



Ground-coupled heat pumps for new buildings

Fig. 1



- ▶ **Proven in field test: devices and systems are technically mature**
- ▶ **Average annual coefficient of performance for hot water and heating reaches 3.9**
- ▶ **Most frequent weak point: system design and control strategy**
- ▶ **Simple systems are most frequently preferable**

Heat pump with installed measurement equipment.

In recent years, the heat pump has become increasingly popular on the heating market. For new buildings and building refurbishment, users can expect lower energy costs and environmentally friendly, low-maintenance operation. There is much heated debate as to the degree of efficiency at which heat pumps work. The debate arises on the one hand from the conflicting interests of manufacturers, energy providers and fuel suppliers. However, in particular, it illustrates that there is not yet sufficient concrete data available from practical use. Measuring results from test stands are only of very limited relevance for real operation, since the efficiency of the heat pump is much more dependent on the conditions of use than with other heating systems. Thus for example, a condensing boiler is dependent on the lowest possible temperature of the heat distribution in the building. With the heat pump, the temperature level and connection

to the environmental heat used also plays a key role. The annual coefficient of performance of a heat pump, as a measure of energy efficiency, can therefore vary significantly from building to building. The “heat pump efficiency” field test by the Fraunhofer Institute for Solar Energy Systems ISE, supported by the German Federal Ministry of Economics and Technology, now aims to create a clear picture for use in new buildings with low annual heating requirements of between approx. 40 and 100 kWh/m².

Although the research project will not be completed until the summer of 2010, the results of two full measurement years are already available.

The most important findings for borehole heat exchanger and ground collector facilities will be presented below. The results for air source heat pumps will be published separately.

► Heat pumps in new buildings with low heating requirements

In the “heat pump efficiency” field test, heat pumps in new buildings with low heating requirements were studied. With a heated living space of between 120 and 350 square metres (194 m² on average), the heating capacity installed lies between 5 and 10 kW. The heat is distributed solely using under-floor heating surfaces. Of the 68 heat pumps studied which use the earth as a heat source, 50 systems are operated with bore-hole heat exchangers, and 18 with ground collectors.

Data acquisition

Comprehensive measurement analyses aimed to determine the efficiency of different facility concepts under different conditions of use, and to create a basis for improving the devices and system technology. For this purpose, temperatures, flow quantities, heat levels and power consumption of the heat pump and auxiliary drives were continuously measured and retrieved daily via remote data retrieval, checked for plausibility and evaluated.

Efficiency characteristic

The most important characteristic for the efficiency of a heat pump is the annual coefficient of performance. This gives the ratio between the amount of heat emitted over a year and the energy used. Even if the annual coefficient of performance does not cover all aspects of the heat pump, it does describe the efficiency of a heat pump under real conditions. The German Energy Agency classifies an electric heat pump as “energy efficient” when the annual coefficient of performance lies above 3.0, and as “significantly energy efficient” when it lies above 3.5.

► Evaluation

The evaluation of two full years provides a concrete data basis. The monthly coefficient of performance of the ground source heat pumps is shown in Figure 2. The additional electric heating, which was used with only a small number of facilities, and usually in

order to dry out the building, is here taken into account. The figures on the month bar correspond to the respective facilities covered. The bars on the monthly coefficients of performance give the heating (red) and domestic hot water energy (blue) in absolute values.

Averaged over all facilities and the period of observation, the coefficient of performance lies at 3.9. The lower coefficients of performance during the summer months result from the relatively higher proportion of hot water heating, which requires a greater temperature range.

Over the entire period of observation, bore-hole facilities achieved a coefficient of performance which was 0.13 points higher than the ground collector systems close the surface. However, several of the annual progressions have not yet been fully understood, so that the result must be interpreted with a certain degree of caution: The ground collectors draw the heat from out of the earth at a depth of between 1 and 2 m. Here, irradiation from the sun, air temperature and precipitation have a significant influence, too. The ground temperatures are significantly higher during the autumn months than in the spring. For borehole heat exchanger facilities, effects of this nature are not important. From a depth of approx. 10 m, there is almost no further influence on the temperatures. In the light of these aspects, the coefficients of performance of the facilities with collectors should approximate or, if necessary, exceed those of facilities with borehole heat exchangers during the summer, and possibly also the autumn months.

The links between the coefficients of performance and the temperatures of the heat source and heat sink are shown in Fig. 3. The brine temperatures of the collector and borehole heat exchanger facilities vary between 4 and 13 °C during the year. The heat sink temperature results from a weighted average of the heat circuit (36 °C) and the charge temperature of the domestic water storage tank (51 °C). The difference between this and the heat source temperature results in the progression of the temperature range. It has been confirmed that the coefficient of performance is indirectly proportionate to the temperature range.

Fig. 2: Average coefficients of performance, structure of heating energy and hot water

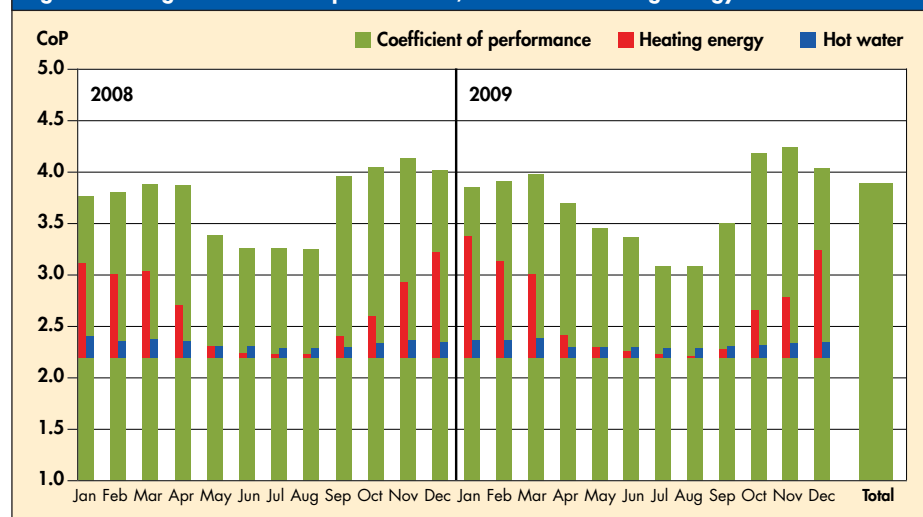
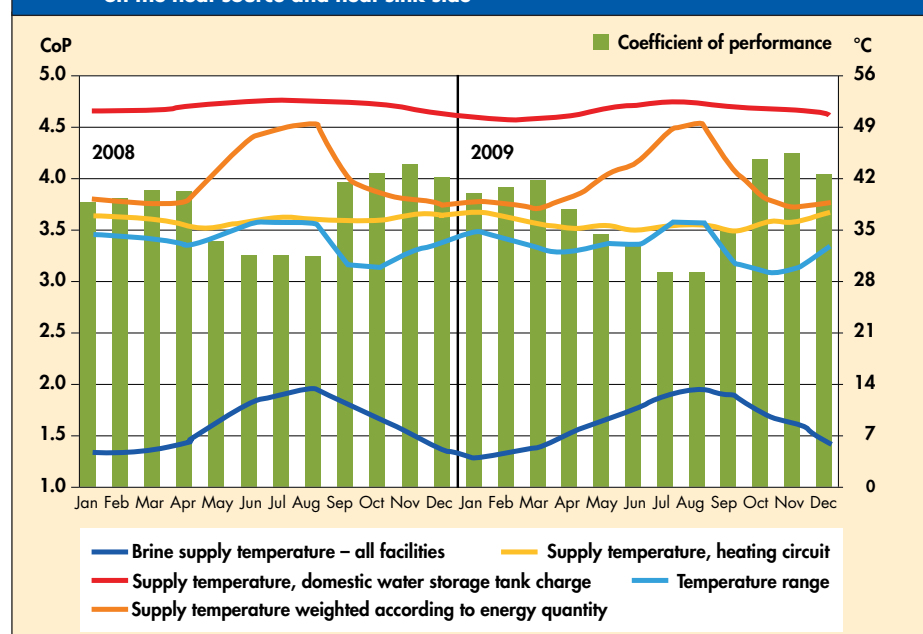


Fig. 3: Relationships between coefficients of performance and temperatures on the heat source and heat sink side



New materials for borehole heat exchangers

Improvements in the details can further improve the efficiency and economy of ground-coupled heat pumps. Here, a project will be presented which exemplifies a large number of research efforts in which new synthetic materials for borehole heat exchangers with higher heat conductivity were studied. To date, borehole heat exchangers have usually been made of polyethylene, which is a relatively poor heat conductor, as a result of which the heat transfer capacity is reduced. The Forschungsinstitut für Tief- und Rohrleitungsbau (FITR) is cooperating with partners from industry and scientific research to develop a synthetic compound with significantly higher heat conducting properties. For this purpose, researchers have added various heat conducting materials to the polyethylene. On the laboratory scale, they studied this compound for heat conductivity, processability (extrusion, welding) and mechanical properties. They then optimised the polymer material, extruded the heat conducting pipes as a pilot series and produced the first borehole heat exchangers as a prototype. The heat conductivity of the pipes produced in this manner increased from 0.4 W/mK to 1.0 W/mK. The heat exchangers could be stored, transported and installed in a similar way to conventional borehole heat exchangers. The improved heat transfer enables shorter heat exchangers, and thus lower drill depths, which improves economic efficiency. Long-term measurements are currently being conducted in a geothermal field near Weimar.

Fig. 4: New heat exchanger materials improve heat transfer



► Simplicity pays

How does the storage tank concept affect the efficiency of the facility? While systems with or without buffer storage tanks hardly differ in this respect, the systems with a combined hot water and buffer storage tank are far less efficient (Fig. 5). One reason for this is the frequently observed, non-optimal charge strategy of the storage tank.

The structure of the hydraulic system is also a highly influential factor. Researchers divided the facilities into three groups on the basis of their complexity. Facilities with simple hydraulics and a low number of system components were classified as the “complexity level 1” group. These achieved coefficients of performance at an average of almost 4.0. Facilities in group level 3 with several pumps, 3-way valves, additional heat exchangers, combined storage tanks and active or passive cooling options achieved significantly lower values. It was shown that complex systems are more difficult to regulate and are less able to withstand potential installation errors. The simpler the hydraulic systems, the better the coefficients of performance in general.

Avoidable errors

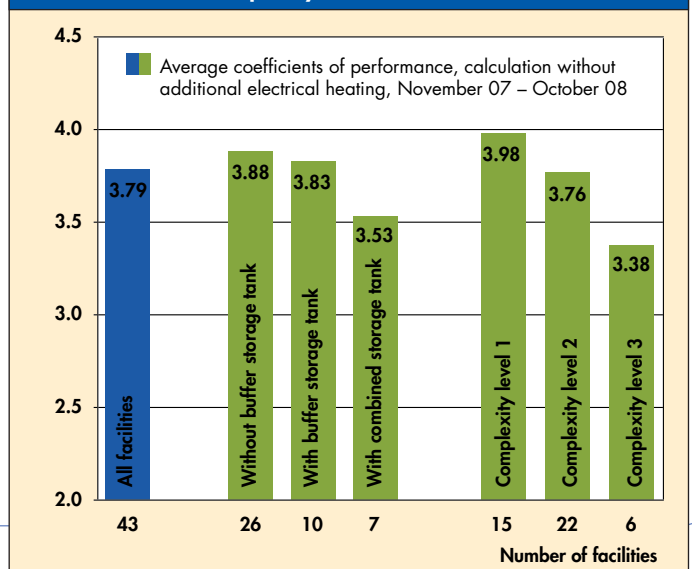
The detailed resolution of the measurement data makes it possible to analyse error sources and identify potential for optimisation. For systems with combined storage tanks or in combination with solar energy systems, non-optimal heat management of the storage tank reduced the coefficients of performance, for example. In extreme cases, the heating energy storage tank was charged to approx. 55 °C, even though the underfloor heating required only 35 °C. 3-way valves which do not close fully, and non-return valves which have been incorrectly installed, or not installed at all, lead to unnecessary heat loss or even to a discharge of the domestic water storage tank. For charging or heating circuits, highly efficient pumps should be used. Improved regulation algorithms could also in many cases reduce run times significantly. The brine pumps run at an excessively high operating level in some cases.

What should be taken into account when installing the heat pumps?

For improved functioning of the facilities, the researchers have formulated the following recommendations, among others:

- Meticulous design of the entire facility, coordination of the individual components (heat source, storage tank, heat sink, etc.) and integrated planning, i.e. covering all trades, as well as being building-specific.
- Inspection of the charge strategies of the storage tank, in particular with combined storage tanks, and monitoring of the supply temperature.
- Meticulous hydraulic compensation and complete insulation of pipes and components.
- Deactivation of the heating rods. Correctly designed facilities require no additional electric heating, unless needed for drying out buildings.
- Planning and construction of facilities with simple hydraulic principles – several heat generators, complex hydraulics and storage systems frequently fail to provide the desired level of efficiency.

Fig. 5: Coefficients of performance depending on the storage tank model and complexity level



► Conclusion and outlook

Both borehole heat exchanger and ground collector facilities are technically mature and achieve a high degree of efficiency under real conditions. In the field test of new buildings, the average coefficient of performance was 3.9 for combined heating and hot water operation. For several facilities, coefficients of performance greater than four were measured in combined operation. This illustrates what is possible. The meticulous care taken by planners and engineers with regard to the design, installation and control strategy is decisive. The training and further qualification of the skilled workers involved appears to be bearing results: Newer facilities generally show a significantly higher design quality than older facilities. Not least, building residents have significant influence on system efficiency as a result of their behaviour. They should therefore receive support for a better understanding of heat pump operation. Researchers at the ISE are conducting a further field test to study how the use of heat pumps can be proven as a replacement for oil boilers in old buildings. For this purpose, buildings were selected which were constructed before 1980, and which to date have not been modernised in terms of energy efficiency, or have only been modernised to a low degree. On average, a coefficient of performance of 3.3 was measured for this type of building. Here, a decisive factor is in many cases the supply temperature of the heating. The lower the supply temperature, the more effectively the heat pump operates. In order to maintain the temperature at below 50 °C as far as possible, the heat surfaces should be enlarged if appropriate. The hydraulic concept also plays an important role, together with the hydraulic compensation and the optimal setting of the heating curve. Meticulous planning and installation of the facilities not only improves the coefficient of performance, but also minimises power consumption for all components of the heat pump system. According to data provided by the Bundesverband Wärmepumpe (BWP) e. V., around 55,000 heat pumps were sold in Germany in 2009. The overall number was thus increased to over 330,000. In one study, the association assumes that sales figures will continue to rise. According to sector statistics, the number of reversible heat pumps, which can be used not only for heating, but also for cooling, has increased significantly. This trend is likely to continue. In the coming years, the electric heat pump could face greater competition from heat-driven systems. Different manufacturers are developing variants of the devices, which are as a rule gas-fired, or are already conducting field tests. These are most likely to be used in refurbished old buildings. ■

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► ADDITIONAL INFORMATION

Internet

- <http://wp-effizienz.ise.fraunhofer.de>
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- Fig. 4: Forschungsinstitut für Tief- und Rohrleitungsbau, Weimar, Germany

Service

- This Projektinfo brochure is also available as an online document at www.bine.info under Publikationen/Projektinfos. Additional information in German, such as other project addresses and links, can be found under “Service”.

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