, imposed by both the ground heat exchanger and the heating/cooling system of the building, integrated GSHP systems incorporating proper technological solutions are being developed.

Ground source heat pumps (GSHP) are reversible water-to-water source heat pump systems comprising ground heat exchangers (pipes buried within the ground where water is circulated as a heat carrier) and low temperature heating (and cooling) system (floor heating, fan-coils, etc.).

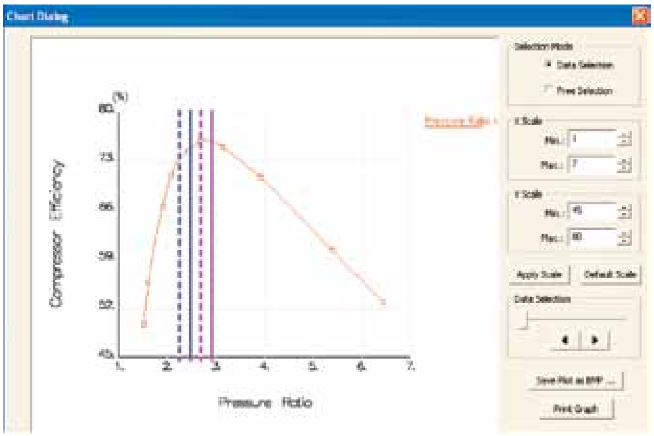
In order to be able to optimize a GSHP system, not only the heat pump but also the integrated system must be optimized. The vapour compression software package IMST-ART, developed by personnel from the 'INSTITUTE FOR ENERGY ENGINEERING' at the Polytechnical University of Valencia in Spain, offers the possibility of carrying out some studies in order to optimize heat pump design. Regarding the compressor, which is the heart of the heat pump, several optimization studies were carried out under the framework of the Ground-Med project at full load and compared with part load working conditions of the unit. For typical cooling and heating mode operating temperatures at GSHP applications, pressure ratios for cooling and heating mode at full load and part load were calculated and performance curves for a typical scroll compressor were represented.

It was pointed out the importance of finding a compressor with the optimal efficiency located near the pressure ratios at which the unit is expected to work. As it is shown in figure 1, it was concluded from the studies for one conventional unit that part load conditions were favorable for heating mode but not for cooling mode where the efficiency of the compressor falls down.

Regarding the brazed plate heat exchangers (BPHE) design, it was concluded from studies made under the framework of the Ground-Med project that BPHE width should be as small as possible, that means for the same heat exchanger area, that length should be the highest. The number of plates should be as high as possible in terms of performance, taking into consideration that this is not always the most economical solution. A compromise between cost and performance needs to be found. The depth of the BPHE channels didn't have practically an influence on the performance of the heat pump, so, as all manufactures use a standard, the BPHE channels depth should be kept equal to 2 mm. The optimal corrugation angle was the highest as possible (120).
An auxiliary component that has an important role on the system performance and final comfort is the tank storage in the distribution circuit. This tank helps to decouple the thermal load of the building from the heating/cooling capacity of the heat pump/chiller unit allowing on/off control.



Cooling mode
Pratio(full load)= 2.46 ———
Pratio(part load)= 2.3 - - - - -



Heating mode
Pratio(full load)= 2.98 ———
Pratio(part load)= 2.7 - - - - -

Figure 1. Scroll compressor performance at different pressure ratios corresponding to different working modes of the heat pump.

Two different positions of the tank were considered: If the buffer tank is located at the supply (outlet of the heat pump), control temperature sensor is recommended to be located at the outlet of the heat pump just in the entrance of the buffer tank. This way, chilled water temperature sent to the air handling units (AHU) will be more controlled and will keep constant and equal to the desired fixed value. This improves users' comfort. On the other hand, if the buffer is located at the return (inlet of the heat pump), the control sensor should be located at the outlet of the buffer tank so that the operation of the heat pump won't be affected by the fluctuation of the AHU demand and will be much more controlled and uniform.
A literature survey was performed to analyze the influence of the volume of the tank on system performance. It leads to the conclusion that systems must provide sufficient thermal inertia to allow an adequate operation of the compressor. Typically minimum time-on of around 2 minutes is suggested in order to allow the oil return to the compressor.

In order to optimize the seasonal performance factor (SPF) of the system, different control strategies have also been analyzed by UPV and UCD 'University College of Dublin (Ireland)'. The main existing control parameter corresponds to the on/off compressor control switch. Other control parameters are as follows:

- Internal and external circulation pump frequency control (secondary side fluid circulation flow rate)
- Fan coil water return temperature set point control (secondary side fluid temperature control)
- Thermostat temperature set point control (building air temperature control).
- Secondary side fluid temperature bandwidth control.
- Building air temperature bandwidth control.

It must be pointed out that by locating the optimized setting of each of these parameters, it is possible to provide more effective cooling/heating to a building.

The analysis and energy optimization of a ground source heat pump for heating and cooling in an institutional building at the Universidad Politécnica de Valencia was carried out. A special focus was given on examining the **influence of the frequency of the water circulation pumps of the indoor (water distribution system) and outdoor (ground source) loops in the overall system performance** in order to make an energy optimization. It was possible to find an optimal operating frequency for the circulation pumps, which improves the system performance and provides energy savings. Results show that the optimum is different for each pump in cooling and heating mode. Running the system at the optimal frequency for each circulation pump, means a 26 % higher efficiency of the system in cooling mode and 7 % in heating mode compared to operating at a constant nominal speed of 50 Hz for both circulation pumps. The results clearly indicate large potential savings for this type of installation if the frequency inverters are used to vary the speed of the pumps and an integrated intelligent control is applied.
In order to examine how control of building circuit variables affects overall system performance, several studies were carried out under the frame of the Ground-Med project by UPV and UCD (University College of Dublin) and results were presented in 'Energy and Building'. Several optimization strategies, including set-point control of room air temperature, room air bandwidth temperature, building loop return water temperature and building loop return bandwidth temperature were analyzed.

Assessment was carried out by means of a system quasi-steady state mathematical model, which was developed using Engineering Equation Solver. The dominant factor affecting system power consumption was found to be building space set-point temperature. Space set-point temperature directly affects heat gains to the building and by association the cooling load. Under quasi-steady state conditions, as the set-point temperature increased from 21 to 25 °C, the daily system power consumption decreased significantly from 67.54 kWh to 48.23 kWh. Moreover, as Tspace increases, the rate of heat pump cycling was also noted to decrease as compressor ON time was reduced from 48.85 % to 30.05 %.

The effect of varying building return water temperature was found to have less influence than space temperature set-point on system power consumption. Higher water return temperature reduces the ON time operation of the heat pump, and results in an increase of daily heat pump performance of approximately 5 % per each degree increase of the building water return temperature.

Building water return bandwidth was noted to have almost a negligible effect on system and compressor power consumption, and compressor ON time was noted to decrease only marginally with increased temperature bandwidth. Daily performance factor values for the system and the heat pump were not significantly affected by water return bandwidth. Space temperature bandwidth was also observed to have a negligible effect on compressor and system performance.

UPV will present more details on its work in the field of energy optimization of a GSHP system for heating and cooling in an office building at the next IIR INTERNATIONAL CONFERENCE held on April 5th to 8th of 2011 in Padova (Italy).
J.M. Corberan, C. Montagud
INSTITUTO DE INGENIERÍA ENERGÉTICA,
Universidad Politécnica de Valencia (UPV), Spain

next meetings

EHPA EVENTS

Education Committee
21–22.03.2011 | Prague, CZ

Executive Committee
23.03.2011 | Brussels, BE

Norms & Standards Committee
25.03.2011 | Brussels, BE

EHPA workshop and 2011 "Heat pump city of the year" award
14.04.2011 | Brussels, BE

Executive Committee
04.05.2011 | Budapest, HU

General assembly
31.05.2011 | London, UK

4th EHPA European Heat Pump Forum
01.06.2011 | London, UK
EHPA hosts this years conference in London. Speakers from DECC and the UK HPA will provide insights into the national market. This will be balanced by updates on EU developments.

PROJECT MEETINGS

Qualicert meeting
28–29.03.2011 | Brussels, BE

SEPEMO project meeting
07–08.06.2011 | Utrecht, NL

Ground-Med intermediate conference
05–06.10.2010 | Marseille, FR

OTHER EVENTS

Czech international heat pump conference
21.03.2011 | Prague, CZ

IIR International conference
05-08.04.2011 | Padova, IT

EUSEW 2011
11–15.04.2011 | Brussels, BE

4th international conference Ammonia Refrigeration Technology
14–16.04.2011 | Ohrid,
Republic of Macedonia

12nd Annual Conference of the RHC Platform
05–06.05.2011 | Budapest, H

5th RENEXPO® Central Europe
05–07.05.2011 | Budapest, H

10th IEA Heat Pump Conference 2011
16–19.05.2011 | Tokyo, JP

World Geothermal Energy Policy Council's
22–25.05.2011 | Minneapolis, USA

15th International Passive House Conference 2011
27–28.05.2011 | Innsbruck, AT

New Energy World 2011
13–14.06.2011 | Stockholm, SE

23rd IIR International Congress of Refrigeration
21–26.08.2011 | Prague, CZ

European Heat Pump Summit 2011
28–29.09.2011 | Nürnberg, DE

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