Technology Collaboration Programme
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Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

IEA HPT

Annex 32

Economical heating and cooling systems for low energy houses

Final Report – Part 5

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Preface

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

The IEA

The IEA was established in 1974 within the framework of the Organization for Economic Cooperation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster cooperation among the IEA participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development (R&D). This is achieved, in part, through a programme of energy technology and R&D collaboration, currently within the framework of nearly 40 Technology Collaboration Programmes.

The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) forms the legal basis for the implementing agreement for a programme of research, development, demonstration, and promotion of heat pumping technologies. Signatories of the TCP are either governments or organizations designated by their respective governments to conduct programmes in the field of energy conservation.

Under the TCP, collaborative tasks, or “Annexes”, in the field of heat pumps are undertaken. These tasks are conducted on a cost-sharing and/or task-sharing basis by the participating countries. An Annex is in general coordinated by one country which acts as the Operating Agent (manager). Annexes have specific topics and work plans and operate for a specified period, usually several years. The objectives vary from information exchange to the development and implementation of technology. This report presents the results of one Annex.

The Programme is governed by an Executive Committee, which monitors existing projects and identifies new areas where collaborative effort may be beneficial.

Disclaimer

The HPT TCP is part of a network of autonomous collaborative partnerships focused on a wide range of energy technologies known as Technology Collaboration Programmes or TCPs. The TCPs are organized under the auspices of the International Energy Agency (IEA), but the TCPs are functionally and legally autonomous. Views, findings and publications of the HPT TCP do not necessarily represent the views or policies of the IEA Secretariat or its individual member countries.

The Heat Pump Centre

A central role within the HPT TCP is played by the Heat Pump Centre (HPC).

Consistent with the overall objective of the HPT TCP, the HPC seeks to accelerate the implementation of heat pump technologies and thereby optimize the use of energy resources for the benefit of the environment. This is achieved by offering a worldwide information service to support all those who can play a part in the implementation of heat pumping technology including researchers, engineers, manufacturers, installers, equipment users, and energy policy makers in utilities, government offices and other organizations. Activities of the HPC include the production of a Magazine with an additional newsletter 3 times per year, the HPT TCP webpage, the organization of workshops, an inquiry service and a promotion programme. The HPC also publishes selected results from other Annexes, and this publication is one result of this activity.

For further information about the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) and for inquiries on heat pump issues in general contact the Heat Pump Centre at the following address:

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Best Practice IEA HPP Annex 32

IEA HPP Annex 32

Economical heating and cooling systems for low energy houses

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Federal Office of Energy SFOE

Best Practice Systems

Heat pump systems with good performance in field monitoring

Worked out by

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International Energy Agency
Heat Pump Programme

Imprint

IEA HPP Annex 32 " Economical heating and cooling systems for low energy houses"

The work presented here is a contribution to the Annex 32 in the Heat Pump Programme (HPP) Implementing Agreement of the International Energy Agency (IEA)

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PREFACE

Introduction to IEA HPP Annex 32

Since the mid of the nineties low energy buildings with a significantly reduced energy consumption down to ultra-low energy standard (typical space heating energy need of 15 kWh/(m^{2}a)) or even net zero energy consumption (on an annual basis by an integration of on-site renewable energy systems) have been realised.
These building concepts recently show strong market growth in different European countries. Many governments address the spread of low energy buildings as a major strategy to reach climate protection targets according to the Kyoto protocol. Heat pump markets are growing in many countries as well.
Low energy buildings have significantly different load characteristics compared to conventional existing buildings. This requires adapted system solutions to entirely use energy-efficiency potentials for the remaining energy needs.
Integrated heat pump solutions have favourable features for the use in low energy houses. The main advantages are the potential for internal heat recovery and simultaneous operation to cover different building needs at the same time as well as installation space and cost benefits. This leads to a significantly improved system performance in an adequate capacity range to reduce primary energy consumption and cut CO_2-emissions and costs.
However, in many countries, no adequate system solutions are available on the market or energy performance of available and newly-introduced low energy house technology is not yet approved by field experience. Therefore, system development and field approval of functionality and real-world operational performance of the systems are needed. These are the main working areas of IEA HPP Annex 32.

Main objectives of IEA HPP Annex 32

The main objectives of the IEA HPP Annex 32 are the further development and field monitoring of integrated heat pump systems for the use in low energy buildings, leading to the following objectives:

- To characterise the state-of-the-art in the different participating countries
- To assess and compare the energy performance of different system solutions for the residential low energy house sector
- To develop and lab-test new system solutions of integrated heat pumps in the low-energy-house capacity range including the use of natural refrigerants
- To accomplished field tests of new developments and marketable systems and to document best-practice examples
- To disseminate the results

Results of the IEA HPP Annex 32

The results of IEA HPP Annex 32 comprise:

- Overview of market system solutions of integrated heat pumps for low energy houses
- Design recommendations of the standard system solutions
- New system developments as prototypes including lab-test and simulation results
- Documentation of field monitoring results of new and marketable systems
- Dissemination of results by a website, workshop presentation and reports

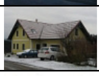
Best Practice Sheets

In IEA HPP Annex 32 extensive field monitoring of marketable combined operating heat pump systems has been performed. Results of the field tests in single countries have been documented in a final report on the field monitoring projects.

In this report single field-monitored heat pumps of the national field tests with good performance results have been selected and documented in more detail as 4-page Best Practice Sheets in order to provide good examples of real-world heat pump performance.

Tab. 1 gives an overview of Best Practice Systems. To go to the respective Best Practice Sheet, just click on the description.

Tab. 1: Overview of documented Best Practice systems in Annex 32

Country	Object	Description of Best-Practice heat pump system
AT		Retrofitted SFH with A/W-HP for radiator heating and DHW (Meiseldorf)
AT		SFH with B/W-HP for floor heating and fresh water system (Felling)
AT		SFH with A/W-HP for floor heating and DHW (Rutzenmoos)
AT		SFH with W/W-HP with floor heating and fresh water system (St. Peter)
AT		ground-source compact unit in passive house incl. passive SC (Judendorf)
AT		ground-source compact unit in passive house incl. passive SC (Hitzendorf)
CH		ventilation compact unit for SH, DHW and Vin MINERGIE®-Haus (Gelterkinden)
CH		B/W-HP for SH, DHW and passive SC in MINERGIE-P® MFH (Basel)
CH		B/W-HP for SH, DHW and passive SC in MINERGIE® SFH (Muolen)
DE		B/W-HP with borehole heat exchanger for SH and DHW in SFH (Köngen)
DE		B/W-HP with horizontal collector and energy fence for SH/DHW (Spechbach)
DE		S/W-WP with borehole heat exchanger for SH and DHW in SFH (Gaggenau)
DE		Outdoor air/W-HP for floor heating and exhaust air-HP for DHW (Buchenbach)
DE		B/W-HP with borehole heat exchanger for SH and DHW (Neuffen)
JP		Inverter-controlled B/W HP, A/W-Eco-cute and V in SFH (Naganuma, Hokkaido)
JP		Inverter-controlled B/W-HP for SH, DHW, solar collector, V in SFH (Sapporo)
US		16 B/W HP in SFH (Hope Crossing, Oklahoma City Habitat for Humanity)

Best practice

IEA HPP Annex 32

Economical heating and cooling systems for low energy houses

Retrofitted single-family house with air-to-water heat pumps for radiator space heating emission system and domestic water operation

AUSTRIAN INSTITUTE OF TECHNOLOGY
TOMORROW TODAY

Contribution of the Austrian national project

Summary

The Austrian Institute of Technology (AIT) developed a standardised heat pump monitoring as quality control measure.
This Best Practice Sheet presents field monitoring results of an air-to-water heat pump for space heating. The heat pump is installed in a house with a measured specific heat load in the range of 70 W/m^2. The building was renovated in the year 2007 and therefore, the existing space heating emission system with radiators is used. The average temperature at the heat pump outlet is with 34°C very low for a radiator emission system. The space heating system contains a 400 l storage installed in the supply line of the emission system.
The DHW is produced by a second, already existing 20-year-old air-to-water heat pump and stored in DHW storage.
Despite the system configuration of an air-to-water heat pump coupled to a radiator emission system the heat pump reaches a high seasonal performance factor of the generator of an SPF-G of 3.2 in space heating mode. The DHW is produced at an SPF-G of 2.6 yielding an overall SPF-G of 3.1.
Compared to a condensing gas boiler with an efficiency of 97% the heat pump system can reduce the CO_2-eq.-emissions by 52% and reaches as primary energy performance of 2.5 kWh_{th}/ kWh_{pe} and thereby a reduction of primary energy of 64% based on CO_2-eq.-emission and primary energy factors used in Austria.

Building data

- Location: Klein Meiseldorf, Austria
- Inhabitants: 5 persons
- Year of construction: 2007
- Medium-weight construction, heated area 500 m^2
- Design heat load (ÖN B8135): 23 kW (46 W/m^2)

International Energy Agency
Heat Pump Programme

Background

The Austrian Institute of Technology AIT has developed a standardised monitoring method for heat pump systems in order to enhance the quality management in heat pump installations. The monitoring method is an instrument to prove the functionality and performance of installed heat pump systems. In the course of the IEA HPP Annex 32 project, heat pump systems were tested under real condition in order to evaluate their efficiency. Therefore, nine conventional heat pump systems and two compact units, which were situated in Upper-, Lower Austria and Styria, had been analyzed. The system described in this best practice sheet uses an air-source two-compressor heat pump system with radiator emission system for space heating and a separate air-to-water heat pump for DHW production.

The front view of the monitored building

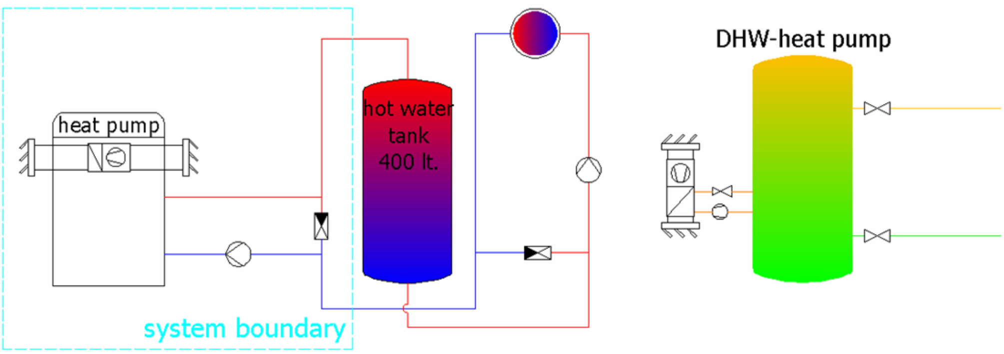
Technical concept

The building is equipped with an air-to water heat pump for space heating and a separate air-to-water heat pump for the domestic water production. The space heating heat pump incorporates two scroll compressors in parallel. The system operates monovalently, i.e. no back-up heating is installed.
The compact air-to-water heat pump is installed outside and operates with two parallel connected scroll compressors for having 2 capacity steps in order to match the heating capacity to the heat load.
The space heating emission system consists of radiators. A 400 l buffer storage is integrated in the supply line of the emission system. By the integration of the storage, the lowest return temperature is returned back to the heat pump unit during the heat pump is in operation. Thereby, the capacity of the rather quick reacting radiator system is increased, a cyclic operation can be reduced and the heat pump works with lower supply temperatures.
The existing radiator system was designed to low temperatures of 55 °C/45 °C, i.e. the radiator area is relatively high compared to common designs in boiler systems to 70 °C/55 °C. Due to the renovation of the building the heat load decreased and therefore the existing radiator system can be operated at even lower supply temperatures.
The DHW is produced independently of the space heating operation by a second already existing 20-year-old air-to-water heat pump, which was already existing before the retrofitting of the building, and stored in a DHW storage.

The "Alpha Innotec" heat pump unit

Market status

The heat pump is available on the market.



Hydronic sketch of the space heating and DHW system of the investigated heat pumps and system boundary for the performance evaluation

Technical data of the unit

Heating unit:	**air-to-water heat pump with two parallel scroll compressors**
Thermal output / COP (heating unit):	
A7/W35:	**36 kW / 4.2**
A2/W35:	**33 kW / 3.8**
A-7/W35:	**27.6 kW / 3.1**
Refrigerant:	**R404A, charge 12.2 kg**
Buffer storage:	**400 l installed in supply line**
DHW-unit:	**separate 20 year-old air-to-water heat pump**

Field monitoring

In the AIT standard monitoring of heat pumps the system boundary includes the generation system comprising the heat pump and eventually installed back-up heaters as well as the source system. Inlez and outlet temperature and mass flows of the heat pump source and sink side are monitored in a 1 s interval and stored as 15 min average values. The electrical energy consumed by the heat pump compressor, the compressor on-/ off cycles and the operating hours are registered every 15 min to characterise the performance.

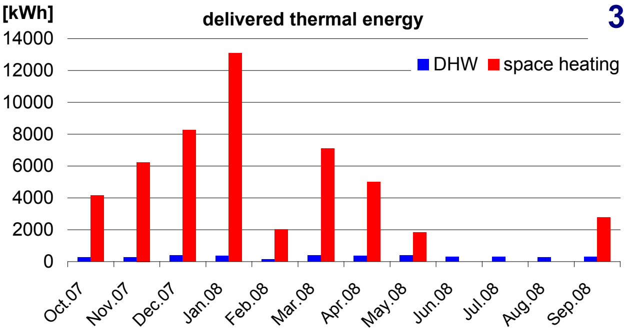
The monitoring period covers year-round monitoring data of Oct. 2007 until Sept. 2008. However, due to a failure of the recording system, no measurements could be evaluated between 29.1.-19.2.2008.

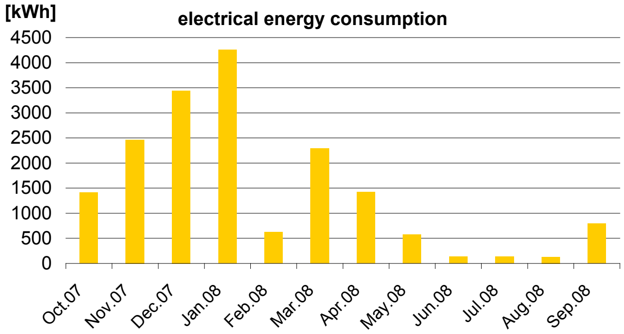
The total heat energy produced by the heat pumps in the monitored period was 54008 kWh. 94% of the heat or 50511 kWh (100 kWh/m2) are consumed for space heating operation which is consistent with the standard building based on the legal requirement of the period. The DHW consumption is with 3497 kWh or 700 kWh/persons in a common range, as well. The DHW share, however, is with 6% low, which is due to the size of the building and the therefore high specific heat load.

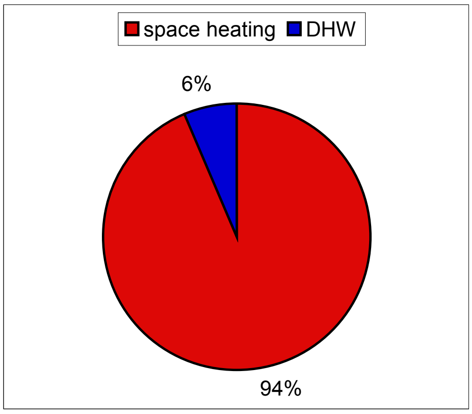
The corresponding electrical energy consumed is 17698 kWh. The overall Seasonal Performance Factor of the generator system (SPF-G) of the complete system is 3.1, resulting in a SPF-G in SH-mode of 3.2 and SPF-G in the DHW-mode of 2.6. Due to the energy fractions the low-temperature space heating operation is determining the overall performance.

While the SPF-G in the DHW mode is in the common range and benefits from higher outdoor air temperatures during the summer months, the SPF of the space heating operation is above the average of outdoor-air heat pumps with radiator emission systems. Due to the renovation of the building the heat load decreased and therefore the existing radiator system can be operated with lower supply temperatures, resulting in a low average outlet temperature of only 34.3 °C, which is similar to the common design of a floor heating system. Therefore, the seasonal performance factor also reaches a value similar to a floor heating system.

Furthermore the house owners accepted a rather low indoor temperature of 18.4 °C during heating season.

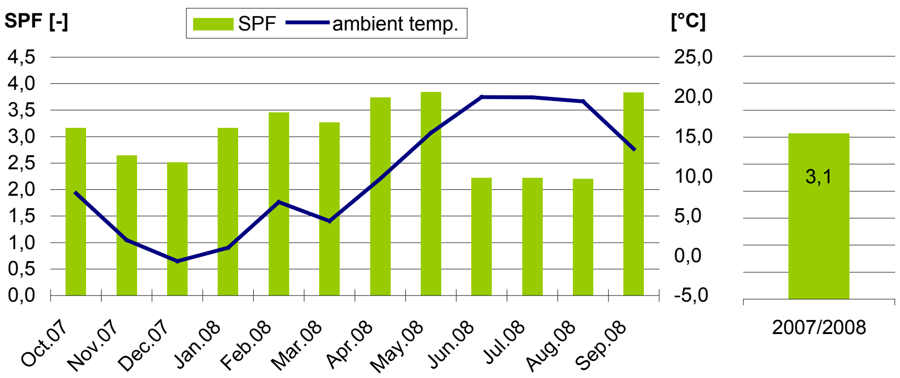






Space Heating:	50511,0	kWh
Hot water:	3497,0	kWh
Total:	**54008,0**	**kWh**
Total energy Input:	17698,0	kWh

Energy delivered and consumed in 2007/2008



Seasonal performance factor (monthly profile and total value for monitoring period) and ambient temperature (monthly average)

Performance indicators

__Seasonal performance factors__

Overall SPF-G of the system:	**3.1**
SPF-G heating unit:	**3.2**
SPF-G domestic water unit:	**2.6**

__Operation time:__

Heating period:	**226 d**
DHW period:	**year-round**

System performance and optimisation

Due to the renovation of the building the heat load decreased and therefore, the existing radiator system can be operated with very low supply temperatures similar to a floor heating system which is favourable for a good performance factor of air-to-water heat pumps.
For the radiator system a heating buffer tank is installed, since the heating system has little inertia functioning as thermal capacity. Moreover, the air-to-water heat pumps need the heating buffer tanks in the defrost operation with reversible refrigeration cycles, since otherwise the heat pump would extract heat directly from the building during defrosting.
In this system configuration a heat pump with 2 scroll compressors is used to have 2 capacity steps in order to match the heating capacity of the heat pump to the heat load of the building. Especially air-to-water heat pumps have increasing heating capacity with increasing outside air temperatures. The heat pump capacity increases opposite to the heat load of the building. Therefore, a capacity control contributes to the good performance of the heat pump.
Due to the realised low temperature level and the capacity control, the heat pump reaches a good seasonal performance in the retrofitted building in the same range as in new buildings.
Thus, the good performance documented in this Best Practice Sheet confirms the feasibility of retrofitting projects with outdoor air source heat pumps if supply temperatures can be lowered to an adequate range of an annual average around 35°C.

Economy, Ecology and Costs

Environmental impact of the heat pump based on thermal energy produced*:

CO_{2eq} emission factor:	370 g/kWh$_{el.}$
CO_{2eq} emission***:	6548.3 kg
Primary energy factor:	1.26 kWh$_{prim.}$/kWh$_{el.}$
Primary energy:	22299.5 kWh$_{prim.}$
SPF based on primary energy:	2.46

Comparative environmental impact of a condensing gas boiler based on thermal energy produced**:

CO_{2eq} emission factor:	247 g/kWh$_{th.}$
CO_{2eq} emission***:	13752.5 kg
Primary energy factor:	1.14 kWh$_{prim.}$/kWh$_{th.}$
Primary energy:	63473.3 kWh$_{prim.}$
Efficiency boiler ****:	97 %
Primary energy efficiency	0.85

* values based on GEMIS Österreich 4.5
**values based on FANINGER, 2007
***values based on produced thermal energy from 10/07 until 09/08
****value based on SIMADER, 2007

Conclusion

The presented data confirm that an air-to-water heat pump system can be operated monovalently to cover the entire space heating of the house. Due to low temperature design of the radiator heating system after building renovation the SPF of 3.2 in space heating mode is good and similar to new buildings.
The calculated results of CO_2-emissions and primary energy consumption confirm significant saving potentials compared to a condensing gas boiler.

Imprint

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Literature

Andreas Zottl, Heinrich Huber and Christian Köfinger
Field test of integrated heat pumps systems – Field test of 10 heat pump systems
IEA HPP Annex 32 country report Austria Task 3, N 161, Austrian Institute of Technology, Vienna, Sept. 2009

IEA HPP Annex 32

IEA HPP Annex 32 is a corporate research project on technical building systems with heat pumps for the application in low energy houses.
The project is accomplished in the Heat Pump Programme (HPP) of the International Energy Agency (IEA).

Internet: http://www.annex32.net

Best practice

Single-family house with brine-to-water heat pump and fresh water system for domestic water mode

AUSTRIAN INSTITUTE OF TECHNOLOGY

Contribution of the Austrian national project

Summary

The Austrian Institute of Technology (AIT) developed a standardised heat pump monitoring as quality control measure.
This Best Practice Sheet presents field monitoring results of a brine-to-water heat pump for combined space heating and DHW operation in alternate mode installed in a low energy house with a specific heat load of 34 W/m². The system is operated monovalently, i.e. no back-up heater is installed. The system uses three single U-tube borehole heat exchangers of about 50 m as heat source. As space heating emission system a 272 m² floor heating system at low design temperatures of 35°C/30°C is applied. The domestic hot water (DHW) is produced instantaneously by a fresh water system connected to a 500 l DHW storage.
The brine-to-water heat pump yields a good seasonal performance factor of the generator system of an SPF-G = 4.3 in space heating mode due to low supply temperatures. In DHW operation, on the other hand, the Seasonal Performance Factor with an SPF-G = 2.4 is significantly lower due to the higher supply temperature of the DHW operation. However, an overall SPF-G = 4.0 is reached due to a fraction of 87% space heating energy.
Compared to a condensing gas boiler with an efficiency of 97% the heat pump system can reduce the CO_2-eq.-emission by 63% and reaches an SPF based on primary energy of 3.2 and thereby a reduction of primary energy of 73% based on CO_2-eq.-emission and primary energy factors used in Austria.

Building data

- Location: Felling, Lower Austria
- Inhabitants: 4 persons
- Year of commissioning: 2004
- Medium-weight construction, heated area 272 m²
- Design heat load (ÖN M7500): 9.3 kW (34 W/m²)

Introduction

The Austrian Institute of Technology (AIT) has developed a standardised monitoring method for heat pump systems in order to enhance the quality management of heat pump installations. The monitoring method is an instrument to prove the functionality and performance of installed heat pump systems. In the course of the IEA HPP Annex 32 project, heat pump systems were tested under real condition in order to evaluate their performance. Therefore, nine conventional heat pumps for space heating and domestic hot water (DHW) and two compact units, which were situated in Upper- and Lower Austria as well as Styria, have been analysed. The system described in this Best Practice Sheet uses a ground-source heat pump with floor heating emission system for space heating and a fresh water system with 500 l storage in DHW operation.

The front view of the monitored building

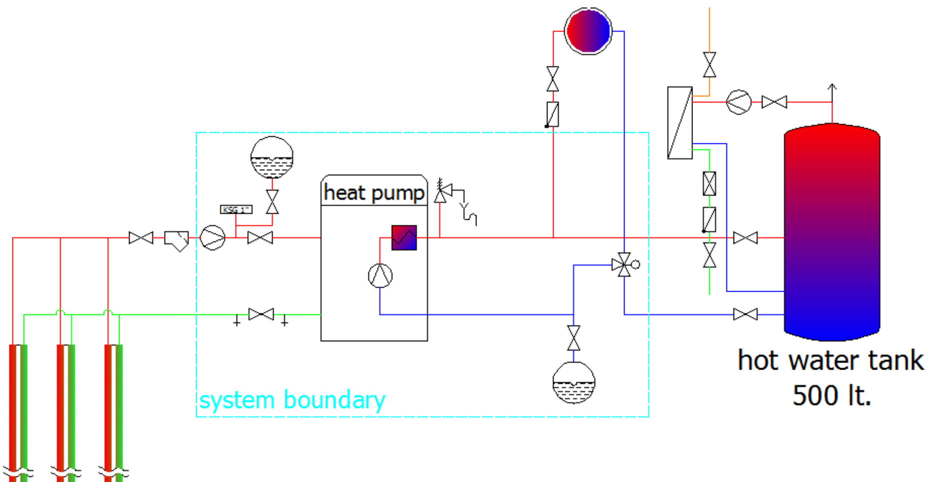
Technical concept

The building of a specific heat load of 34 W/m^2 is equipped with a brine-to-water heat pump with scroll compressor for alternate space heating and DHW. The heating capacity of the heat pump is 11.8 kW at B0/W35. The ground-source consists of 3 single U-tube boreholes with a pipe diameter of 40 mm and a length of 58 m, 53 m and 49 m, respectively. This yields a specific heat extraction of 58 W/m. The nominal electrical power of the installed source pump is 130 W.
In space heating operation the heat pump is directly connected to a 272 m^2 floor heating emission system designed for a maximum flow temperature of 35 °C and a design temperature difference of 5 K. The circulation pump of the space heating system has a nominal electrical power consumption of 55 W. The low temperature design and the direct connection of the heat pump to the floor heating emission system, which has sufficient capacity, improves the seasonal performance.
In DHW operation the heat pump is switched to a 500 l DHW storage, which is connected to a fresh water system by an external heat exchanger. The installed emission pump or storage loading pump, respectively, has an electrical power of 55 W.
The system operates monovalently, i.e. no back-up heating is installed.
The DHW temperature was set to 48 °C, but the measured average temperature was 51.6 °C. The advantages of a fresh water system are a hygienic DHW production, which avoids legionella, no separate DHW storage is necessary and there are no problems with calcinations of the components, e.g. heat exchangers.

The heat pump unit

Market status

The system is available on the market.



Sketch of the hydronic integration of the space heating and DHW system

Technical data of the system

Heat pump unit:	**brine-to-water heat pump with 3 single U-tube borehole heat exchangers of ≈50 m**
Operation mode:	**alternate SH/DHW**
Capacity of the source:	**9.3 kW (58 W/m)**
Refrigerant:	**R407C (2.35 kg)**
Thermal output / COP (heating unit)	
B0/W35:	**11.8 kW / 4.6**
B0/W50:	**11.1 kW / 3.1**
Floor heating system:	**272 m^2**
Design temperatures:	
Space heating	**35 °C/30 °C**
DHW	**48 °C**
Electrical consumption:	
Source pump:	**130 W**
Sink pump:	**55 W**
DHW:	**Fresh water system**
DHW storage:	**500 l**

Field monitoring

The system boundary includes the generation system comprising the heat pump and eventually installed back-up heaters as well as the source system. Inlet and outlet temperatures as well as mass flows of the heat pump source and sink side are monitored in an interval of 1 s and stored as 15 min average values. The electrical energy consumed by the heat pump compressor, the compressor on-/ off cycles and the operating hours are registered every 15 min to characterise the performance.

The monitoring period covers year-round monitoring data from 01. February 2008 to 01. February 2009.

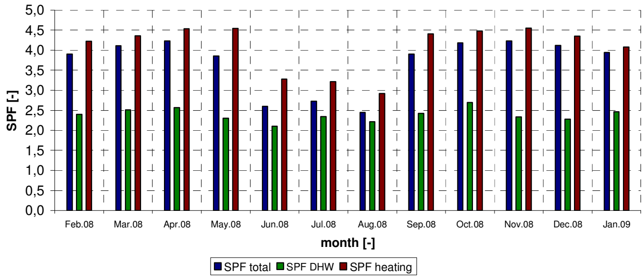
The total heat energy produced by the heat pump in the monitored period was 15191 kWh. 13624 kWh (50 kWh/(m^{2}a), 90 % of the heat), is produced in space heating mode which is consistent to the low energy building and better than the legal requirement of the period. The annual DHW consumption is with 1567 kWh quite low. The corresponding consumed electrical energy is 3168 kWh in space heating mode and 659 kWh in DHW mode yielding a total consumption of 3827 kWh. Thus, the fraction of DHW energy is only roughly 10% of the space heating energy consumption, which is on the one hand due to the large area of the building. On the other hand, the DHW energy consumption of 400 kWh/(pers.·a) is relatively low.

The space heating operation yields a good Seasonal Performance Factor of the Generator system (SPF-G) of 4.3, while the performance in DHW operation is with an SPF of 2.4 significantly lower due to the higher measured supply temperature of 52 °C. The overall SPF of the system is 4.0 due to the high fraction of space heating energy.

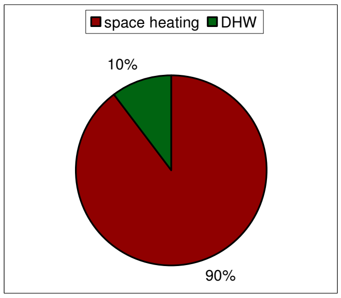
The space heating energy depicted in summertime is due to an error in the three way valve, which automatically switches to space heating operation. Therefore, at the start of the DHW operation, the three-way-valve has to switch first, which leads to a small fraction of space heating energy even in the summertime, i.e. in the months from June to August, where only DHW is needed. Due to the higher DHW temperatures, the SPF for this energy produced for space heating leads to a lower SPF.

Source temperatures were evaluated to 6.3 °C in winter and to 14 °C in summer. This leads to an annual average temperature of 8.5 °C.

Due to the measurement concept the auxiliary energy consumption could not be evaluated separately.

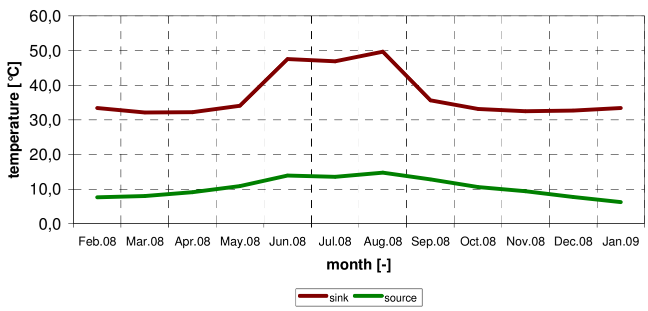


Seasonal performance factor Generator 2008/2009

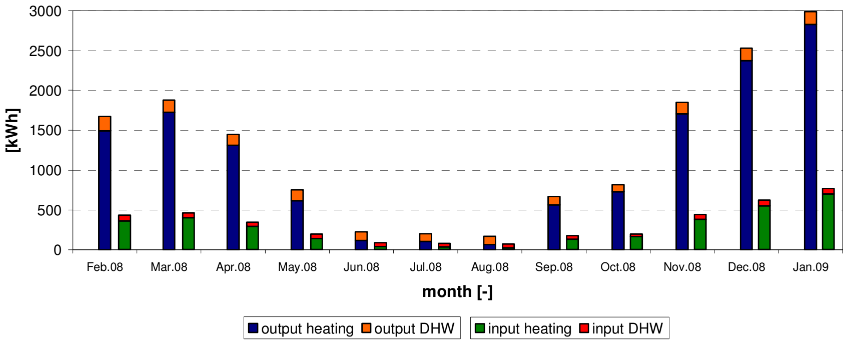


Space Heating:	13624,0 kWh
Hot water:	1567,0 kWh
Total:	**15191,0 kWh**
Total energy Input:	3827,0 kWh

Fractions of energy use 2008/2009



Monthly average source and sink temperature



Monthly energy input and output in the monitoring period

Performance indicators

Seasonal performance factors

Overall SPF-G:	**4.0**
SPF-G space heating:	**4.3**
SPF-G domestic hot water:	**2.4**

Operation time:

Heating period:	**229 d**
DHW period:	**year-round**
Total operation time	**1373 h**
DHW operation time	**600 h**

System performance and optimisation

Due to the low temperature design the space heating performance is with 4.3 quite good, but the DHW operation is with 2.4 rather on the lower end. However, the overall seasonal performance is with 4.0 in the typical range of the generator seasonal performance factors of systems measured in other field tests.

The evaluated source temperatures are with an average value of 8.5 °C and a minimum of 6.3 °C quite high. This is a further reason for the good seasonal performance. Additionally, the source system could have been dimensioned smaller. Nevertheless, water as source fluid should be considered, a feasible fluid, if a temperature above 0 °C can be guaranteed. Water as source fluid has the advantages of a higher specific heat capacity and a lower viscosity, which lowers the hydraulic resistance and the auxiliary energy of the source system.

Due to the instantaneous water heater principle, the good heat transfer by an external plate heat exchanger and the large DHW storage of 500 l makes it possible to set a lower temperature for DHW. Moreover, the instantaneous water heater principle of the fresh water system avoids problems with legionella.

No operational problems occurred during the field monitoring. The house owners were satisfied with the good seasonal performance.

Economy, Ecology and Costs

Environmental impact of the heat pump based on produced thermal energy*:

CO_{2eq} emission factor:	370 $g/kWh_{el.}$
CO_{2eq} emission***:	1415.9 kg
Primary energy factor:	1.26 $kWh_{prim.}/kWh_{el.}$
Primary energy***:	4822.0 $kWh_{prim.}$
SPF based on primary energy:	3.15

Comparison to thermal energy of condensing gas boiler**:

CO_{2eq} emission factor:	247 $g/kWh_{th.}$
CO_{2eq} emission***:	3868.2 kg
Primary energy factor**:	1.14 $kWh_{prim.}/kWh_{th.}$
Primary energy***:	17853.3 $kWh_{prim.}$
Annual efficiency****:	0.97
Primary energy efficiency:	0.85

* values based on GEMIS Österreich 4.5
** values based on FANINGER (2007)
*** values based on produced thermal energy from 02/08 until 01/09
****value based on SIMADER (2007)

Conclusion

The presented data confirm that brine-to-water heat pumps can be operated monovalently with a high overall performance factor of 4.0 for space heating and DHW due to the low flow temperature design of 35 °C.

The calculated results of CO_2-emissions and primary energy consumption approve that the described heat pump yields impressive savings of 63% CO_2-emissions and 73 % primary energy even compared to the best fossil fuel heat generator of a condensing gas boiler with 97% efficiency based on factors used in Austria

Imprint

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Date of Best Practice Sheet: March 2010

Literature

Andreas Zottl, Heinrich Huber and Christian Köfinger
Task 3 – Field test of integrated heat pumps systems - Field test of 10 heat pump systems
Report Task 3 IEA HPP Annex 32, N 161, Austrian Institute of Technology, Vienna, Sept. 2009

Best practice

IEA HPP Annex 32

Economical heating and cooling systems for low energy houses

Single-family house with air-to-water heat pump for floor heating emission system and alternate domestic water production

AUSTRIAN INSTITUTE OF TECHNOLOGY
TOMORROW TODAY

Contribution of the Austrian national project

Summary

The Austrian Institute of Technology developed a standardised heat pump monitoring as quality control measure.
This Best Practice Sheet presents field monitoring results of an air-to-water heat pump for space heating and DHW. The system is a split type air-to-water heat pump system, where the evaporator is located on the outside. The space heating emission system is a 309 m^2 floor heating system with maximum design temperature of 40°C. The measured average temperature at the heat pump outlet is 31°C and thus considerably lower.
The space heating emission system is directly connected to the heat pump without a buffer storage. DHW is produced by switching the heat pump to an 800 l storage, which supplies the heat to instantaneously heat the water. The average DHW temperature is 42.5 °C and thus very low.
In heating mode, the air-to-water heat pump yields a good seasonal performance factor of the generator system SPF-G of 3.4. In DHW operation, the seasonal performance factor is with an SPF-G of 3.6 even better and significantly higher than SPF values commonly reached with conventional air-to-water heat pumps. Thus, the overall seasonal performance of SPF-G of 3.5 is high for an air-to-water heat pump.
Compared to a condensing gas boiler of high efficiency the heat pump system can reduce the CO_2-eq.-emission by 58% and reaches an SPF based on primary energy of 2.8. Thereby, a reduction of primary energy of 69% is reached. These values are based on primary energy and CO_2-eq.-emission factors used in Austria.

Building data

- Location: Rutzenmoos, Upper Austria
- 2 inhabitants
- Year of commissioning: 2006
- Medium-weight construction, heated area 309 m^2
- Design heat load (ÖNORM B 8135): 6.7 kW (22 W/m^2)

Background

The Austrian Institute of Technology AIT has developed a standardised monitoring method for heat pump systems in order to enhance the quality management of heat pump installations. The monitoring method is an instrument to prove the functionality and performance of installed heat pump systems. In the course of the IEA HPP Annex 32 project, heat pump systems were tested under real conditions in order to evaluate their efficiency. Therefore, nine conventional heat pump systems and two compact units, which were situated in Upper-, Lower Austria and Styria, had been analysed. The system described in this Best Practice Sheet uses a split-type air-to-water heat pump system with floor heating emission system for space heating (SH) and for domestic hot water (DHW) production.

The front view of the monitored building

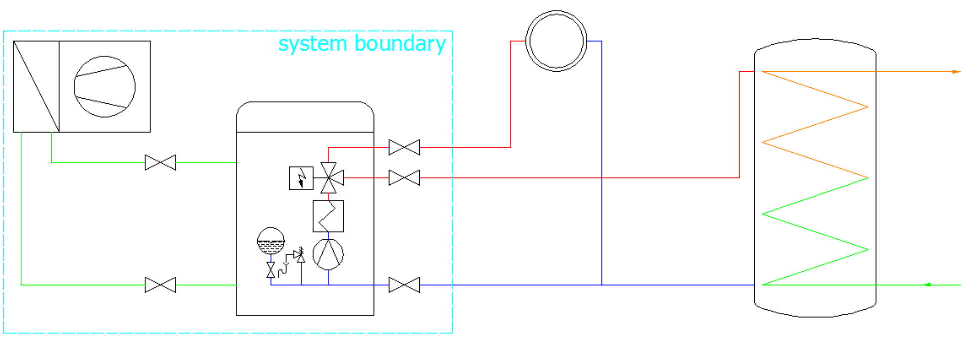
Technical concept

The low energy building with a specific heat load of 22 W/m^2 is equipped with an air-to-water heat pump for alternate space heating and domestic hot water production.
The heat pump is a split unit, where the evaporator is installed on the outside and the heat pump inside the building. The nominal heating capacity of the heat pump is 8.3 kW at A2/W35. An additional 2.7 kW direct electrical back-up heating is installed to cover peak loads.
The space heating emission system consists of a floor heating system, which is directly connected to the heat pump without a buffer storage. This avoids additional storage losses and due to the thermal capacity of the floor heating, no problems with cycling of the heat pump are expected. The maximum supply temperature was set to 40 °C during planning to reach an indoor temperature of 20 °C at a design outdoor temperature of -14 °C. However, the surface of the floor heating system is with 309 m^2 quite large. The circulation pump of the distribution system has a nominal electrical power consumption of 80 W.
The DHW is produced by switching the air-to-water heat pump from the space heating to the DHW operation. An 800 l storage is included as DHW storage tank.
The DHW is produced by the instantaneous water heater principle. The DHW temperature was set to the relatively low temperature of 45 °C.

Evaporator of the split air- to-water heat pump unit

Market status

The heat pump is available on the market.



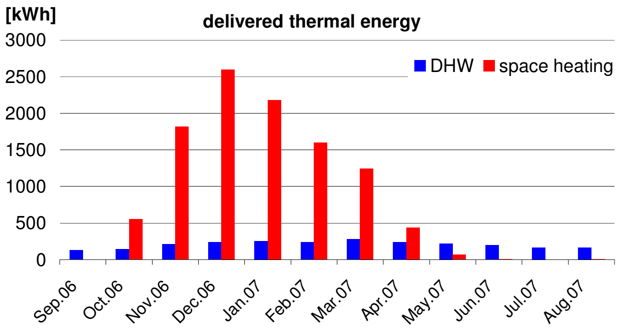
Hydraulic sketch of the space heating and DHW system of the investigated heat pump and system boundary for the performance evaluation

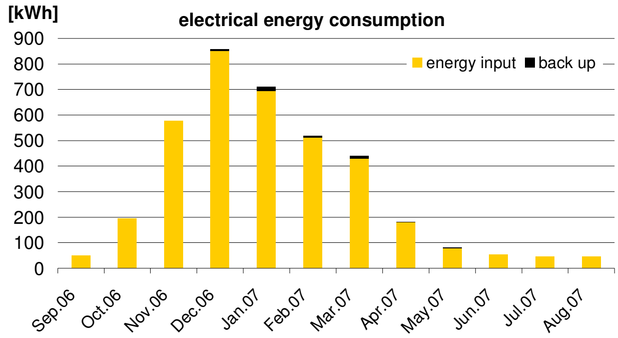
Technical data of the unit

Heating unit:	**air-to-water heat pump with scroll compressor for alternate SH and DHW operation**
	Split unit with evaporator located outside
	DHW production by instantaneous water heating
Thermal output / COP (heating unit):	
A2/W35:	**8.3 kW / 3.5**
A-7/W35:	**6.6 kW / 3**
DHW mode:	
A7/W50:	**8.4 kW / 2.8**
Refrigerant:	**R404A, charge 4 kg**
DHW storage:	**800 l**
Nominal power of the circulation pump	
	80 W

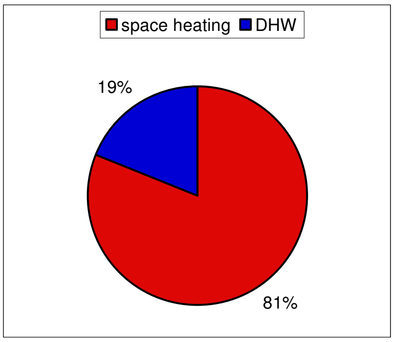
Field monitoring

The system boundary includes the generation system comprising the heat pump and eventually installed back-up heaters as well as the source system.
The monitoring period covers year-round monitoring data from 4. Sept. 2006 - 4. Sept. 2007
The total heat energy produced by the heat pumps in the monitored period is 13036 kWh. 81% of the heat corresponding to 10567 kWh (42 kWh/m^2) are consumed for space heating operation which is lower than the standard building consumption of the period and in the range of a low energy house. The DHW consumption is with 2469 kWh or a fraction of 18% on the lower edge of the typical consumption of a low energy house, but the house is inhabited by only 2 persons. The corresponding electrical energy consumed is 3714 kWh.
The electrical energy consumption of the direct electrical back-up heater occurs mainly in the winter month January and is with 54 kWh (1.5% of total electricity consumption) negligible.
The overall Seasonal Performance Factor of the Generator (SPF-G) of the complete system is 3.5, resulting of a SPF-G in SH-mode of 3.4 and SPF-G in the DHW-mode of 3.6. The SPF-G in the SH mode is quite high regarding the rather high design temperature of the floor heating system of 40°C. However, due to the large area of the 309 m^2 floor heating emission the average supply temperature during the heating operation has been evaluated to 31 °C. The indoor air temperatures are in the range of 22 °C, so sufficient heat is emitted to the room.
The SPF-G of the DHW operation, though, is quite high and even higher than in space heating operation. Due to the instantaneous water heater principle and the large DHW storage of 800 l, it is possible to set a low average temperature for DHW. The design temperature of 45°C is already quite low. During the measurement, however, the average temperature in the DHW storage is with 42.5 °C even lower. Thus, with high outdoor air heat source temperatures the monthly PF-G for DHW in summer time surpass the space heating values in wintertime. With these temperature combinations, the slightly higher SPF in DHW mode can be explained.
Due to the measurement concept, only the total electricity consumption has been measured, and thus the auxiliary energy can be evaluated separately.



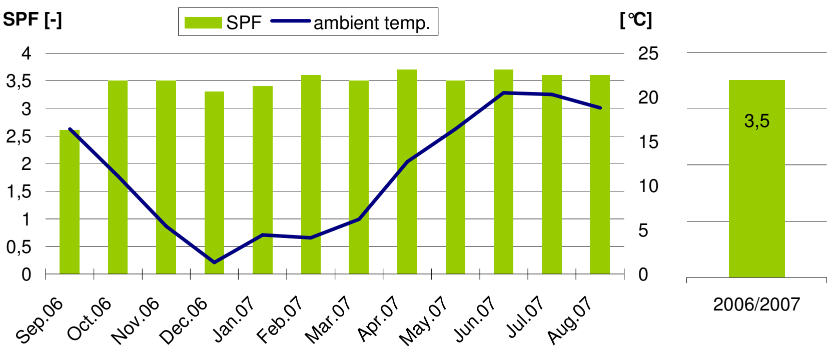


Energy delivered and consumed in 2006/2007



Space Heating:	10567,2 kWh
Hot water:	2469,0 kWh
Total:	**13036,2 kWh**
Total energy Input:	3714,0 kWh

Energy delivered and consumed in 2006/2007



Seasonal performance factor (monthly profile and total value for monitoring period) and ambient temperature (monthly average)

Performance indicators

Seasonal performance factors

Overall SPF-G of the system:	**3.5**
SPF-G heating unit:	**3.4**
SPF-G domestic water unit:	**3.6**

Operation time:

Heating period:	**190 d**
DHW period:	**year-round**

System performance and optimisation

The overall seasonal performance factor of the generator of 3.5 is very high for an outdoor-air heat pump and is higher than typical seasonal performance factors evaluated in other field tests which are in the range of 3.0. In particular the DHW performance is uncommon, but can be explained by the low measured DHW storage temperatures of 42.5 °C during the measurement period. Moreover, the monthly average outdoor air temperature is constantly above 0°C indicate the mild winter in the measurement season 2006/07.
Due to the instantaneous water heater principle and the large DHW storage of 800 l it is possible to set a low temperature for DHW. However, the average measured temperature in the DHW storage is with 42.5°C very low. Therefore, the monthly PF-G for DHW mode in summertime can be explained by the high heat source temperature of the outdoor air and the quite low DHW temperatures.
On the system side, no significant optimisation potentials are identified, since hydraulic is simple and robust, the measured temperature levels of the emission system are low and the reached seasonal performance is already above the average. However, an optimisation potential on the building side is the thermal insulation of the envelope, which was not finished during the measurements.
There have been no failures during operation, which led to full customer satisfaction.
Thus, the Best Practice Sheet gives an example, that also air-to-water heat pumps can be operated very efficiently with consequent low temperature design.

Economy, Ecology and Costs

Environmental impact of the heat pump based on thermal energy produced*:

CO_2-eq.-emission factor:	370 g/kWh$_{el.}$
CO_2-eq.-emission***:	1374.2 kg
Primary energy factor:	1.26 kWh$_{prim.}$/kWh$_{el.}$
Primary energy:	4679.6 kWh$_{prim.}$
SPF based on primary energy:	2.77

Comparative environmental impact of a condensing gas boiler based on thermal energy produced**:

CO_2-eq.-emission factor:	247 g/kWh$_{th.}$
CO_2-eq.-emission***:	3319.5 kg
Primary energy factor:	1.14 kWh$_{prim.}$/kWh$_{th.}$
Primary energy:	15320.9 kWh$_{prim.}$
Efficiency of the boiler****:	0.97
Primary energy efficiency	0.85

* values based on GEMIS Österreich 4.5
**values based on FANINGER, 2007
***values based on produced thermal energy from 09/06 until 09/07
****value based on SIMADER, 2007

Conclusion

The presented data confirms that an air-to-water heat pump system can be operated at high performance factors, if average temperatures of the space heating emission system are consequently lowered, in this system down to 31 °C for space heating.
The calculated results of CO_2-eq.-emissions and primary energy confirm considerable savings compared to a condensing gas boiler based on primary energy and CO_2-eq.-emssion factors used in Austria.

Imprint

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Date of Best practice sheet: March 2010

Literature

Andreas Zottl, Heinrich Huber and Christian Köfinger
Field test of integrated heat pumps systems –
Field test of 11 heat pump systems
IEA HPP Annex 32 country report Austria Task 3
Austrian Institute of Technology, Vienna, July 2010

IEA HPP Annex 32

IEA HPP Annex 32 is a corporate research project on technical building systems with heat pumps for the application in low energy houses.
The project is accomplished in the Heat Pump Programme (HPP) of the International Energy Agency (IEA).

Internet: http://www.annex32.net

Best practice

IEA HPP Annex 32

Economical heating and cooling systems for low energy houses

Single-family house with water-to-water heat pump and fresh water system for domestic water mode

AUSTRIAN INSTITUTE OF TECHNOLOGY
TOMORROW TODAY

Contribution of the Austrian national project

Summary

The Austrian Institute of Technology developed a standardised heat pump monitoring as quality control measure.
This Best Practice Sheet presents field monitoring results of a ground water-to-water heat pump for combined space heating and DHW operation.
As space heating emission system a 241 m^2 floor heating system at low design temperatures 35 °C/30 °C is applied. The space heating includes a buffer storage.
The domestic hot water (DHW) is produced alternately by switching the heat pump to the 500 l DHW storage, which is connected to a fresh water system.
In heating mode, the water-to-water heat pump reaches a high seasonal performance factor of the generator SPF-G of 4.5. In DHW operation, the performance is with SPF-G of 3.1 also higher than for other sources despite a high measured average DHW temperature of 54 °C. The energy weighted overall performance factor yields a SPF-G of 4.2 due to a fraction of 85% space heating energy.
Compared to a condensing gas boiler with high efficiency the heat pump system can reduce the CO_2-eq.-emissions by 66% and reaches an SPF based on primary energy of 3.3 and thereby a reduction of primary energy of 75%, if primary energy and CO_2-eq.-emission factors used in Austria are taken for the calculation.

Building data

- Location: St. Peter/Au, Lower Austria
- Inhabitants: 6 persons
- Year of commissioning: 2004
- Medium-weight construction, heated area 264 m^2
- Design heat load (ÖN M7500): 16.2 kW (61 W/m^2)

International Energy Agency
Heat Pump Programme

Introduction

The Austrian Institute of Technology (AIT) has developed a standardised monitoring method for heat pump systems in order to enhance the quality management in heat pump installations. The monitoring method is an instrument to prove the functionality and performance of installed heat pump systems. In the course of the IEA HPP Annex 32 project, heat pump systems were tested under real conditions in order to evaluate their efficiency. Therefore, nine conventional heat pump systems and two compact units, which were situated in Upper-, Lower Austria and Styria, had been analysed. The system described in this Best Practice Sheet uses a ground water-source heat pump with floor heating emission system for space heating and a fresh water system with 500 l storage for DHW operation.

The front view of the described building

Technical concept

The building of a calculated specific heat load of 61 W/m^2 is equipped with a ground water-to-water heat pump with scroll compressor for alternate space heating and DHW.

The heating capacity of the heat pump is 19.4 kW at W10/W35, i.e. the system design is monovalent and no back-up heating is installed.

The ground water source is connected directly by an extraction well and an injection well. The source pump has a nominal electrical power consumption of 370 W and the installed circulation pump of the space heating distribution system has a nominal power of 90 W. The design source temperature was set to constantly 10 °C and yields ideal temperature conditions for the heat pump operation. On the other hand, the auxiliary energy to connect the source is with 370 W higher and the costs for the connection of the source are more elevated compared to other heat sources.

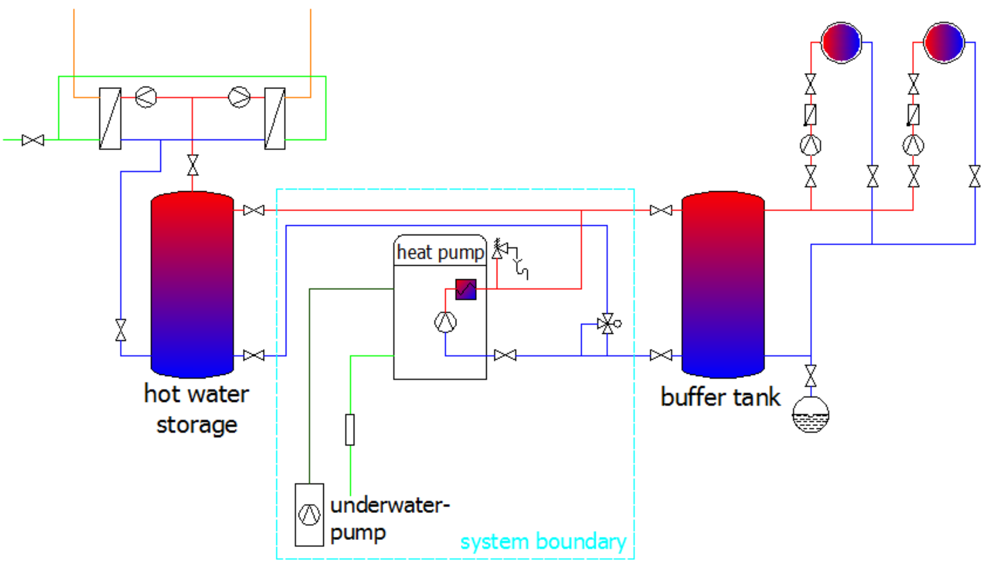
For space heating operation the heat pump is connected to a 241 m^2 floor heating emission system by a buffer storage tank, since several distribution cycles are connected to the heat pump. The design supply temperature of the distributions cycles is 35 °C.

In DHW operation the heat pump is switched to a 500 l DHW storage which is connected to a fresh water system by external heat exchangers. The design DHW temperature was set to 48 °C.

The “Waterkotte” heat pump unit

Market status

All system components are available on the market.



Sketch of the hydronic integration of the space heating and DHW system and system boundary for the performance evaluation

Technical data of the unit

Heat pump unit: ground water-to-water heat pump for alternate SH and DHW operation

Thermal output / COP:

- **W10/W35:** 19.4 kW / 5.9
- **W10/W50:** 18.1 kW / 4

Refrigerant: R407C (2.65 kg)

Floor heating emission system: 241 m^2

Design temperatures: 35 °C/30 °C

Electrical power consumption:

- **Source pump:** 370 W
- **Sink pump:** 90 W

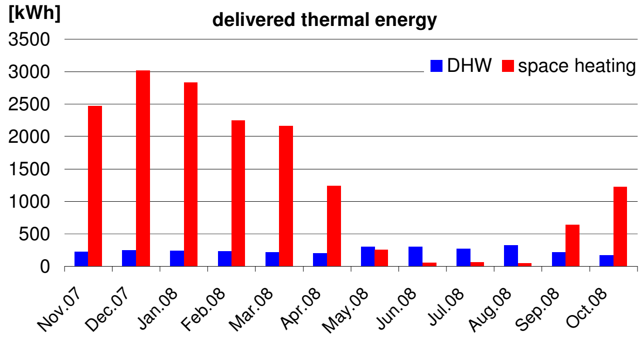
DHW operation: Fresh water system

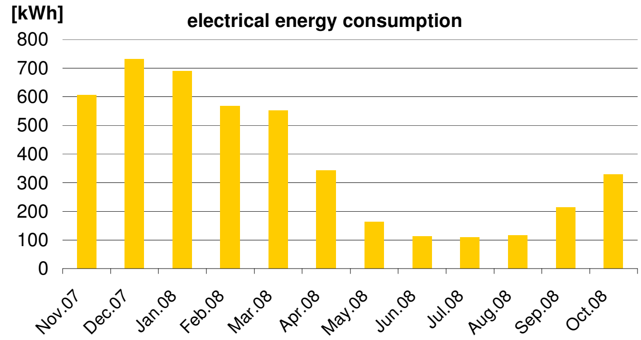
DHW temperature: 48 °C (design)

DHW storage: 500 l

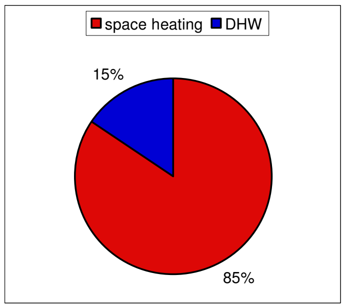
Field monitoring

The system boundary includes the generation system comprising the heat pump and eventually installed back-up heaters as well as the source system.
The monitoring period covers year-round monitoring data of Nov. 2007 to Oct. 2008.
The total heat energy produced by the heat pumps in the monitored period was 19250 kWh. 85% of the heat or 16273 kWh (62 kWh/(m^{2}a)) is consumed for space heating operation which is higher than the consumption of a low energy building, but better than the legal requirement of the period.
The annual DHW consumption is with 2977 kWh or 15% of the overall heat consumption rather low for a low energy house and regarding the fact, that the house is inhabited by 6 persons.
The total electrical energy consumption is 4532 kWh, which can be split up to 3584 kWh for the space heating operation and 948 kWh for the DHW operation.
The space heating operation yields a good Seasonal Performance Factor of the generation system (SPF-G) of 4.5, even though the average measured sink temperature of the period is with 36.9°C rather high. However, the average and stable source temperature of 13.8°C explains the high performance. The measured range of source temperatures of the heat pump is between 13.1 °C and 16.3 °C.
The DHW operation is with an SPF-G of 3.1 also good and on average higher than for other heat sources. This is mainly due to the stable and high source temperatures also in wintertime in comparison to the average for other heat sources. Therefore, the SPF-G is above 3 despite the rather high measured DHW temperatures of 54 °C.
The overall performance of the system is SPF-G = 4.2 as energy weighted average of the two operation modes.
An evaluation of the source energy would have been interesting, since ground water source heat pumps have normally higher auxiliary expense on the source side. However, due to the measurement concept the fraction of auxiliary energy could not be evaluated separately, but only the total electricity consumption.



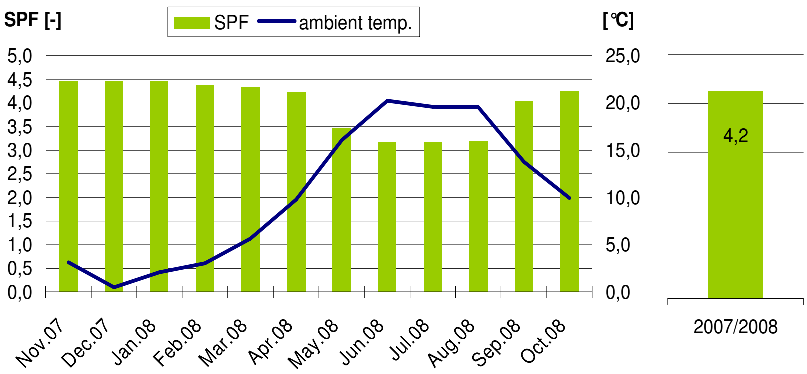


Energy delivered and consumed in 2007/2008



Space Heating:	16273,0 kWh
Hot water:	2977,0 kWh
Total:	**19250,0 kWh**
Total energy Input:	4532,0 kWh

Energy delivered and consumed in 2007/2008



Seasonal performance factor (monthly profile and total value for monitoring period) and ambient temperature (monthly average)

Performance indicators

Seasonal performance factors

Overall SPF space heating and DHW:	**4.2**
SPF heating unit:	**4.5**
SPF domestic water unit:	**3.1**

Operation time:

Heating period:	**215 d**
DHW period:	**year-round**

System performance and optimisation

The overall seasonal performance factor of 4.2 is good and reflects the excellent source temperatures of ground water source systems. A space heating performance factor of 4.5 is in the range of the best indirect ground-coupled systems which have a design temperature of the emission system below 30 °C. Direct expansion systems and systems with CO_2 borehole heat exchanger reached seasonal performance factors above 5 in field tests. A DHW performance factor above 3 is also good, in particular for the high measured DHW temperatures of 54 °C.
The building includes 2 flats, and therefore the buffer storage tank is integrated in the heating distribution system, which on the one hand has the advantage of decoupling the generation and the heating needs, but on the other hand causes heat losses, which, however, are low due to the low temperature level.
Due to the instantaneous water heater principle and the large DHW storage of 500 l it is normally possible to set a low temperature for DHW operation, and consequently, the design DHW temperature has been set to 48 °C. However, during the measurement the average temperature in the DHW storage was evaluated to 54 °C. Furthermore, the instantaneous water heating principle avoids legionella problems and thereby the need to heat the storage volume to high temperatures.
Concluding, the performance of the heat pump is good and has no significant optimisation potentials.

Economy, Ecology and Costs

Environmental impact of the heat pump based on thermal energy produced*:

CO_2-eq.-emission factor:	370 $g/kWh_{el.}$
CO_2-eq.-emission***:	1676.8 kg
Primary energy factor:	1.26 $kWh_{prim.}/kWh_{el.}$
Primary energy:	5710.3 kWh_{prim}
SPF based on primary energy:	3.33

Comparative environmental impact of a condensing gas boiler based on thermal energy produced**:

CO_2-eq.-emission factor:	247 $g/kWh_{th.}$
CO_2-eq.-emission***:	4901.8 kg
Primary energy factor:	1.14 $kWh_{prim.}/kWh_{th.}$
Primary energy:	22623.8 $kWh_{prim.}$
Efficiency****:	97 %
Primary energy efficiency:	0.85

* values based on GEMIS Österreich 4.5
**values based on FANINGER, 2007
***values based on produced thermal energy from 02/08 until 01/09
****value based on SIMADER, 2007

Conclusion

The presented data confirms the good performance of water-to-water heat pumps with low temperature emission system and the excellent source temperature.
The calculated results of environmental impact CO_2-eq.-emissions and primary energy consumption presented above prove that the described heat pump contributes to significant savings even compared to best of commonly installed boiler systems, a condensing gas boiler.

Imprint

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Date of Best practice sheet: February 2010

Literature

Andreas Zottl, Heinrich Huber and Christian Köfinger
Task 3 – Field test of integrated heat pump systems – Field test of 11 heat pump systems
Report Task 3 IEA HPP Annex 32,
Austrian Institute of Technology, Vienna, July 2010

Best practice

Economical heating and cooling systems for low energy houses

Passive house with ground-coupled heat pump compact unit and ventilation heat recovery

AUSTRIAN INSTITUTE OF TECHNOLOGY
TOMORROW TODAY

Contribution of the Austrian national project

Summary

The Austrian Institute of Technology developed a standardised heat pump monitoring as quality control measure.
This Best Practice Sheet presents field monitoring results of a brine-to-water heat pump compact unit with ventilation heat recovery for the operation modes space heating, DHW, space cooling and ventilation in one unit. The compact unit is installed in a passive house with a specific heat load of 17 W/m^2.
While the space heating energy is emitted to the room by a low temperature floor heating system, the passive space cooling energy uses a thermally-activated ceiling. For the compact unit an extended monitoring has been performed.
The overall seasonal performance of the generator SPF-G reaches a value of 4.1. In space heating mode, a good performance factor of 4.3 is reached, while the generator SPF in DHW operation is with 3.7 high and benefits from the higher ground temperature in summertime due to the passive cooling operation.
The passive cooling operation by direct coupling of the horizontal ground source collector to the thermally activated ceiling reaches an SPF-G of 9.0, which is a good performance factor, as well, and is in the range of SPF values measured with borehole heat exchangers in residential applications.
Compared to a condensing gas boiler of high efficiency the heat pump system can reduce the CO_2 emission by 59% and reaches a seasonal performance factor based on primary energy of 3.3 and thereby a reduction of primary energy of 70%, referring to efficiencies, primary energy and emission factors used in Austria.

Building data

- Location: Judendorf-Straßengel, Styria, Austria
- Detached single family passive house, 4 inhabitants
- Year of commissioning: 2008
- lightweight construction, heated area 210 m^2
- Design heat load (EN 12831): 3.5 kW (17 W/m^2)

Introduction

The Austrian Institute of Technology (AIT) has developed a standardised monitoring method for heat pump systems in order to enhance the quality management in heat pump installations. The monitoring method is an instrument to prove the functionality and performance of installed heat pump systems. In the course of the IEA HPP Annex 32 project, heat pump systems were tested under real conditions in order to evaluate their efficiency. Therefore, nine conventional heat pump systems and two compact units, which were situated in Upper-, Lower Austria and Styria, had been analysed. In the case of two ground-source heat pump compact units with ventilation heat recovery installed in passive houses an extended monitoring has been performed, which includes also the space heating circulation pump. Results are used to prove the functionality and performance of the system, since they have recently been introduced into the market.

The front view of the passive house

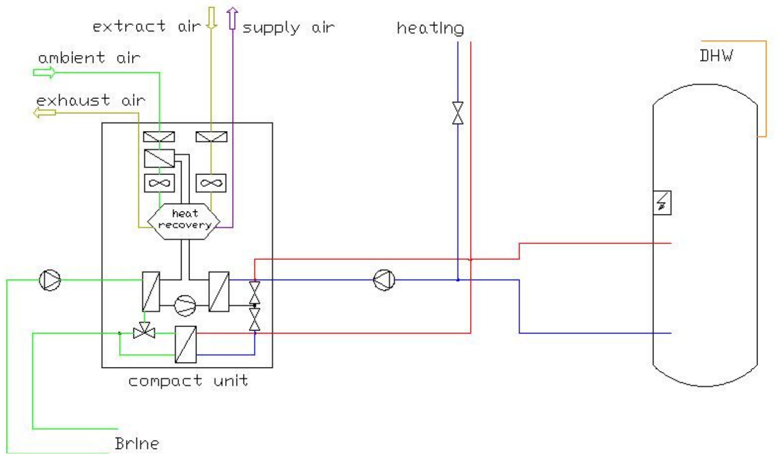
Technical concept

The building is designed according to the passive house standard which has the main requirements of max. space heating energy need of 15 kWh/(m^2·a) and an approved air-tightness of the building envelope n_{50} of max. 0.6 h^{-1}.
The building is equipped with a highly integrated water heat pump compact unit with ventilation heat recovery which covers the building functions space heating (SH), domestic hot water (DHW), space cooling (SC) and ventilation with one unit. Contrary to common heat pump compact unit designs for passive houses, where the heat emission is provided by the ventilation system, i.e. the system is equipped with air heating and uses solely exhaust air as heat source, this system concept uses a ground source and a hydronic emission system, which enables higher capacities and lower supply temperatures. In this case a 130 m^2 floor heating is used. The nominal heating capacity of the heat pump is 3.3 kW at B0/W35 and the design temperatures of the floor heating 35 °C/30 °C. The source system consists of a 200 m horizontal ground collector, which also provides passive space cooling in summertime. For the emission of cooling power to the room, the system does not use the floor as same emission system as in space heating mode, but an additional activation of the ceiling with 200 m of pipe embedded in the concrete is used. Thereby, the passive cooling can be operated with even higher supply temperatures near the indoor temperature, since the ceiling yields a better heat transfer in cooling mode than the floor.
Moreover, a 300 l domestic hot water storage is integrated in the casing, which is charged by a desuperheater. For preheating of the outdoor air of the comfort ventilation system the heat pump includes a condensate subcooling.

The ground-coupled compact unit with heat pump and ventilation heat recovery

Market status

The heat pump compact unit is available on the market.



Sketch of the ground-coupled heat pump compact unit with ventilation heat recovery

Technical data of the unit

Heat pump unit: brine-to-water heat pump compact unit with ventilation heat recovery
Ground-source system: 200 m horizontal collector
Capacity of the source: 2.5 kW (12.5 W/m)
Thermal output/COP:
B0/W35: 3.3 kW / 4.5
Floor heating emission system: 130 m^2
Ceiling emission for space cooling: 200 m^2
Design temperatures 30 °C/25 °C
DHW system:
Design temp.: 52 °C
DHW storage: 300 l
Ventilation system:
Volume flow: 135 m^3/h
Heat recovery efficiency: 85%
Nom. Fan power: 2x35 W

Field monitoring

The evaluation was made based on three system boundaries including the generation system which comprises the heat pump and eventually installed back-up heaters as well as the source system, and on the other hand the system including sink pumps. Thus, in- and outlet temperatures as well as mass flows of the heat pump source and sink side are monitored in a 1 s interval and stored as 15 min average values. The electrical energy consumed by the heat pump compressor, the compressor on-/ off cycles and the operating hours are registered every 15 min to characterise the performance.

The monitoring period covers year-round monitoring data from Oct. 2008 to Oct. 2009.

The total energy produced by the heat pump and source system in the monitored period was 9369 kWh. 62% or 5823 kWh corresponding to 27.7 kWh/(m^{2}a) is consumed for space heating operation which is consistent to the low energy building better than the legal requirement of the period.

The annual DHW consumption is with 1539 kWh quite low, but due to the low space heating consumption still 21% of the total consumption of space heating and DHW. 20% is a typical range of low energy houses.

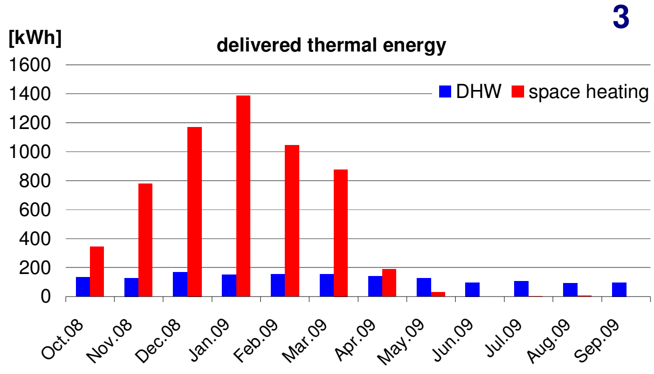
919 kWh were used for pre-heating the outdoor air of the comfort ventilation system by the subcooler of the heat pump.

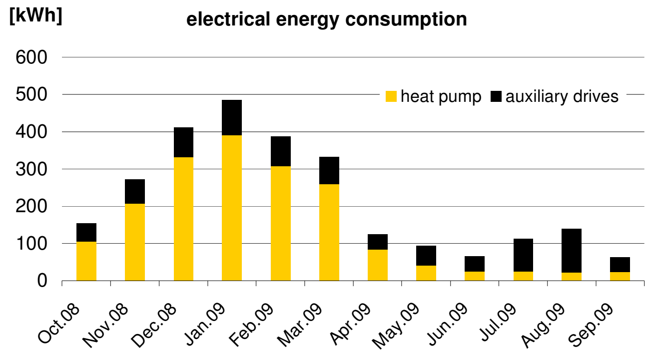
The total corresponding electrical energy consumed for the space heating, DHW, space cooling and ventilation is 2640 kWh.

The SPF_1 of the heat pump, without auxiliary drives, is 4.6 for the measured period. The SPF_2 of the generator system including source auxiliary energy was split up into the SPF_2 for heating and the SPF_2 for domestic hot water. The whole system reached an SPF_2-value of 4.1. The space heating reached a value of 4.3 and the domestic hot water production 3.7. The high seasonal performance factor for DHW is due to the high heat source temperature during summer, which is increased by the passive cooling operation. By considering all auxiliary drives the SPF_3 reached a value of 3.4. The passive ground-coupled cooling mode reaches an SPF of 9.0.

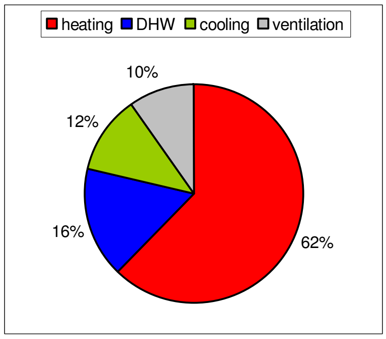
The average outlet temperature of the heat pump was 29.2 °C for the measured period, and the average source temperature at the outlet of the ground collector was 2.9 °C.

The highest monthly averaged performance factors are registered in the transitional period in October and November with low supply temperatures in the space heating mode.



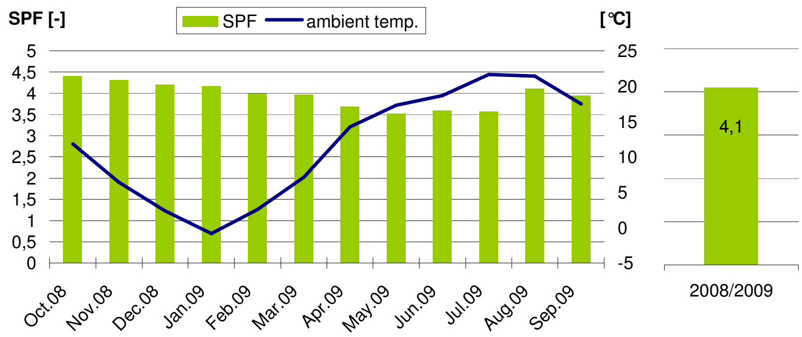


Energy delivered and consumed in 2008/2009



Space Heating:	5823 kWh	Ventilation:	919 kWh
Hot water:	1539 kWh	Cooling:	1088 kWh
Total Output:	**9369 kWh**	**Energy Input:**	**2640 kWh**

Energy delivered and consumed in 2008/2009



Seasonal performance factor (monthly profile and total value for monitoring period) and ambient temperature (monthly average)

Performance indicators

Seasonal performance factors

Overall SPF SH, DHW and SC:	**4.1**
SPF space heating:	**4.3**
SPF domestic water unit:	**3.7**
SPF space cooling	**9.0**

Operation time:

Heating period:	**256 d**
DHW period:	**year-round**
Operation SH	**1452 h**
Operation DHW	**362 h**

System performance and optimisation

The overall generator performance factor of 4.1 is a good value for a ground-coupled heat pump with horizontal collector. Also the single performance factor in the space heating mode is with 4.3 good. The DHW factor is with 3.7 in the upper range of measured seasonal performance factors.
The SPF in passive cooling mode is with 9.0 also in a range which is measured in other field test projects, as well. In systems with borehole heat exchangers, performance factors of 8-15 and seasonal performance factors in the range of 8 have been measured in residential buildings.
The relatively high fraction of auxiliary energy consumption of 45% of the total electricity consumption is also due to the passive cooling operation, since in the summer operation, heat pump electricity is only used for the DHW operation, while in passive cooling operation, only the pumps are operated. The fraction for space heating and DHW is usually in the range of 10%, but the ratio is shifted for systems with passive cooling to higher fractions of auxiliary use. Consequently, this means that the efficiency of auxiliary components has a higher impact on the performance factor, so the choice of pumps and design of the hydraulic system get more important for a good performance factor. In general, the performance of the passive cooling is mainly affects by the hydraulic performance and the cooling needs, since the pump energy is nearly constant and independent of the cooling energy extracted.

Economy, Ecology and Costs

Environmental impact of the heat pump based on thermal energy produced*:

CO_{2eq} emission factor:	370 g/kWh$_{el.}$
CO_{2eq} emission***:	977 kg
Primary energy factor****:	1.26 kWh$_{prim.}$/kWh$_{el.}$
Primary energy:	3326.4 kWh$_{prim.}$
SPF based on primary energy:	3.25

Condensing gas boiler based on thermal energy produced**:

CO_{2eq} emission factor:	247 g/kWh$_{th.}$
CO_{2eq} emission***:	2385.7 kg
Primary energy factor:	1.14 kWh$_{prim.}$/kWh$_{th.}$
Primary energy:	11010.9 kWh$_{prim.}$
Boiler Efficiency ****:	97 %
Primary energy efficiency:	0.85

* values based on GEMIS Österreich 4.5
** values based on FANINGER (2007)
*** values based on produced thermal energy from 10/08 until 09/09
**** value based on SIMADER, 2007

Conclusion

The presented data confirms that a brine-to-water compact heat pump system can be operated monovalently to cover the entire space heating and DHW energy of a passive house. Due to low flow temperature design of 35℃ the SPF of 4.3 in space heating mode is good.
The computed results of CO_2 emissions and primary energy consumption presented above prove that the described heat pump significantly outperforms a condensing gas boiler of high efficiency referring to factors commonly used in Austria.

Imprint

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Date of Best practice sheet: February 2010

Literature

Andreas Zottl, Heinrich Huber and Christian Köfinger
Field test of integrated heat pumps systems –
Field test of 11 heat pump systems,
IEA HPP Annex 32 report Austria Task 3,
Austrian Institute of Technology, Vienna, August 2010

Best practice

IEA HPP Annex 32

Economical heating and cooling systems for low energy houses

Passive house with ground-coupled heat pump compact unit and ventilation heat recovery

AIT AUSTRIAN INSTITUTE OF TECHNOLOGY TOMORROW TODAY

Contribution of the Austrian national project

Summary

The Austrian Institute of Technology developed a standardised heat pump monitoring as quality control measure.
This Best Practice Sheet presents field monitoring results of a brine-to-water heat pump compact unit with ventilation heat recovery for the operation modes space heating, DHW, space cooling and ventilation in one unit. The 3.3 kW compact unit is installed in a passive house and connected to a 350 m^2 horizontal ground collector as heat source. The space heating energy is emitted to the room by an 80 m^2 low temperature wall heating system with a design temperature of 35 °C/30 °C.
The seasonal performance factor of the generator SPF-G reaches an overall SPF-G of 4.3. In space heating operation, the SPF-G reaches a good value of 4.7. In DHW operation, the seasonal performance factor is with an SPF-G of 3.6 significantly higher than SPF-values commonly reached with conventional brine-to-water heat pumps. The larger SPF-G value may be due to higher ground temperature caused by the passive cooling operation. The passive cooling operation by direct coupling of the horizontal ground source collector to the wall heating distribution system reaches an SPF-G of 4.7.
Compared to a condensing gas boiler of high efficiency the heat pump system can reduce the CO_2-eq.-emission by 61% and reaches an SPF based on primary energy of 3.4 and thereby a reduction of primary energy of 71%. These values are based on efficiencies, primary energy and CO_2-eq.-emission factors used in Austria.

Building data

- Location: Hitzendorf, Styria, Austria
- Detached single family passive house, 4 inhabitants
- Year of commissioning: 2006
- Medium-weight construction, heated area 180 m^2
- Design heat load (EN 12831): 3.8 kW (21.1 W/m^2)

Introduction

The Austrian Institute of Technology (AIT) has developed a standardised monitoring method for heat pump systems in order to enhance the quality management of heat pump installations. The monitoring method is an instrument to prove the functionality and performance of installed heat pump systems. In the course of the IEA HPP Annex 32 project, heat pump systems were tested under real conditions in order to evaluate their efficiency. Therefore, nine conventional heat pump systems and two compact units, which were situated in Upper-, Lower Austria and Styria, had been analysed. In the case of two ground-source heat pump compact units with ventilation heat recovery installed in passive houses an extended monitoring has been performed, which includes also the DHW storage and the space heating circulation pump. Results are used to prove the functionality and performance of the system, since they have been recently introduced into the market.

The front view of the passive house

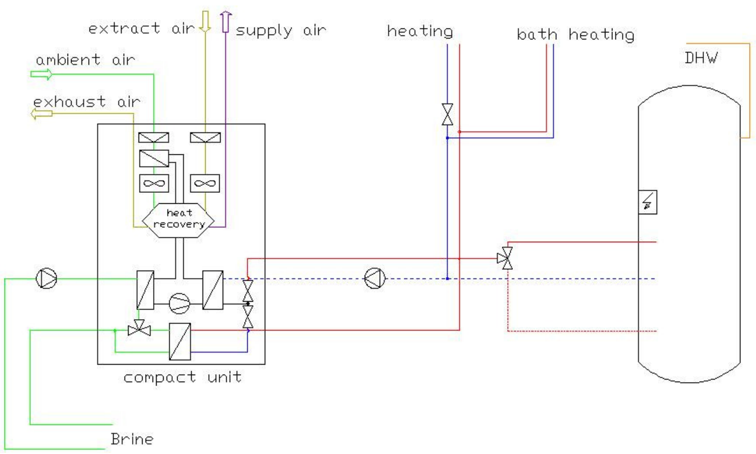
Technical concept

The building is designed according to the passive house standard which has the main requirements of maximum space heating energy need of 15 kWh/(m^{2}a) and an approved air-tightness of the building envelope n_{50} of max. 0.6 h^{-1}.
The building is equipped with a highly integrated so-called heat pump compact unit with ventilation heat recovery which covers the building functions space heating (SH), domestic hot water (DHW), space cooling (SC) and ventilation (V) with one unit. Contrary to common heat pump compact unit designs for passive houses, where the heat emission is provided by the ventilation system, i.e. the system is equipped with air heating and uses solely exhaust air as heat source. This system concept uses a ground source and a hydraulic emission system, which enables higher capacities and lower supply temperatures. The nominal heating capacity of the heat pump is 3.3 kW at B0/W35 and the design temperatures of the floor heating 35 °C/30 °C. The source system consists of a 350 m horizontal ground collector, which also provides passive space cooling in summertime. For the emission of cooling power to the room, the system uses the same emission system as for space heating, in this case an 80 m^2 wall heating.
Moreover, a 300 l domestic hot water storage is integrated in the casing, which is charged by a desuperheater. The heat pump includes a condensate subcooling used for preheating the outdoor air.
The system is normally operated monovalently, i.e. the installed direct electrical back-up heating is usually deactivated.

The ventilation compact unit with ground-source heat pump

Market status

The heat pump compact unit is available on the market.



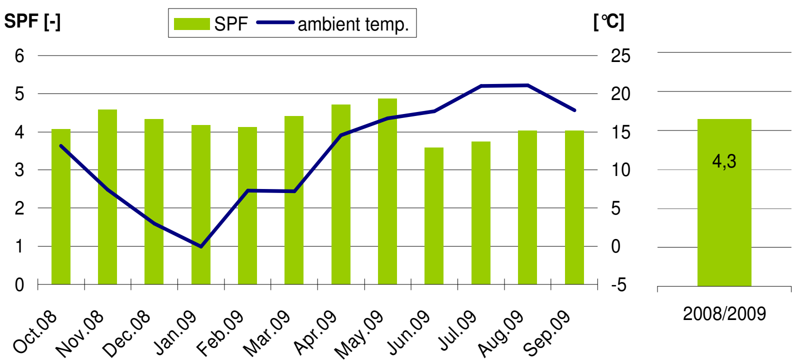
Sketch of the ground-coupled heat pump compact unit with ventilation heat recovery

Technical data of the unit

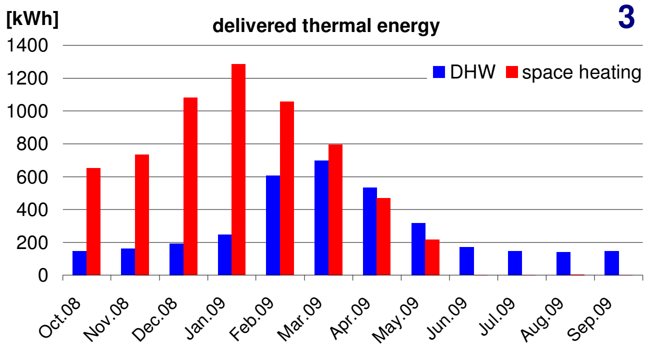
Heat pump unit:	**brine-to-water heat pump compact unit with ventilation heat recovery**
Ground-source system:	**350 m pipe in the working space of the building**
Capacity of the source:	**2.5 kW (7.2 W/m)**
Thermal output/COP:	
B0/W35:	**3.3 kW / 4.5**
Wall heating emission system:	**80 m^2**
Design temperatures	**35 °C/30 °C**
DHW system:	
Design temp.:	**52 °C**
DHW storage:	**300 l**
Ventilation system:	
Volume flow:	**160 m^3/h**
Heat recovery efficiency:	**85%**
Nom. Fan power:	**2x35 W**

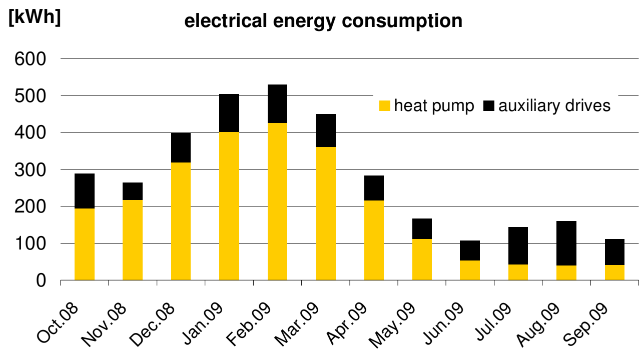
Field monitoring

The evaluation was made based on three system boundaries including the generation system which comprises the heat pump and eventually installed back-up heaters as well as the source system. Thus, in- and outlet temperatures and mass flows of the heat pump source and sink side are monitored in a 1 s interval and stored as 15 min average values. The electrical energy consumed by the heat pump compressor, the compressor on-/ off cycles and the operating hours are registered every 15 min to characterise the performance.
The monitoring period covers year-round monitoring data of Oct. 2008 - Sept. 2009.
The total energy consumption in the monitored period is 12700 kWh. 49% of the energy or 6302 kWh (35 kWh/(m^2a)) is consumed for space heating operation which is consistent to the low energy building better than the legal requirement of the period, however, the passive house consumption is not reached. The annual DHW consumption is 3511 kWh and thereby 50% of the total consumption, which underlines the low space heating energy consumption. The corresponding overall electrical energy consumed is 3403 kWh.
The seasonal performance factor of the heat pump operation SPF_1, without auxiliary drives, was evaluated to 4.8 for the measured period. The SPF_2 for the generator incl. auxiliaries was split-up into the SPF_2 for space heating and the SPF_2 for domestic hot water. The space heating operation yields a very good generator SPF of 4.7, while the performance in DHW operation is with an SPF of 3.6 lower, but also high for the DHW operation. The high seasonal performance factor for DHW can be explained by the high heat source temperature during summer, generated by the passive cooling operation. The overall SPF of 4.3 for space heating and DHW is due to the higher energy fraction in the space heating mode. The performance of the space cooling yields a performance factor of 4.7.
Concerning the evolution of the seasonal performance factor, the highest values are registered in April and May, when ground temperatures are high and supply temperatures of the space heating are low. The lowest value is reached in June with DHW-only operation, while in the following summer month the space cooling operation augments the SPF a bit.
By considering all auxiliary drives the SPF_3 reaches a value of 3.7.
The average outlet temperature during heat pump operation is 35.4 °C at an average source temperature of 6.6 °C.

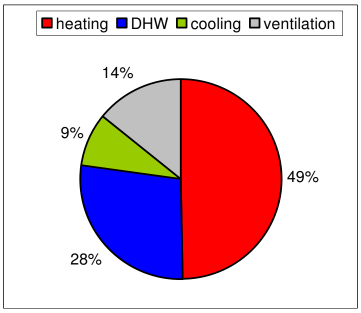


Seasonal performance factor (monthly profile and total value for monitoring period) and ambient temperature





Energy delivered and consumed in 2008/2009



Space Heating:	6302 kWh	Ventilation:	1804 kWh
Hot water:	3511 kWh	Cooling:	1083 kWh
Total Output:	**12700 kWh**	**Energy Input:**	**3403 kWh**

Energy delivered and consumed in 2008/2009

Performance indicators

Seasonal performance factors

Overall SPF space heating/DHW:	**4.3**
SPF heating unit:	**4.7**
SPF domestic water unit:	**3.6**
SPF space cooling	**4.7**

Operation time:

Heating period:	**324 d**
DHW period:	**year-round**
Operation SH	**1533 h**
Operation DHW	**848 h**

Performance and optimisation potentials

The seasonal performance factor in the space heating mode is with 4.7 in the upper range of measured SPF-G. The DHW SPF-G is with 3.6 high, as well, leading to a good overall SPF value of 4.3.

In passive cooling mode, only auxiliary energy is used, since only the pumps are running without a heat pump operation. Therefore, the SPF in the passive cooling mode is with 4.7 rather low. For systems with ground-coupled borehole heat exchangers performance factors around 8 have been measured in residential buildings which still yield potentials for an improvement.

Reasons for the lower seasonal performance can be on the one hand a low amount of energy extracted from the house in the cooling mode, which is due to the fact, that the auxiliary energy consumption is almost constant and not affected by the extracted cooling power.

On the other hand, horizontal ground collectors may have higher ground temperatures in summer due to the higher impact of the outdoor air temperature. Ground temperatures may even be too high to operate the system in the cooling mode.

Moreover, the efficiency of the auxiliary components themselves and thereby the auxiliary consumption could have an impact. Performance factors can be significantly increased by the use of efficient pumps.

Economy, Ecology and Costs

Environmental impact of the heat pump based on thermal energy produced*:

CO_2-eq.-emission factor:	370 g/kWh$_{el.}$
CO_2-eq.-emission***:	1259 kg
Primary energy factor:	1.26 kWh$_{prim.}$/kWh$_{el.}$
Primary energy***:	4288 kWh$_{prim.}$
SPF based on primary energy:	3.41

Comparative environmental impact of a condensing gas boiler based on thermal energy produced**:

CO_2-eq.-emission factor:	247 g/kWh$_{th.}$
CO_2-eq.-emission***:	3234 kg
Primary energy factor:	1.14 kWh$_{prim.}$/kWh$_{th.}$
Primary energy***:	14926 kWh$_{prim.}$
Primary energy efficiency****:	0.85

* values based on GEMIS Österreich 4.5
**values based on FANINGER, 2007
*** values based on produced thermal energy from 10/08 until 09/09
****value based on 97% efficiency according to SIMADER, 2007

Conclusion

The presented data confirms that a ground-coupled compact unit reaches a high generator seasonal performance factor of 4.3 due to low flow temperature design of 35 °C in monovalent operation.

The calculated results of CO_2-eq.-emissions and primary energy consumption presented above prove significant reduction potentials of 61% and 71% respectively compared to a condensing gas boiler with an efficiency of 97% and factors used in Austria

Imprint

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Date of Best practice sheet: March 2010

Literature

Andreas Zottl, Heinrich Huber and Christian Köfinger
Field test of integrated heat pump systems –
Field test of 11 heat pump systems,
IEA HPP Annex 32 report Austria Task 3,
Austrian Institute of Technology, Vienna, August 2010

IEA HPP Annex 32

IEA HPP Annex 32 is a corporate research project on technical building systems with heat pumps for the application in low energy houses.
The project is accomplished in the Heat Pump Programme (HPP) of the International Energy Agency (IEA).

Internet: http://www.annex32.net

Best practice

Single Family House according to MINERGIE® with Heat Pump Compact Unit and Ventilation Heat Recovery

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Federal Office of Energy SFOE

Contribution of the Swiss national project

Summary

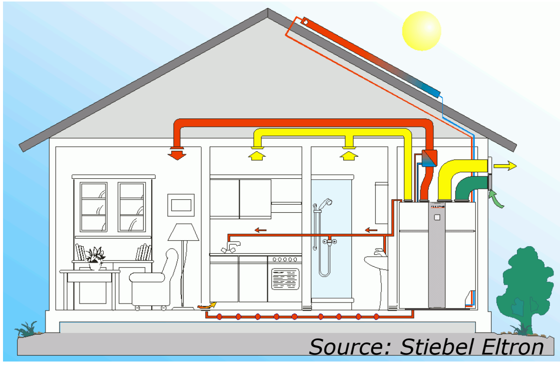
This Best Practice Sheet describes field monitoring results of a heat pump compact unit with ventilation heat recovery installed in a single family low energy house according to the Swiss MINERGIE® standard. The MINERGIE® standard implies low U-values, a high quality glazing and a controlled ventilation, which enhances the indoor thermal comfort.
The low space heating demand of 44 kWh/(m^{2}a) enables the use of a low temperature heat emission system. In the field monitoring plant, the used floor emission system was designed for a low flow temperature below 30°C at design conditions. Such low temperatures optimise the heat pump COP and a self-regulation can be used for the control of the system.
The measured overall seasonal performance factor of the heat pump for space heating and DHW production is 3.7 (based on the boundary of COP testing) and 3.1 for the entire system incl. ventilation, DHW storage and auxiliaries. The good performance proves that the unit operates feasible combining the advantages of small installation space/costs and a monoenergetic operation. Direct electrical back-up use is with ≈5% very low and limited to the coldest period of the year.
The total cost of the system is ≈22.000 € incl. the compact unit, floor emission system, installation and design, excl. the DHW distribution. No specific maintenance was required during the monitoring period.

Building data

- Location: Gelterkinden, canton Basel-Landschaft
- 3 inhabitants (2 adults, 1 child in school age)
- Energy reference area: 153 m^2/net living space 125m^2
- Design heat load: 4.1 kW (SIA 384/2)
- Annual space heating demand: 157 MJ/m^2 (SIA 380/1)
- U-value walls: 0.21 W/(m^2·K), roof 0.13 W/(m^2·K)
- U-value windows (incl. frame) 1.2 W/(m^{2}K)

Background

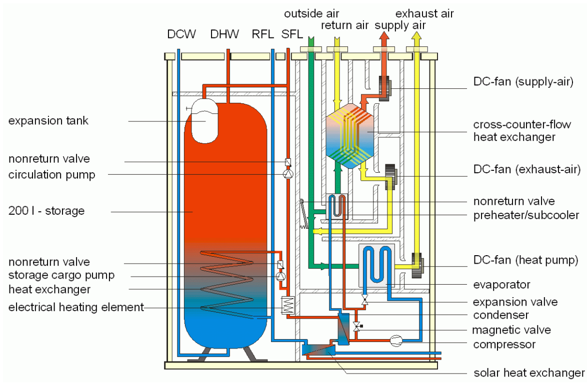
Due to an air-tight building envelope low energy houses require a mechanical ventilation system to guarantee hygienic air exchange. In most cases a ventilation heat recovery is installed to reduce the space heating demand.
To further recover the energy from the ventilation exhaust air, a heat pump can provide space heating and domestic hot water. With regard to installation space and cost, ventilation compact units with exhaust air heat pump were introduced into the market, combining the three functions in one unit. These systems are very popular in German passive houses.



Sketch of the ventilation compact unit installed in the single family house. The functions ventilation, space heating and DHW are combined in one unit.
A solar collector is optional and not installed in the field monitoring object.

Technical concept

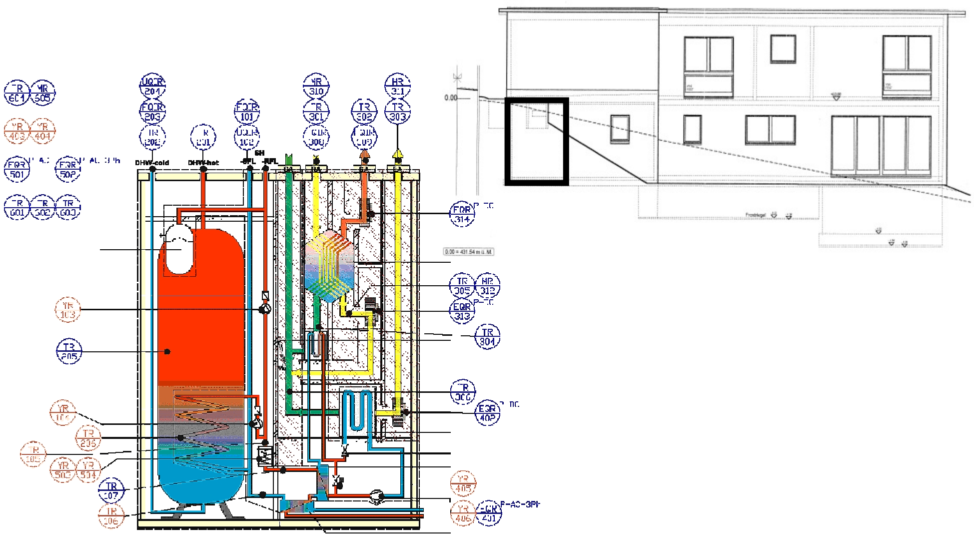
The monitored compact unit is designed for low energy residential houses in the range of 3-5 kW design heat load, e.g. according to the Swiss MINERGIE® standard.
In this capacity range outdoor air serves as additional heat source for the heat pump evaporator. An electrical back-up heater covers peak loads.
Furthermore, the unit includes an additional air pre-heater to prevent frosting of the ventilation heat recovery. The pre-heater uses the subcooling energy of the heat pump refrigerant cycle and avoids thereby a frosting of the heat recovery. The heat pump evaporator has to be defrosted regularly due to a relatively high outdoor air fraction.
The compact unit is designed for a floor heating system. The floor heating has been dimensioned to a very low design flow temperature below 30 °C (Low-Ex layout) in order to maximise the COP of the heat pump.
At these low flow temperatures the self-regulation effect can be used. It refers to the effect that the heat flux is reduced in case of a low temperature difference between indoor temperature and the emission system, i.e. in case of increasing room temperatures the heat emission of the space heating system is reduced by itself. A self-regulation can only be used in systems with low temperature differences to the room.
A 200 l domestic hot water (DHW) storage is included in the compact unit for the DHW operation.



Components and layout of the heat pump compact unit with ventilation heat recovery

State of market introduction

The compact unit is fabricated in serial production and is available on the market for several years with increasing market shares.



Cross section of the dwelling in Gelterkinden. The compact unit, which is depicted as cut-away view including the sensors, is placed in the marked technical room in the basement

Technical data of the unit

Type:	**Ventilation compact unit with outdoor/exhaust air heat pump**
Refrigerant	**R 407 C**
Output capacity	**4.1 kW (A2/W35)**
Electricity	**1.3 kW (A2/W35), COP 3.2**
Electrical backup	**1.4 + 2.8 kW, 4.2 kW in total**
Noise emissions	**49 dB(A)***
Weight	**223 kg unit/ 153 kg storage (w/o water)**
Storage volume	**200 l**
Ventilation rate	**80-230 m^3/h**

* at A2/W35, 170m3/h ventilation air at 50 Pa

Field monitoring

The field monitoring was carried out over a whole year in the period 26.April 2004 – 25. April 2005.

The measurement points are set in such a way that, as far as possible, energy balances for all component groups and operation modes can be carried out. This included also measurement points inside the compact unit in order to determine e.g. the contribution of the subcooler for the ventilation air preheating and the fraction of the electrical resistance heat for space heating and DHW. The evaluation in focus was the electricity input, the generated heat and the used heat.

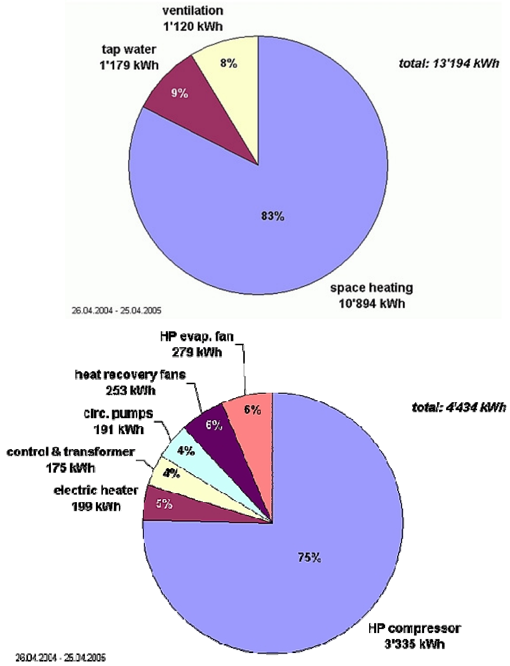
The control of the system is based on an outdoor air dependent heating curve. In systems with self regulation effect, the setting of the heating curve is important, i.e. also for small systems in single family houses, an initial commissioning is required. Moreover, control comprises balance points for the use of the back-up heater, i.e. above a certain outdoor temperature the back-up is deactivated. Moreover, in order to maximise energy fractions covered by the heat pump, a time delay for the supplementary back-up heater is set, i.e. the back-up is only switched-on after a certain time of heat pump operation.

The field monitoring showed a higher energy consumption for the space heating operation than expected according to the standard calculation. Explanations for the higher consumption are not finished drying-out of the building, less solar gains due to the user's shading behaviour and wind exposure.

The DHW consumption makes-up only about 10% of the total heat consumption and is therefore relatively low for a low energy house. These low values could be explained by specific user behaviour.

The ventilation heat recovery reduces the space heating demand by about 10%.

The room air temperatures are most of the time in the desired range of 20 °C to 24 °C. Only at outside air temperatures below -8 °C the room air temperature drops slightly below 20 °C. At outside air temperatures over 26 °C the temperature in the room stays in 50% of these times below 26 °C.



Fractions of produced heat and electricity use

Performance indicators

Seasonal performance factors

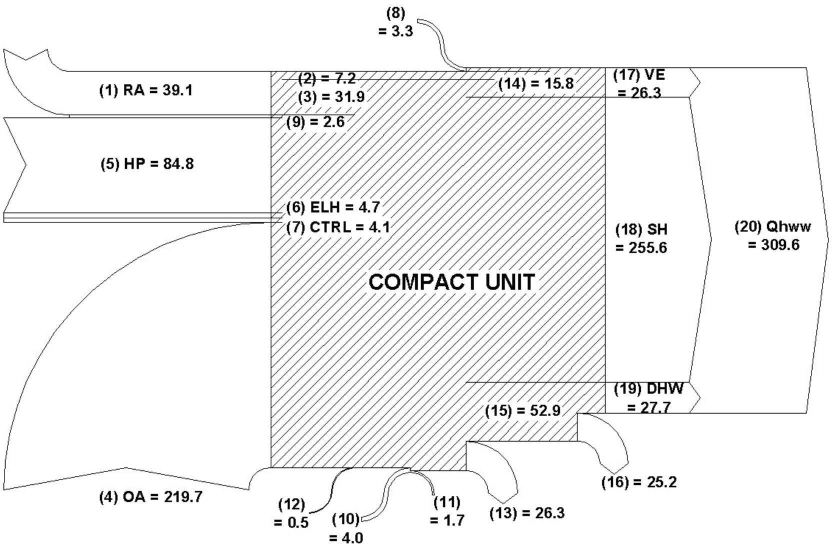
SPF generator (boundary HP, BU & source)	**3.6**
SPF system (all system components)	**3.1**

Fractional losses/consumption

Fraction storage losses (of total heat)	**8%**
Fraction back-up (of total electricity)	**5%**
Fraction of auxiliaries (of total electricity)	**20 %**

Operation times

Ventilation system	**year-round**
Heat pump space heating	**2496 h**
Heat pump for DHW	**609 h**



No	Description	Energy
1	recovered heat from return air (RA) for SH	1666 kWh
2	heat from RA recovered in ventilation heat recovery for SH	308 kWh
3	heat from RA recovered by the heat pump for SH and DHW	1358 kWh
4	heat from outside air (OA) used by heat pump	9360 kWh
5	electricity consumption of heat pump (HP)	3614 kWh
6	electricity consumption of electrical back-up heater (ELH)	199 kWh
7	electricity consumption of control and transformer (CTRL)	175 kWh
8	electricity consumption of supply air fan	141 kWh
9	electricity consumption of return air fan	112 kWh
10	electricity consumption of space heating circulating pump	171 kWh
11	non recoverable waste heat of space heating circulating pump	71 kWh
12	electricity consumption of domestic hot water loading pump	20 kWh
13	heat losses of compact unit to technical room	1121 kWh
14	generated heat of HP for ventilation by preheater	671 kWh
15	generated heat of HP and ELH for domestic hot water	2252 kWh
16	heat losses of domestic hot water storage	1073 kWh
17	heat energy need by ventilation losses in mechanical ventilation	1120 kWh
18	heat energy need of the space heating distribution system	10894 kWh
19	heat energy need of the domestic hot water distribution system	1179 kWh
20	heat energy need of the SH and DHW distribution system according to [26]	13194 kWh

Energy balance of the ventilation compact unit with air-source heat pump installed in a SFH according to MINERGIE®

System performance and optimisation

The heating season comprises the months from October to April. During the heating season with space heating operation the heat pump with the evaporator fan uses 84% of the electricity consumption. The heat recovery fans consume 4%, control and transformer 3% and circulation pumps 5%. The electrical back-up heater with the remaining consumption of only 5% stresses the good performance, where most of the heat is produced with the heat pump.

In summertime, where the heat pump is operated only in the DHW mode, the heat pump electricity makes up for about 50% of the total electricity consumption, while the ventilation system and other auxiliaries use the rest. No back-up operation for the support of the DHW heating takes place in summertime due to the control setting of a balance point for the DHW operation. Storage temperatures in the upper part of the storage of about 55°C could be reached with the heat pump operation.

With an overall generator SPF of 3.6 and a system performance of 3.1, the performance of the system is good for an air-source system, in particular in space heating, which underlines the benefit of the low supply temperatures.

However, in DHW operation, storage losses are higher than expected. The storage losses are affected by the low DHW consumption, though. Nevertheless, optimisation potential is in the DHW performance, e.g. by a further reduction of the storage losses to increase the seasonal performance of the entire system.

Economy, Ecology and Costs

Based on a SIA documentation* on the building energy certificate, CO_2-eq.-emissions/primary energy for Switzerland are:

CO_2-eq.-emission factor*:	155 g/kWh$_{el}$
CO_2-eq.-emissions**:	590 kg/a
Primary energy factor*:	2.97 kWh$_{prim}$/kWh$_{el.}$
Primary energy**:	11844 kWh$_{prim}$
SPF based on primary energy:	1.2

Comparison to condensing gas boiler with yields:

CO_2-eq.-emission factor*:	241 kg/kWh$_{th}$
CO_2-eq.-emissions**:	3342 kg/a
Primary energy factor*:	1.15 kWh$_{prim}$/kWh$_{th.}$
Primary energy**:	15945 kWh$_{prim}$
Primary energy efficiency***:	0.84

Concerning the investment cost for the compact unit is 10000 €**** and the total cost for the system is 22000 €*****
Due to self regulation, costs for thermostatic valves are avoided. However, the floor heating system has to be designed for lower flow temperatures, which may increase the costs, thus an avoided investment is difficult to evaluate.
Compared to fuel systems no connection to the gas network and no costs and space for the fuel storage are required.
During the monitoring, no specific maintenance was needed. The air filters of the ventilation were changed by the user.

* Based on SIA Merkblatt 2031 (2009) Energieausweis für Gebäude, Swiss Engineers and Architects Association, Zurich
** based on system boundary "generator"
*** based on efficiency 96% of field test of 59 boilers (Wolff et al. 2004)
**** Catalogue price 2007 w/o VAT, exchange rate Sept. 2007
***** including ventilation compact unit, floor heating system, ventilation system, design and installation, excluding DHW distribution system

Imprint

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Literature

Wemhoener, C., Dott, R., Afjei, Th., Huber, H., Keller, P., Helfenfinger, D., Furter, R.
Calculation method for heat pump compact units and validation
Final report SFOE research project, Muttenz 2007
Download:
http://www.bfe.admin.ch/dokumentation/energieforschung/index.html?lang=de&publication=9170

Best practice

Multi-Family House CosyPlace® according to MINERGIE-P® with ground-coupled heat pump for space heating, DHW and passive cooling

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Federal Office of Energy SFOE

Contribution of the Swiss national project

Summary

This Best Practice Sheet gives field monitoring results of a ground-coupled heat pump system which is used for heating and DHW production in winter and passive cooling and DHW in summer. It is installed in a multi-family ultra-low energy house according to the Swiss MINERGIE-P® standard. This standard implies very low U-values and high quality glazing as well as a mechanical ventilation with heat recovery, which further reduces ventilation losses.

In the field monitoring plant, the used floor emission system was designed for a flow temperature of 40 °C at design conditions. However, after the first monitoring period, the supply temperature could be lowered.

To increase thermal comfort during summertime, the system allows passive cooling by the floor emission system. This is achieved with just one additional heat exchanger and two 3-way valves.

The measured overall seasonal performance factor of the heat pump for space heating reached values of 3.9 (based on the boundary of the whole system except ventilation). Passive cooling needs only energy for the pumps and control. Therefore SPF for cooling was about 8.0, which, however, can be further increased.

Significant saving potentials of 83% CO_2-eq. emissions and 33% primary energy are achieved compared to a condensing gas boiler of an efficiency of 96%, based on the CO_2-eq. emission factors and primary energy factors used in Switzerland.

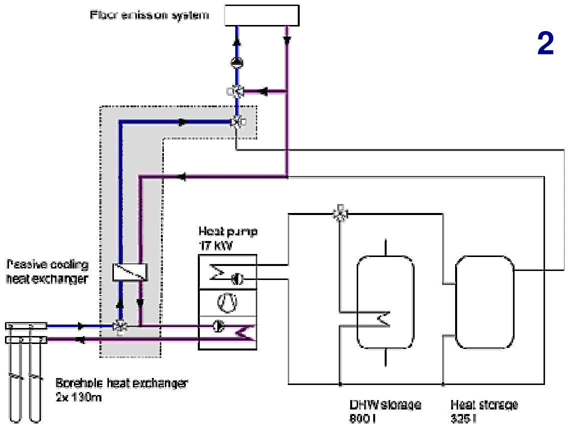
Building data

- Location: Basel, canton Basel-Stadt
- Heavyweight building with 5 flats in north-oriented hillside
- Energy reference area 1064 m^2/net living space 737 m^2
- Design heat load: 11.8 kW
- Calculated annual space heating demand: 10 kWh/(m^2a)
- U-value walls: 0.11 W/(m^2·K), roof 0.1 W/(m^2·K)
- U-value glass: 0.5 W/(m^2K), g-value:0.51

Background

On the background of increasing summer temperatures due to global warming and higher comfort demand, comfort cooling for residential buildings is becoming more common in Switzerland recently. In order to keep electricity consumption down, only energy efficient systems should be used. The approach of passive, ground-coupled cooling is very interesting from an energy point of view. Critical points, though, may be the risk of condensation, loss of comfort due to excessively low floor temperatures as well as problems of cycling between cooling and heating operation. The measurement results shall show the potential of this cooling concept and help to find optimal parameters for the control.

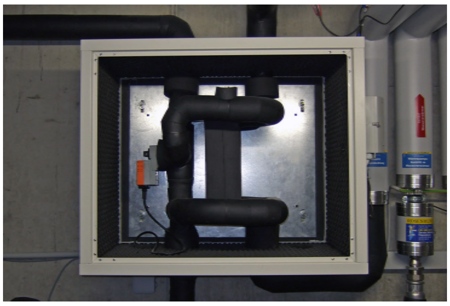
2



Simplified sketch of the ground-coupled heat pump. (Components of the passive cooling in the grey block)

Technical concept

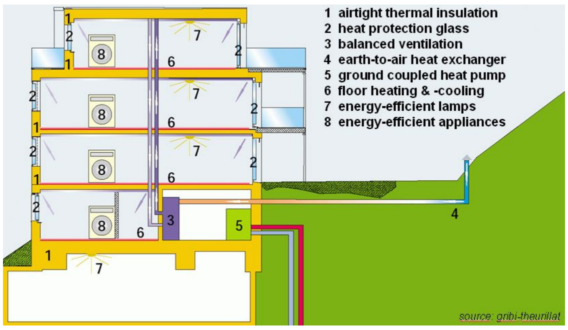
The monitored unit is designed for ultra-low energy multi-family houses according to the Swiss MINERGIE-P® standard.
For heating, a conventional brine-to-water heat pump is used. The unit is designed for a floor heating system. The floor heating has been dimensioned to low flow temperatures. The flow temperature has been set to 40 °C in the first heating period, but were lowered based on the monitoring. Two 130 m borehole heat exchangers are used as heat source. No back-up heating system is installed.
Besides architectural optimisations to prevent overheating in summer, the cooling concept includes a ground-coupled passive cooling by means of the floor emission system as well as ventilation. The ventilation includes a ground-to-air heat exchanger and an automated summer-bypass of the heat-recovery unit. Both systems are intended for a soft, but highly efficient cooling effect at higher outdoor temperatures.
While cooling, the floor emission system serves as a heat collector. It is coupled to the same borehole that is used as a source of heat during winter, using one additional heat exchanger and two 3-way valves. Therefore, passive cooling can be added easily and at low costs to the existing heat pump unit. Since all heat emission surfaces are equipped with thermostatic valves, the system includes a 325 l buffer storage tank to prevent cyclic operation of the heat pump.



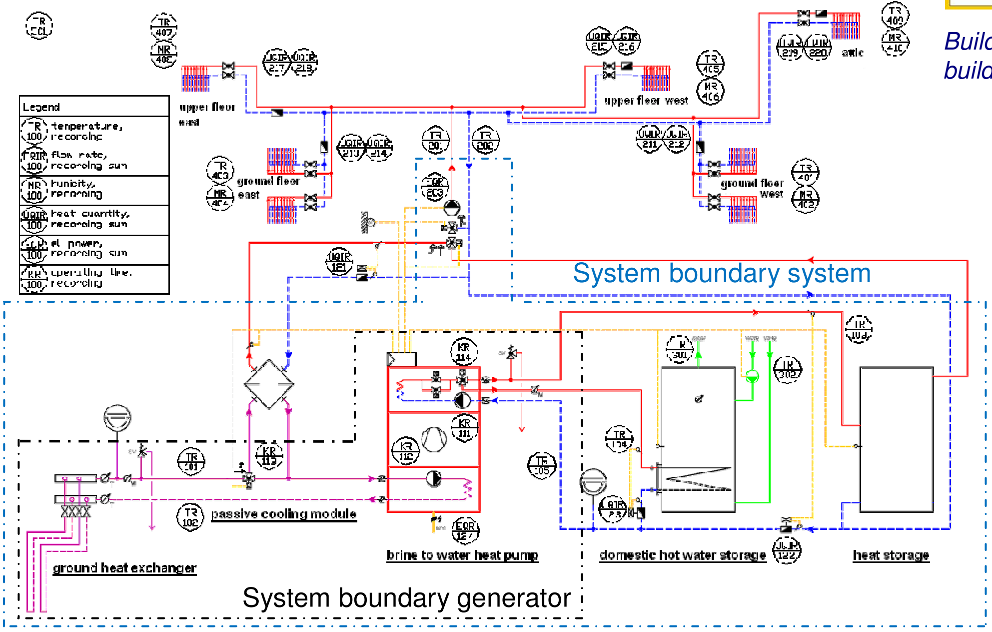
One additional heat exchanger and two valves are required to upgrade the system for passive cooling.

State of market introduction

Technical building components used are based on systems available on the market. However, passive cooling with ground-coupled heat pump has not been monitored in residential low energy houses, yet.



Building technology installed in the MINERGIE-P® building CosyPlace®



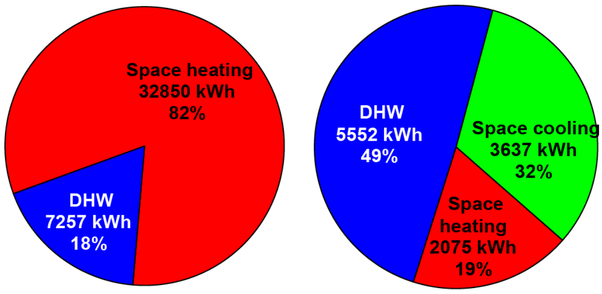
Measurement concept and system boundaries of MINERGIE-P® building CosyPlace®

Technical data of the unit

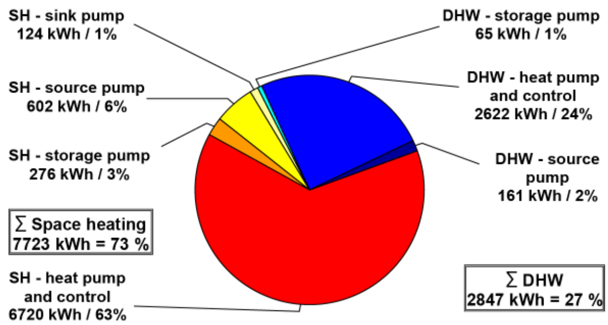
Type:	**Brine-to-Water heat-pump unit**
Refrigerant	**R407C**
Output capacity	**15.5 kW (B0/W35)**
Electricity	**3.6 kW (B0/W35), COP 4.3**
Electrical back-up	**none**
Borehole length	**2 x double U 130 m**
Heat storage	**325 l**
DHW storage	**800 l**
Source pump	**310 W**
Distribution pump	**40 W, EC, Permanent Magnet Motor**
Ventilation	**air change 0.4 h^{-1} summer-bypass**
Ventilation GAHX	**2 x 12 m**

Field monitoring

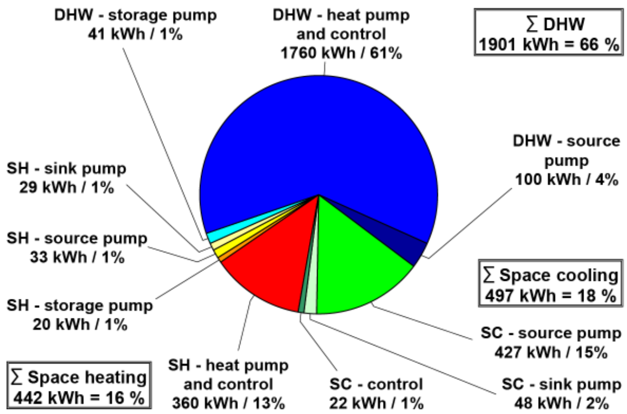
The field monitoring has been carried out in the period of 1. Nov. 2007 - 30. Sept. 2009. The evaluation refers to the measurement period from 1. October 2008 - 30. September 2009.
The measurements include values of energy production and consumption for space heating, cooling and DHW as well as indoor temperatures and humidity. The evaluations in focus were indoor climate conditions, electricity input, generated and used heat as well as heat extracted by the passive cooling system. The ventilation has not been evaluated.
The total heat energy consumption of the period is 49297 kWh. 32850 kWh or 30 kWh/(m^{2}a) are produced for space heating, which is in the range of a low energy house, but does not reach the intended value of a passive house. 12809 kWh are produced for DHW, i.e. the DHW fraction is 26%, which characterises a good low energy house. 3637 kWh of heat is extracted from the flats by the passive cooling operation in summer.
Entirely 13410 kWh electricity has been consumed by the heat pump and auxiliaries in the evaluated period. The fraction of auxiliary consumption for the pumps is 15%, which is increased by 4% by the passive cooling operation.
The seasonal performance of the space heating operation for the boundary generator (system) is with 4.4 (4.3) in the upper range. In DHW operation, a generator SPF of 2.7 is in the normal range. The system SPF of 1.7 is rather low due to the storage losses of 35% of the produced DHW energy.
The performance factor of the space cooling is not yet as effective as expected either, which is due to low extracted amount of heat in the first part of the summer and rather high auxiliary energy consumption. However, overall SPF of the generator (system) is with 3.9 (3.5) in the normal range. Improvement was achieved by optimisation of the system compared to the season 2007/08 (values in brackets).
The room air temperatures were most of the time in a comfortable range of 20 °C-24 °C in winter and 22 °C-26 °C during summer. Indoor temperature could by decrease by about 3 K using the passive cooling. One flat was not cooled in summer due to user decision, and indoor temperatures are on the upper limit, but were accepted by the users.
Relative humidity sometimes dropped below 30% in winter, while it never reached higher values than 65% in summer.



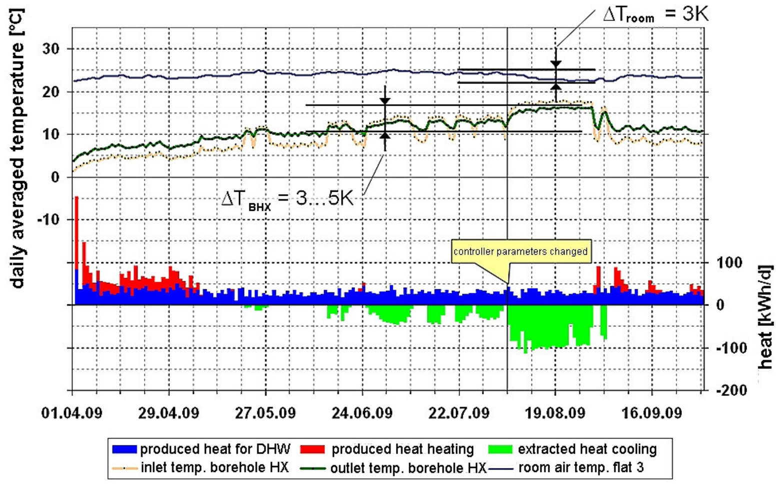
Produced heat for space heating and DHW in winter (left) and produced/rejected heat in space heating, DHW and space cooling in summer 2009 (right)



Breakdown of electricity consumption in winter operation



Breakdown of electricity consumption in summer operation



Temperature of passive cooling operation in building zone and ground

Performance indicators 2007-2009

Seasonal Performance Factor 2008/09 (2007/08)	
SPF overall generator	3.9 (3.8)
SPF overall system	3.5 (3.3)
SPF generator space heating	4.4 (4.1)
SPF system (all components)	4.3 (4.0)
SPF generator DHW	2.7 (2.7)
SPF system DHW	1.7 (1.3)
SPF generator cooling	8.1 (8.8)
SPF system cooling	7.3 (8.0)
Fraction energy/losses	
Fraction storage & distribution losses	35%
Fraction auxiliary pumping energy	15%

System performance and optimisation

An overall seasonal performance factor generator of 3.9 is in the range of other monitored ground-coupled heat pumps without passive cooling. The space heating SPF of 4.4 is good, and the DHW SPF of 2.7 is in the ordinary range. A slight increase of the DHW performance in summer operation from 2.5 in the winter period to 2.9 in the summer period is increased by the passive cooling. The cooling performance factor is at the lower limit. Improvement of performance factor can be achieved with source pumps of better energy efficiency and higher extracted cooling energy.
Auxiliary fraction for the pumps is with ≈15% of the total electricity consumption quite high. The passive cooling contributes ≈25% to the pump consumption. Only 10% is consumed by the distribution pump due to the use of high-performance pumps. The primary pump to load the buffer increases the consumption by ≈15%.
Based on experiences of the first monitoring year several measures to optimise the system performance have been implemented:

- The heating curve was set 10 K above the calculated design value. A reduction of the heating curve could contribute a 10% improvement.
- The heating limit has been lowered, which enables a more efficient cooling operation and avoids parallel heating and cooling with short time delay.
- Since the heat pump starts were numerous, the hysteresis of the relatively small buffer storage has been increased from 2K to 5K.

Results of these measures are better seasonal performance factors than in the year 2007/08.

Economy, Ecology and Costs

Environmental impact of the heat pump:

CO_2-eq emission factor*:	155 $g/kWh_{el.}$
CO_2-eq emission**:	1933 kg
Primary energy factor*:	2.97 $kWh_{prim.}/kWh_{el.}$
Primary energy**:	37039 $kWh_{prim.}$
SPF based on primary energy:	1.31

Comparison of environmental impact of a condensing gas boiler**:

CO_2-eq emission factor*:	241 $g/kWh_{th.}$
CO_2-eq emission**:	11504 kg
Primary energy factor*:	1.15 $kWh_{prim.}/kWh_{th.}$
Primary energy**:	54895 $kWh_{prim.}$
Primary energy efficiency***:	0.85

* values based on SIA Merkblatt 2031 (2009), Energieausweis für Gebäude
** values based on produced thermal energy (without cooling) from 10/08 until 09/09
***value based on an efficiency of 96% acc. to field monitoring of 59 boiler in Wolff et. al. (2004)

Conclusion

The Best Practice Sheet confirms that the described heat pump system achieves a good overall seasonal performance factor of 3.9 and substantial CO_2-eq-emission reductions of 82% and primary energy of 33% compared to a natural gas condensing boiler of 96% efficiency.
The passive cooling reaches a high seasonal performance factor around 8 and has still further optimisation potentials. Thus, ground-coupled passive space cooling can be an attractive and cost-effective solution to enhance the summer comfort in high performance buildings in times of rising outdoor temperatures.

Imprint

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Date of Best practice sheet: February 2010

Literature

Interim report first monitoring period (in German)
R. Dott, Th. Afjei, A. Genkinger, A. Witmer
Sanfte Kühlung mit erdgekoppelten Wärmepumpen im Minergie-P® Wohngebäude CosyPlace, Interim report Muttenz 2009

Final report with both monitoring periods (in German)
A. Genkinger, R. Dott, Th. Afjei, A. Witmer
Sanfte Kühlung mit erdgekoppelten Wärmepumpen im Minergie-P® Wohngebäude CosyPlace, Final report , Muttenz 2010

Best practice

IEA HPP Annex 32

Economical heating and cooling systems for low energy houses

Single Family House according to MINERGIE® with B/W heat pump and vertical borehole heat exchanger for passive cooling operation

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Federal Office of Energy SFOE

Contribution of the Swiss national project

Summary

This Best Practice Sheet gives field monitoring results of a ground-source heat pump system with a passive cooling option installed in a single family low energy house acc. to the Swiss MINERGIE® standard. The MINERGIE® standard implies low U-values, a high quality glazing and a controlled ventilation, which enhances the indoor thermal comfort.

The low space heating demand of about 40 kWh/(m^{2}a) enables the use of a low temperature heat emission system. In the field monitoring plant, the used floor emission system was designed to low flow temperature of below 30°C at design conditions. Such low temperatures optimise the heat pump COP and a self-regulation can be used for the control of the system.

The measured overall seasonal performance factor of the system for space heating, DHW and space cooling is 3.8. The SPF for space cooling reaches a value of 7.3. Due to the simultaneous DHW and passive cooling operation, the SPF for DHW is increased from 2.8 in winter to 3.7 in summer. The good performance proves that the unit operates feasible combining the advantages of small installation space/cost and monovalent operation.

The additional cost of the passive cooling is with about 1500 € investment and 12 €/a moderate. Compared to a condensing gas boiler the $CO_{2eq.}$-emissions are reduced by 82% and the primary energy by 27% based on factors used in Switzerland.

Building data

- Location: Muolen, canton St. Gallen
- 3 inhabitants (2 adults, 1 baby child)
- Energy reference area: 279 m^2
- Design heat load: 6.4 kW (acc. to SIA 384.201)
- Annual space heating demand: 61.4 kWh/(m^{2}a)
- U-value walls: 0.16-0.2 W/(m^2·K), roof 0.19 W/(m^2·K)
- U-value windows (incl. frame): 1.3 W/(m^{2}K), g-value: 0.6

International Energy Agency
Heat Pump Programme

Background

In Switzerland low energy houses according to the MINERGIE® standard show a strong market growth and already reached market shares of 25% for new residential dwellings. Climate change and high glazing fractions, however, hold the risk of overheating in summer, which may increase the interest in residential cooling. Not to spoil the good winter performance by extensive electricity consumption for summer cooling, energy efficient cooling methods are required. A promising solutions is a ground-coupled cooling, which is increasingly used with ground-coupled heat pump systems. This Best Practice Sheet gives year-round results of a single family house with passive cooling in summer.

Technical concept

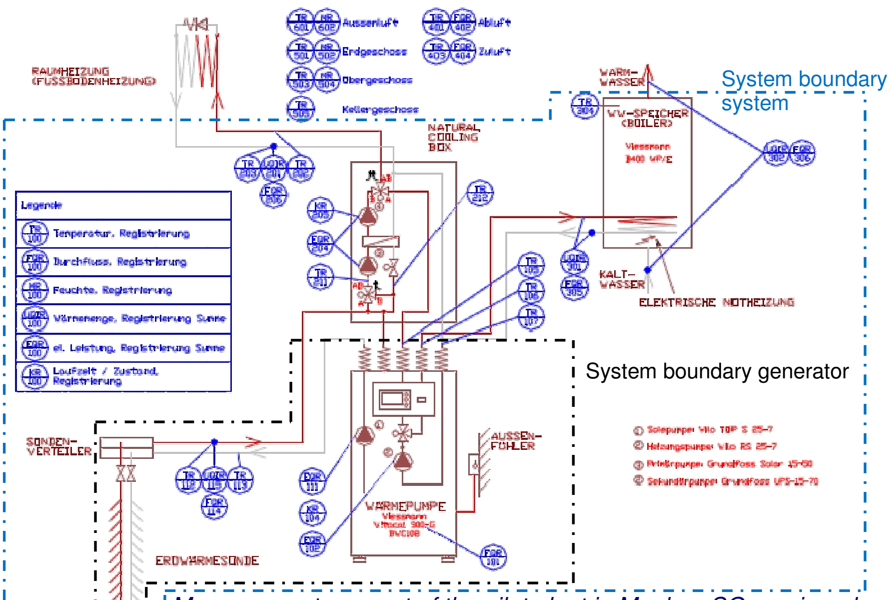
The MINERGIE® dwelling is equipped with a B/W heat pump with electronic expansion valve. As ground source, a 150 m DN 32 double U-tube vertical borehole heat exchanger is installed. The monovalent heat pump works on a 100 m^2 floor heating system which is designed as low-ex system with design temperature of 30 °C/25 °C at outdoor design temperature of -9 °C. Besides maximisation of the COP, this enables to use a self-regulation and to simplify the hydraulic design by avoiding the need for thermostatic valves.

In domestic hot water (DHW) mode the heat pump is switched to a 400 l storage to produce hot water in alternate mode at a design hot water temperature of 50 °C. Furthermore, the building is equipped with a balanced ventilation system including a passive heat recovery of a temperature change coefficient of 80%. Even though not necessarily required by the MINERGIE® standard, balanced ventilation systems are installed in the majority of MINERGIE® buildings in Switzerland.

In summer operation the borehole can be used for ground-coupled passive cooling (also called "free", "direct" or "natural" cooling). The floor emission system is used in passive cooling mode, as well. By the low-ex design, higher cooling supply temperatures are possible and therefore, the ground potentials can be better used also in cooling mode. The system is equipped with a so-called "NC-Box", which comprises all components for the direct connection of the ground-source to the floor emission system.

State of market introduction

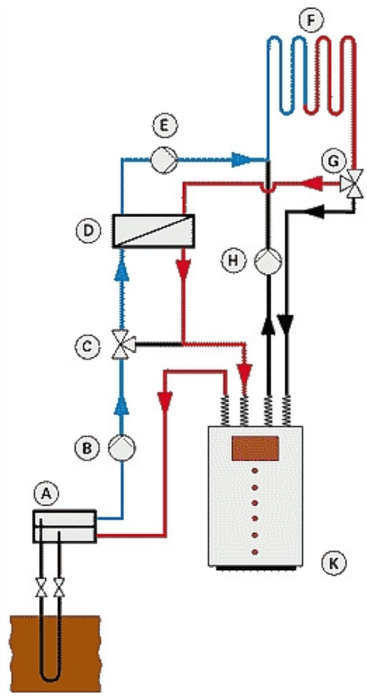
The heat pump with electronic expansion valve and the NC box for ground-coupled passive cooling has been introduced in 2006.



Measurement concept of the pilot plant in Muolen, SG, equipped with a ground-source HP for SH, DHW and passive cooling

Source: Viessmann

The NC-Box contains all hydraulic components to connect the ground-source to the floor emission system for passive ground cooling.



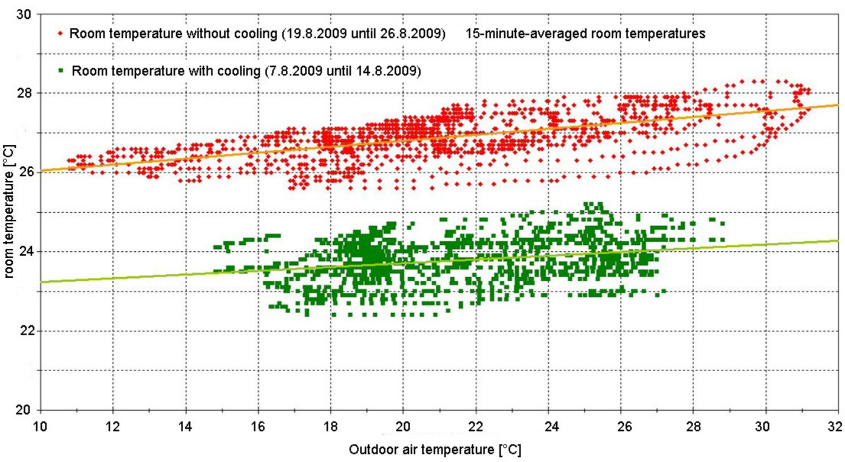
Principle of the passive cooling with ground-coupled heat pump systems (source: Viessmann)

Technical data of the unit

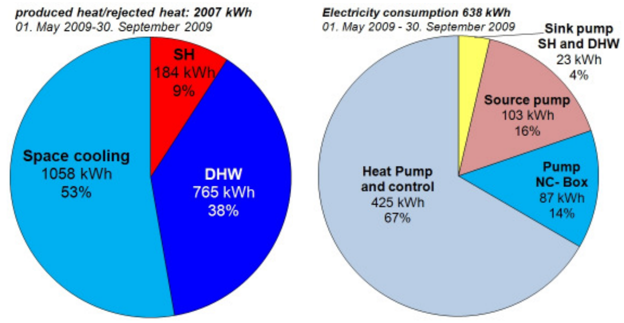
Type:	**monovalent B/W-HP with electronic expansion valve**
Source system:	**150 m double U-tube vertical borehole heat exchanger DN 32**
Refrigerant	**R 407 C, 1.8 kg**
Heating Capacity / COP	
	8.4 kW / 4.6 (B0/W35)
Emission system:	**100 m^2 floor heating**
Design temp.	**30 °C/25 °C**
DHW	**Alternate operation**
Design temp.	**50 °C**
Storage volume	**400 l**
Nominal pump capacity	
source pump:	**three steps: 80-130 W**
nom. vent. rate	**210 m^3/h**
temperature change coefficient: 80%	
power fans:	**99 W**

Field monitoring

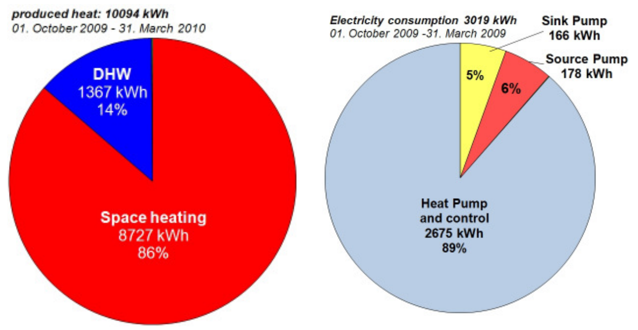
The field monitoring was carried out over a whole year in the period 1. May 2009 – 30. April 2010, but due to problems in the remote data acquisition system, the data of April could only be evaluated for the amount of heat, so that performance factors are related to an 11-month period until 31. March 2010.
The measurement points are recorded every minute and stored as 15-min average values. The measurement concept comprises the system boundary generator and system as depicted in the hydronic scheme.
In winter operation, 10708 kWh or 38.4 kWh/(m^2a) space heating energy are consumed and the average heat load was evaluated to 30 W/m^2 (max. 42 W/m^2), which is in the range of low energy houses. However, the heat pump proved to be over-dimensioned, since the house consumes about ≈1/3 less space heating energy than the calculated value despite an extreme winter in the year 2009/10. The DHW share is with 14% on the lower edge for a low energy house.
Due to the low flow temperature design the heat pump reaches a good SPF generator in heating mode of 3.8 and in DHW mode of 3.1. The actual measured flow temperature, however, is with 34 °C higher than the design value due to the over-dimensioning of the heat pump.
The average extracted power of the ground is 48 W/m at an average ground temperature in the winter season of ≈8 °C. Auxiliary consumption is with 6% and 5% for the sink and source side, respectively, in a good range.
In summer operation, the passive cooling reaches a high performance factor in the range of 7. Moreover, the DHW operation is enhanced and reaches a performance of 3.7 due to simultaneous operation with the passive cooling mode. Due to a holiday period of the users, a comparison of room temperatures with and without passive cooling operation could be performed, which confirms, that an average reduction of room air temperatures by 2-4 K is reached. Thereby, with cooling operation, the indoor temperatures can be kept within the boundaries of category II according to EN 15251 (2007), while without cooling, not even category III can be kept.
The overall SPF adds-up to 3.8 both for the boundaries "generator" and "system", since the performance in passive cooling operation, which is only accounted in the boundary "system", levels out the storage losses of the DHW operation.



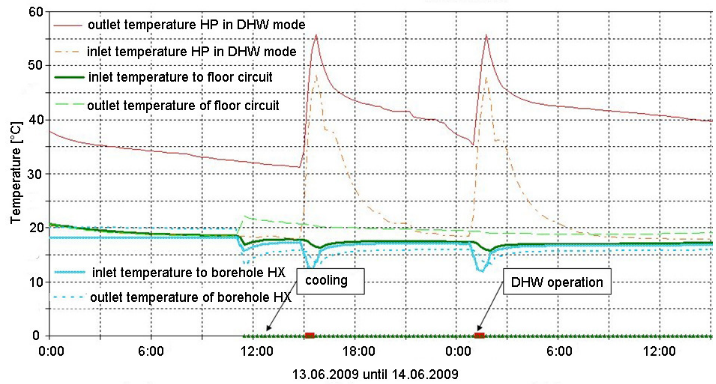
Reduction of indoor room air temperatures by ground-coupled passive cooling



Produced heat and electricity consumption in the summer period of 1. May 2009 - 30. Sept. 2009



Produced heat and electricity consumption in the winter period of 1. October 2009 - 31. March 2010



Diurnal temperatures of 2 following days with simultaneous space cooling and DHW production

Performance indicators

Overall seasonal performance factors	
SPFgenerator (produced heat, source)	3.8
SPF system (used heat, all components)	3.8
SPF operation modes	
SPF heating (summer/winter/total)	- / 3.8 / 3.8
SPF DHW (summer/winter/total)	3.7/2.8/3.1
SPF cooling (summer/winter/total)	7.3/ - /7.3
Operation times	
Ventilation system	6 h at night
Heat pump space heating	2680 h
Heat pump for DHW	514 h
Ground-coupled cooling	675 h

System performance and optimisation

The first measured heating season from 1. December 2008 - 30. April 2009 showed some irregularities in the recorded measurements, so the measured data was not used for the performance characterisation, but to optimise the system. The measured data showed a lower space heating load of 4.4 kW instead of the calculated design heat load of 6.4 kW, so that the heat pump with 8.4 kW nominal capacity is over-dimensioned by 90%. Therefore, the design parameters of the heating curve were adapted. The average of the outside temperature was changed from 3 h to 18 h and the heating limit was reduced from 16 °C to 13 °C plus a hysteresis of 2 K, i.e. at 15°C averaged over 18 h, the heat pump is switched-off. Measured flow temperatures are in the range of 28 °C at outdoor design conditions.

Due to the over-dimensioning of the heat pump, it could be attempted to lower the flow temperatures. By the low supply temperatures and the efficient cooling mode, the overall system seasonal performance factor based on used energy and comprising all electricity expenses is 3.8, which is a good value.

The comfort can be significantly enhanced by the passive cooling, since room air temperature can be kept below 26 °C. By the passive cooling, an average decrease of 3 K is realistic. Moreover, DHW operation is slightly enhanced by a simultaneous operation, which, however, would be similar due to short-term storage in the ground.

Economy, Ecology and Costs

Based on a SIA 2031* on the building energy certificate, CO_2 emissions/primary energy for Switzerland are:

CO_2-eq.-emission factor*:	155 g/kWh_{el}
CO_2-eq.-emissions**:	567 kg/a
Primary energy factor*:	2.97 $kWh_{prim}/kWh_{el.}$
Primary energy:	10861 kWh_{prim}
SPF based on primary energy:	1.28

Comparison to condensing gas boiler*** yields:

CO_2-eq.-emission factor*:	241 g/kWh_{th}*
CO_2-eq.-emissions:	3133 kg/a
Primary energy factor*	1.15 $kWh_{prim}/kWh_{th.}$
Primary energy:	14951 kWh_{prim}
Primary energy efficiency***:	0.83

The additional cost of the passive cooling option is moderate. Additional components add-up to about 1500 €**** for the heat exchanger, valves, control and the operational additional electricity cost are in the range of 12 €/a****.

* based on SIA Merkblatt 2031 (2009) Energieausweis für Gebäude, Swiss Engineers and Architects Association, Zürich

** based on system boundary "generator"

*** based on efficiency 96% of field test of 59 boilers (Wolff et al. 2004)

**** based on evaluations in Dott, Huber, Afjei (2007), Heizen und Kühlen mit erdgekoppelten Wärmepumpen, Final report of the SFOE research project, Research programme Energy Efficiency, Muttenz

Conclusion

The passive ground cooling is a cost-effective way to overcome the increasing cooling needs of residential buildings without significant increase of electricity consumption.

Imprint

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Literature

Lederle, N., Dott, R, Afjei, Th.
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Dott, R., Afjei, Th., Genkinger, A., Lederle, N.
Heizen und Kühlen mit Wärmepumpen - Theorie und Praxis
Conference paper in German,
Proceedings 16. Brenet Status-Seminar, 2./3. Sept. 2010, Zurich
Download: http://www.brenet.ch

Best practice

IEA HPP Annex 32

Economical heating and cooling systems for low energy houses

Single-family house with ground-coupled heat pump for alternate space heating and DHW production

Fraunhofer ISE

Fraunhofer Institut
für Solare Energiesysteme
Freiburg, Germany

Contribution of the German national project

Summary

The Fraunhofer Institute of Solar Energy systems (FhG-ISE) is carrying out a large field test of more than 100 heat pumps installed in low energy houses.
This Best Practice Sheet presents field monitoring results of a ground-coupled heat pump providing thermal energy for a newly built detached house. Two double U-tube borehole heat exchangers of a total length of 144 m are used as heat source. The space heating emission system is a floor heating designed for low supply temperatures of 35 °C, which is directly connected to the heat pump. DHW is produced alternately by switching the heat pump from the space heating operation to a DHW storage. The design temperature of the DHW production is 55 °C. The heat pump operates monovalently without any electrical backup energy use.
The source temperature reaches normal temperatures of 2 °C-11 °C during the year, yielding an overall Seasonal Performance Factor of the generator system SPF-G of 4.0 due to the relatively low DHW energy share of only 6%. The fraction of auxiliary energy used is with 7% around the average value.
Due to the good overall seasonal performance factor, the system reaches CO_2 eq.-emission savings of about 35% compared to a condensing gas boiler with an efficiency of 0.97. In terms of primary energy, savings of about 42% can be reached. The SPF-G based on primary energy yields a value of 1.51 based on the factors used in Germany.

Building data

- Location: Köngen, Baden-Württemberg, Germany
- Inhabitants: 2 persons
- Year of construction: 2006
- Heated area: 190 m^2
- Design heating load (DIN 4701): 15.7 kW (82.6 W/m^2)

International Energy Agency
Heat Pump Program

Introduction

"WP-Effizienz" ("Heat pump efficiency") is a German monitoring project run by Fraunhofer ISE in Freiburg. The aim of the project is to collect real performance data from a large number of new buildings equipped with different types of heat pumps. The data from more than 100 buildings have been collected since 2006. The project will run until 2010. The evaluation of the data allows to draw a wide range of conclusions including efficiency comparisons of different systems, the impact of different operation parameters on the performance, optimisation possibilities, typical reasons for technical failures and system breakdowns as well as explanations for other phenomena. The described building is monitored as part of the "WP-Effizienz" project.

The front view of the monitored building

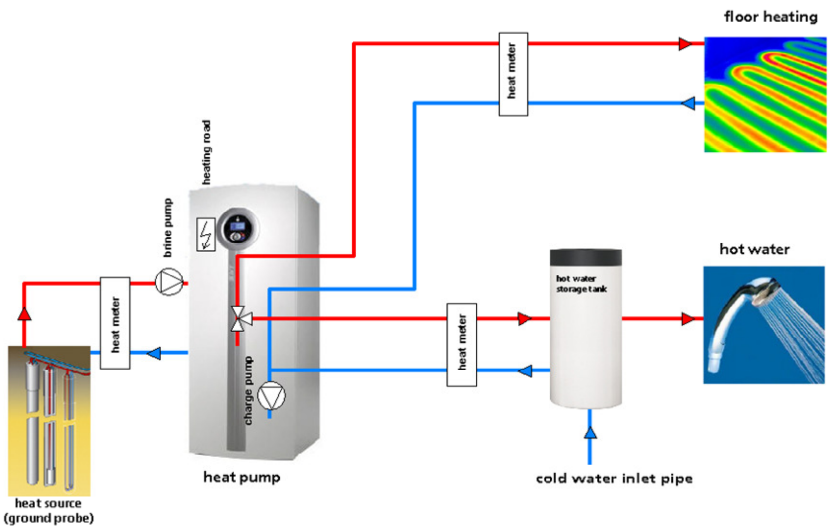
Technical concept

The monitored system is designed for a low temperature floor energy emission system with buffer tank. There is a separate circuit for domestic water heating which is equipped with a storage tank. The source energy for the heat pump is delivered by two boreholes with a total length of 144 m. The electrical back-up heater is supposed to support the heat pump when peak heating load occurs.
The low heating circuit temperature (design: 35°C) combined with the relatively stable and high energy source temperature (2-11°C) provides good thermo-dynamic operating conditions for the heat pump. This leads to a high efficiency of the whole system.
Performance is positively influenced by the fact that the concept of the heat distribution and the emission system is not too complex. The use of a limited amount of control equipment reduces the risk of failures, operation strategy errors and electrical energy consumption.
Another factor contributing to the generally high performance factors is the careful installation of the system. Well designed and executed piping reduces the pressure drop and energy losses which positively affects the general efficiency of the heating system.

The heat pump unit

Current market situation

The monitored system is available on the market.



Sketch and measurement concept of the monitored system

Technical data of the unit

Heating unit:	**ground-coupled heat pump**
Heat source:	**2 boreholes with a total length of 144 m**
Refrigerant:	**R407C**
Defrosting agent:	**25% ethylene glycole**
Emission system:	
	low temperature floor system
SH Design:	**35 °C**
Thermal output / COP:	
B0/W35:	**9.3 kW / 4.4**
B0/W50:	**9.3 kW / 3.1**
DHW design:	**55 °C**

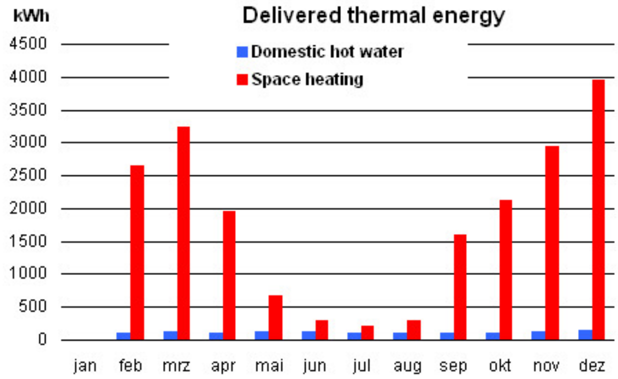
Field monitoring

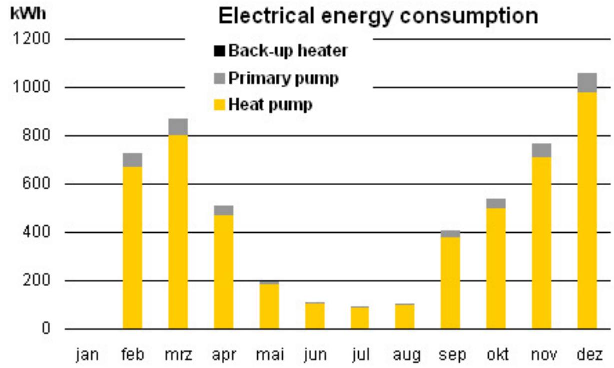
The building is monitored within the scope of the “WP-Effizienz” project since November 2007 and will at least be monitored until the end of 2010. The monitoring period covers the complete year of 2008.

The temperatures, flows, powers and energies in the brine circuit as well as space heating and domestic water heating circuits are recorded once per minute. The consumption of the electrical energy by all system components is stored, as well. The collected data are transmitted to Fraunhofer ISE where automatic data quality control and further processing including data filtration, computation of sums, averages and other factors concerning day, month and year levels are performed.

The thermal energy produced by the heat pump in 2008 was 21249 kWh. The energy share needed for space heating was 94% corresponding to 19952.8 kWh or 105 W/m^2 which is above the normal value. The corresponding electrical energy consumed was 5359.7 kWh (energy share consumed by the heat pump was 93%). There was almost no operation of the back-up heater recorded (only 0.1 kWh).

The overall Seasonal Performance Factor of the generator is 3.96. A yearly profile of the performance factor and the brine inlet temperature is presented in the graph below. Times of lower system performance corresponds to months in which very little energy for space heating was needed. The increase of the average brine inlet temperature observed during these months does not compensate the higher required average temperature of hot water of 55 °C compared to 35 °C and less space heating operation, i.e. the average temperature lift in summertime is still higher. Thus, the performance factor drops. An increase of performance correlating with an increase of the brine inlet temperature can be observed when a high demand of energy for space heating (from February to April) was recorded. Moreover, in DHW-only summer operation, the fraction of auxiliary energy for control in relation to the compressor energy is also higher.

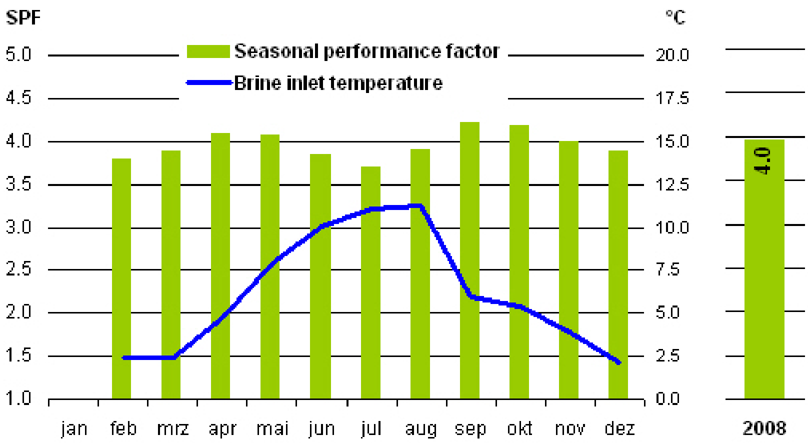




2008 Total	
Space heating:	19952.8
Hot water:	1296.2 kWh
Total:	**21249.0 kWh**

2008 Total	
Heat pump:	4965.6 kWh
Primary pump:	394.0 kWh
Total:	**5359.7 kWh**
Back-up heater:	0.1 kWh

Energy delivered and consumed in 2008



Seasonal performance factor (monthly profile and total value for 2008) and brine inlet temperature

Performance indicators

Seasonal performance factors	
SPF heat pump (excl. backup heater):	4.0
SPF heat pump (incl. backup heater):	4.0
Minimal SPF (July 2008):	3.7
Maximal SPF (September 2008):	4.2

Operation times	
Heat pump total:	2362
Heat pump space heating:	2178
Heat pump for DHW:	184

Economy, Ecology and Costs

Environmental effects of the heat pump based on thermal energy produced*:

CO_2-eq.-emission factor:	650 $g/kWh_{el.}$
CO_2-eq.-emission***:	3484 kg
Primary energy factor:	2.65 $kWh_{prim.}/kWh_{el.}$
Primary energy ratio:	14204 $kWh_{prim.}$
SPF based on primary energy:	1.51

Comparatively environmental impact of a condensing gas boiler based on thermal energy produced**:

CO_2-eq.-emission factor:	252 g/kWh
CO_2-eq.-emission***:	5355 kg
Primary energy factor:	1.15 kWh_{prim}/kWh_{th}
Primary energy:	24437 $kWh_{prim.}$
Primary energy efficiency:	0.85

*values based on a thesis made by Fraunhofer ISE, considering the whole process chain and the supply energy effort
**values based on GEMIS 4.5
***values based on thermal energy produced in 2008
**** values based on efficiency of 0.97

Conclusion

The presented data confirms that a ground-coupled heat pump with floor emission system can achieve high performance. This does not only lead to savings concerning operating costs, but also with respect to the environment. The calculated results of CO_2-eq.-emissions and primary energy presented above prove that the described heat pump affects the environment less than an alternative solution such as a condensing gas boiler.

Imprint

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Date of Best practice sheet: February 2010

Literature

Website of the "WP-Effizienz" project
http://wp-effizienz.ise.fraunhofer.de

Marek Miara, Christel Russ, Rainer Becker
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KI Luft Kälte Klimatechnik, September 2007, p. 24-27
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HP-Efficiency
Presentation Annex 32 Workshop, 9th IEA Heat Pump Conference, Zurich, 2009, download at www.annex32.net

Marek Miara
Richtig geplant, wirklich gespart
Interim results WP-Effizienz IKZ Haustechik Heft 3/2009
(In German), download at www.annex32.net

Best practice

IEA HPP Annex 32

Economical heating and cooling systems for low energy houses

Single-family house with heat pumps using a horizontal collector combined with an energy fence and the return temperature of the heating system as heat source of the DHW production

Fraunhofer ISE

Fraunhofer Institut
für Solare Energiesysteme
Freiburg, Germany

Contribution of the German national project

Summary

The Fraunhofer Institute of Solar Energy systems (FhG-ISE) is carrying out an extensive field test of more than 100 heat pumps installed in low energy houses.
This Best Practice Sheet presents field monitoring results of a heat pump based heating system for a newly built detached house. The system is equipped with two separate heat pumps. The space heating heat pump uses a 100 m^2 horizontal ground collector which is combined with an energy fence that may be used for source regeneration. The domestic hot water unit is a heat pump with integrated storage which uses the return temperature of the heat emission system (floor heating) as energy source.
The space heating emission system is a floor heating designed to low supply temperatures, which is directly connected to the heat pump.
The source temperature reaches temperatures of 2-15°C during the year, yielding an overall Seasonal Performance Factor of the Generator system SPF-G of 3.94 due to the relatively high DHW energy share of only 20%. The fraction of used auxiliary energy is with 3% quite low.
Due to the good overall seasonal performance factor, the system reaches CO_2-eq.-emission savings of about 30% compared to a condensing gas boiler with an efficiency of 0.97. In terms of primary energy, savings of about 40% can be reached. The SPF-G based on primary energy yields a value of 1.49 compared to a condensing gas boiler of a primary energy efficiency 0.85 based on primary energy factors used in Germany.

Building data

- Location: Spechbach, Baden-Württemberg, Germany
- Inhabitants: 4 persons
- Year of construction: 2006
- Heated area: 292 m^2
- Design heating load (DIN 4701): 10.8 kW (37 W/m^2)

International Energy Agency
Heat Pump Program

Introduction

"WP-Effizienz" ("HP-Efficiency") is a German monitoring project run by Fraunhofer ISE in Freiburg. The aim of the project is to collect real performance data from a high number of new buildings equipped with different types of heat pumps. The data from more than 100 buildings have been collected since 2006. The project will run until 2010. The evaluation of the data allows to draw a wide range of conclusions including efficiency comparisons of different systems, the impact of different operation parameters on the performance, optimisation possibilities, typical reasons for technical failures and system breakdowns as well as explanations for other phenomena. The described building is monitored as part of the "WP-Effizienz" project.

The front view of the monitored building

Technical concept

The monitored system is designed for the low temperature floor emission system and consists of two separate heat pumps.

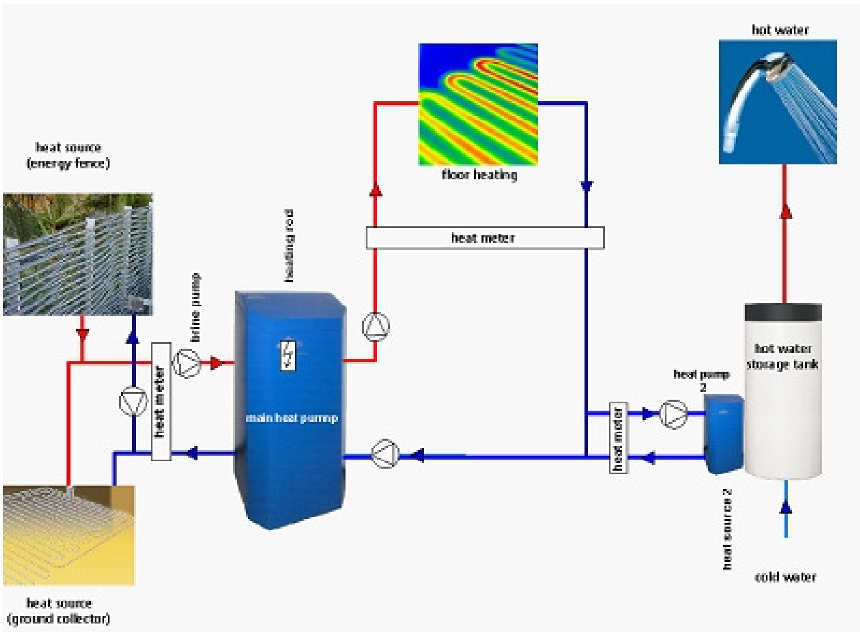
The heat pump for space heating is a ground-coupled one. A horizontal ground collector combined with the energy fence serves as heat source. An energy fence is a system of pipe work located above the ground surface. Brine can be pumped through it, if the environment (solar irradiation, wind or ambient temperature) provides additional energy gain. It can also be used for the regeneration of the ground source – the brine heated by the energy fence can be pumped through the horizontal ground collector without operation of the compressor. This may provide higher brine temperatures than in conventional horizontal ground collectors.

The domestic hot water heat pump includes an integrated storage tank. It uses the floor heating system as heat source. If the space and the DHW heating operate at the same time, the DHW heat pump uses the return of the space heating as heat source. In times with no space heating, the energy stored in the floor emission system thermal mass is used i.e. the building is cooled by the DHW operation. In such a case the circulating water, which nearly has room temperature, is cooled by the heat pump, which provides relatively high source temperatures which positively affects the performance.

The heat pump

Current market situation

All components of the system as well as the system itself are being produced and are available on the market.



Sketch and measurement concept of the monitored heating and DHW system

Technical data of the unit

Space heating unit:
ground-coupled heat pump

Energy emission system:
low temperature floor system

Energy sources: **horizontal ground collector (100 m^2) combined with energy fence**
292 m2 floor heating emission system

Thermal output / COP(space heating):
B0/W35: **11.2 kW / 4.6**

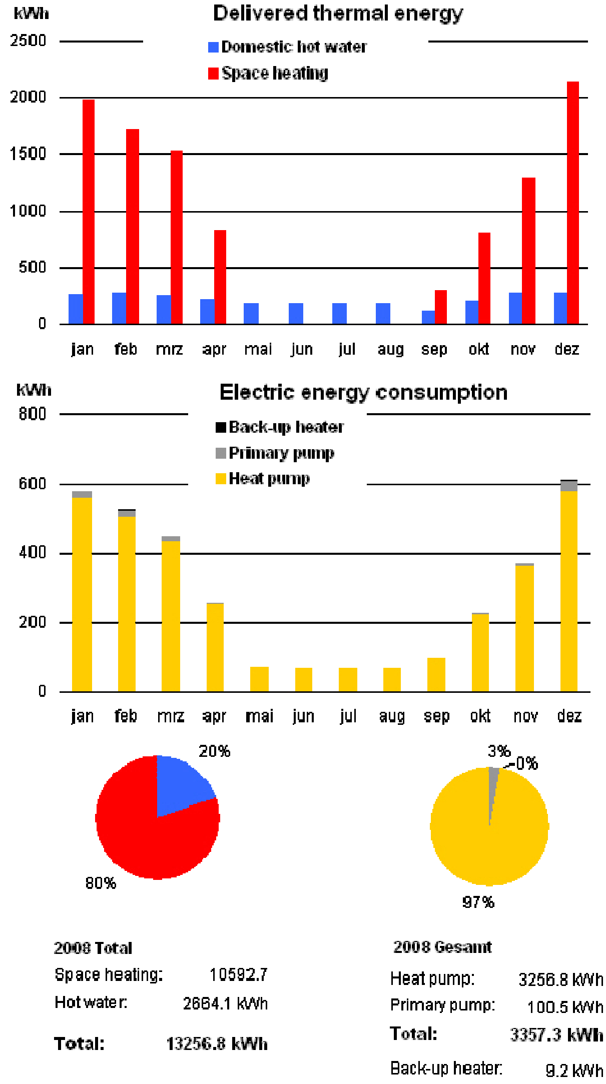
Refrigerant: **R407C**

Defrosting agent: **33% ethylene glycole**

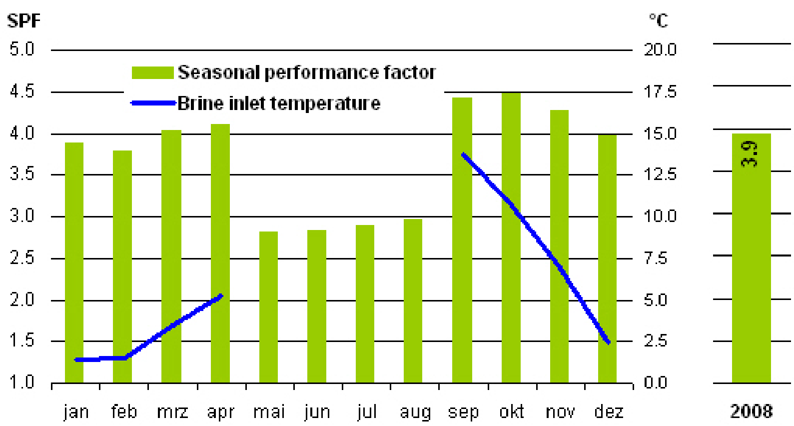
Domestic water unit:
heat pump integrated in the storage

Field monitoring

The building is monitored within the scope of the “WP-Effizienz” project since November 2007 and will at least be monitored until the end of 2010. The monitoring period covers the complete year of 2008.
The temperatures , flows, powers and energies in the brine circuit as well as space heating and domestic water heating circuits are recorded once per minute. The consumption of the electrical energy by all system components is stored as well. The collected data are transmitted to Fraunhofer ISE where automatic data quality control and further processing including data filtration, computation of sums, averages and other factors concerning day, month and year are performed.
The thermal energy delivered by the heating system in 2008 was 13256.8 kWh. The amount of energy used for space heating was 80% corresponding to 10592.7 kWh or 36.2 kWh/(m^{2}a) which is a normal value. The corresponding electrical energy consumed was 3357.3 kWh of which 97% was consumed by the heat pumps. The additional electrical consumption of the back-up heater is with 9.2 kWh negligible.
This energy consumption yields an overall Seasonal Performance Factor of the generation system SPF-G of 3.94.
The yearly profile of the overall SPF-G and the brine inlet temperature are presented in the graph below. Times of lower system performance correspond to months, in which no or very little energy for space heating was needed. During these months only the domestic hot water heat pump was used. As no space heating took place, the heat pump worked with lower source temperature (room temperature) which negatively affected the performance of the heat pump. About 77% of the source energy for the domestic water unit was delivered without simultaneous space heating operation.
The energy fence provides extra energy for the brine circuit of the space heating unit which supports the regeneration of the ground source and increases the temperature of the brine. This results in an increased performance of the whole system. The SPF profile presented below confirms this tendency.



Delivered and consumed energy in 2008



Seasonal performance factor (monthly profile and total value for 2008) and temperature of brine inlet

Performance indicators

Seasonal performance factors

SPF heat pump (without backup heater):	**3.9**
SPF heat pump (with backup heater):	**3.9**
Minimal SPF (Mai 2008):	**2.8**
Maximal SPF (October 2008):	**4.5**

Operation times

Heat pump space heating:	**1060 h**
Heat pump for DHW:	**2353 h**

Economy, Ecology and Costs

Environmental effects of the heat pump based on thermal energy produced*:

CO_2-eq. emission factor:	650 g/kWh$_{el.}$
CO_2-eq. emission***:	2182 kg
Primary energy factor:	2.65 kWh$_{prim.}$/kWh$_{el.}$
Primary energy:	8897 kWh$_{prim.}$
SPF based on primary energy:	1.49

Comparatively environmental impact of a condensing gas boiler based on thermal energy produced**:

CO_2-eq. emission factor:	252 g/kWh$_{th.}$
CO_2-eq. emission***:	3341 kg
Primary energy factor:	1.15 kWh$_{prim.}$/kWh$_{th.}$
Primary energy***:	15245 kWh$_{prim.}$
Primary energy efficiency:	0.85

*values based on thesis made by Fraunhofer ISE, considering the whole process chain and the supply energy effort
**values based on GEMIS 4.5
***values based on thermal energy produced in 2008

Conclusion

The presented data confirms that a ground-coupled heat pump which delivers thermal energy for a floor emission system, can achieve high performance. A relatively high source temperature combined with a low temperature in the heating circuit results in a high Seasonal Performance Factor. This does not only lead to savings as far as operating costs are concerned but also with respect to the environment. The computed results of CO_2 emissions and primary energy factors presented above prove that the monitored heat pump has less environmental impact than an alternative solution such as a condensing gas boiler.

Imprint

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Date of Best practice sheet: March 2010

Literature

Website of the "WP-Effizienz" project
http://wp-effizienz.ise.fraunhofer.de

Marek Miara, Christel Russ, Rainer Becker
Wärmepumpen im Feldtest
KI Luft Kälte Klimatechnik, September 2007, p. 24-27
Outline of project, in German, download at www.annex32.net

Marek Miara
HP-Efficiency
Presentation Annex 32 Workshop, 9th IEA HP Conference, 19.-22. May 2008, Zurich, download at www.annex32.net

Marek Miara
Richtig geplant, wirklich gespart
Interim results WP-Effizienz IKZ Haustechik Heft 3/2009
(In German), download on www.annex32.net

Best practice

Single-family house with ground-coupled heat pump

Fraunhofer ISE

**Fraunhofer Institut
für Solare Energiesysteme
Freiburg, Germany**

Contribution of the German national project

Summary

The Fraunhofer Institute of Solar Energy systems (FhG-ISE) is carrying out a large field test of more than 100 heat pumps installed in low energy houses.
This best practice sheet presents field monitoring results of a ground-coupled heat pump providing thermal energy for a newly built detached house. Two boreholes of a total length of 180 m are used as heat source.
The space heating emission system is a floor heating designed to low supply temperatures of 35°C, which is connected directly connected to the heat pump. DHW is produced alternately by switching the heat pump from the space heating operation to a DHW storage. The design temperature of the DHW production is 50°C. The heat pump operates without support of the electrical backup heater.
The source temperature reaches high temperature of 6-15 °C during the year, yielding an overall Seasonal Performance Factor of the Generator system SPF-G of 3.8 due to the high DHW energy share of 20%. The fraction of auxiliary energy used is with 11% higher than the average of 6%.
Due to the good overall seasonal performance factor, the system reaches a CO_2-eq. emission savings of about 33% compared to a condensing gas boiler with an efficiency of 0.97. In terms of primary energy, savings of about 39% can be reached. The SPF-G based on primary energy yields a value of 1.43 based on the factors used in Germany.

Building data

- Location: Gaggenau, Baden-Württemberg, Germany
- Inhabitants: 2 persons
- Year of construction: 2007
- Heated area: 200 m^2
- Design heating load (EN 12831): 11 kW (55 W/m^2)

Introduction

"WP-Effizienz" ("Heat pump efficiency") is a German monitoring project run by Fraunhofer ISE in Freiburg. The aim of the project is to collect real performance data from a high number of new buildings equipped with different types of heat pumps. The data from more than 100 buildings have been collected since 2006. The project will be run until 2010. The evaluation of the data allows to draw a wide range of conclusions including efficiency comparisons of different systems, the impact of different operation parameters on the performance, optimisation possibilities, typical reasons for technical failures and system breakdowns as well as explanations for other phenomena. The described building is monitored as part of the "WP-Effizienz" project.

Front view of the described building

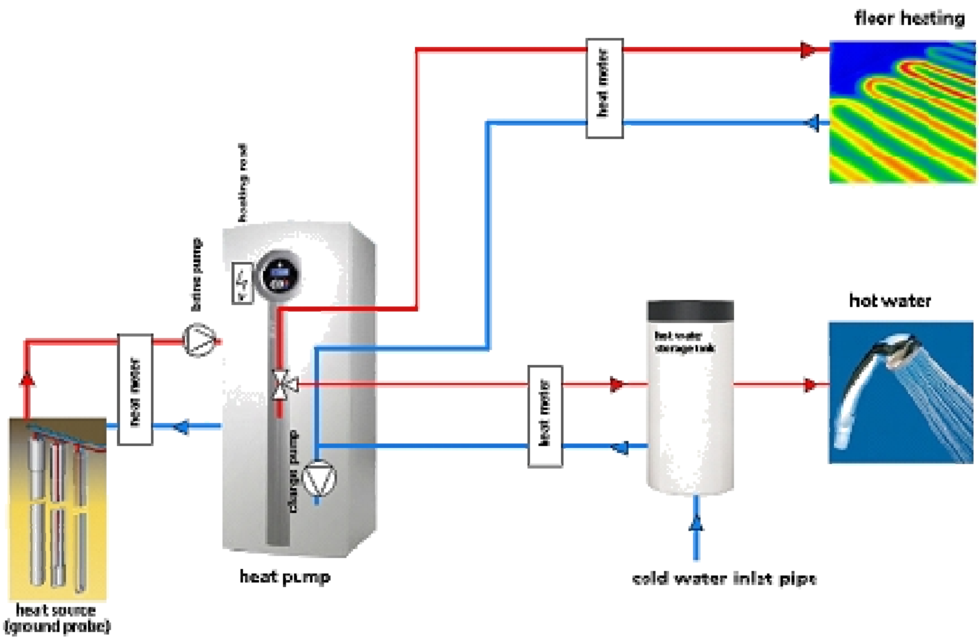
Technical concept

The described system is designed for a low temperature floor emission system. There is a separate circuit for domestic water heating which is equipped with a storage tank. The source energy for the heat pump is delivered by two boreholes with a total length of 180 m. The electrical back-up heater is supposed to support the heat pump when peak heating load occurs.
The low heating circuit temperature (design: 35 °C) combined with the relatively constant and high heat source temperature (6 °C -15 °C) provides good thermo-dynamic operating conditions for the heat pump. This leads to a high efficiency of the whole system.
Performance is positively influenced by the fact that the concept of the heat distribution and the emission system is not too complex. The use of a limited amount of control equipment reduces the risk of failures, operation strategy errors and electrical energy consumption.
Another factor contributing to the generally high performance factors is the careful installation of the system. Well designed and executed piping reduces the loss of pressure and energy which positively impacts the general efficiency of the heating system.

The heat pump and the buffer tank

Current market situation

Heating systems with ground-coupled heat pump, low temperature floor emission system and boreholes as heat source are available on the market.



Sketch and measurement concept of the monitored heat pump system

Technical data of the unit

Heating unit:	**ground coupled heat pump**
Energy source:	**2 boreholes with a total length of 180 m**
Refrigerant:	**R407C**
Defrosting agent:	**28% ethylene glycol**
Energy emission system:	
	low temperature floor system
Design SH:	**35 °C**
Thermal output / COP:	
B0/W35:	**10.9 kW / 5.0**
B0/W50:	**10.1 kW / 3.5**
DHW temperature: 50 °C	

***footnote, e.g. testing standards, points**

Field monitoring

The building is monitored within the scope of the “WP-Effizienz” project since November 2007 and will at least be monitored until the end of 2010. The monitoring period covers the complete year of 2008.

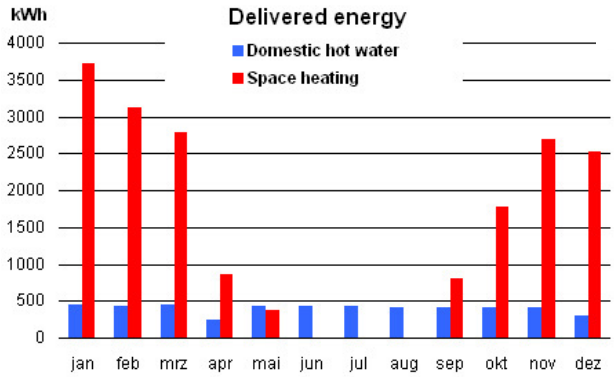
The temperatures and flows, powers and energies in the brine circuit, space heating and domestic water heating circuits are recorded once per minute. The consumption of the electrical energy by all system components is stored as well. The collected data are transmitted to Fraunhofer ISE where automatic data quality control and further processing including data filtration, computations of sums, averages and other factors concerning day, month and year levels are performed.

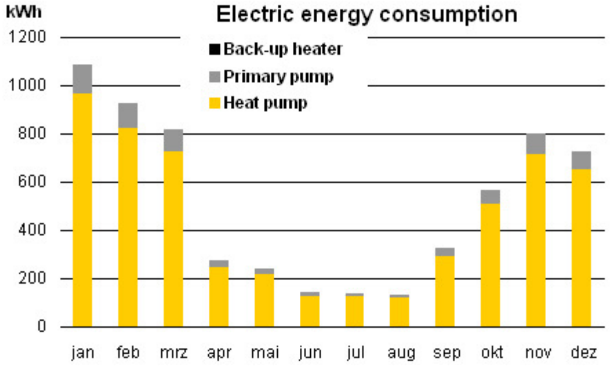
The thermal energy produced by the heat pump in 2008 was 23428 kWh. The amount of energy needed for space heating was 80% corresponding to 18646 kWh or 93 kWh/(m^{2}a) which corresponds to the building directive at the time of erection of the building. The corresponding electrical energy consumed was 6171 kWh, of which 89% are used by the heat pump. No operation of the back-up heater was recorded.

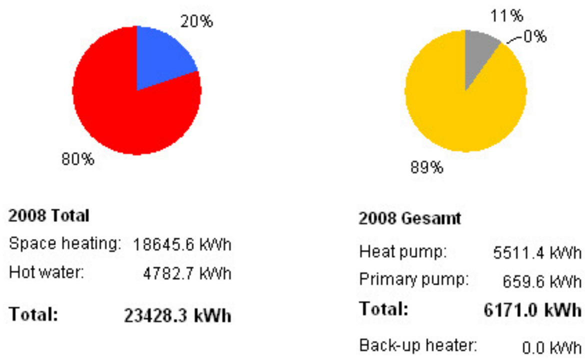
The energy consumptions yield an overall Seasonal Performance Factor of the Generator system SPF-G of 3.8.

A yearly profile of the performance factor and the brine inlet temperature is presented in the graph below. A phase of lower system performance corresponds to months in which very little energy for space heating was needed.

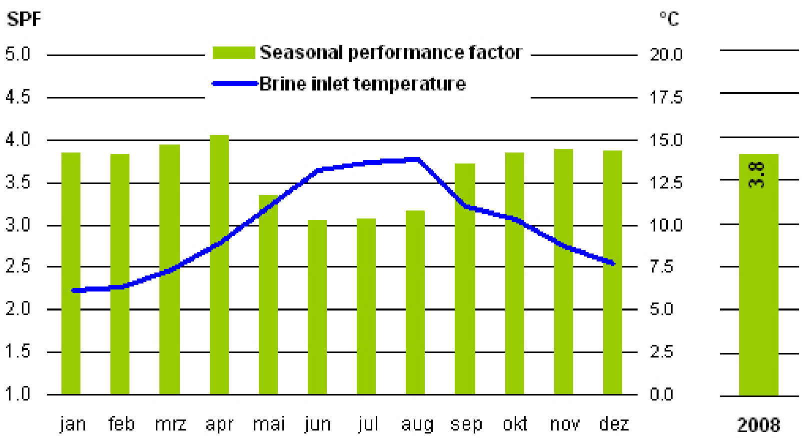
The increase of the average brine inlet temperature observed during these months does not compensate the higher required average temperature of hot water of 50 °C compared to 35 °C in space heating operation, i.e. the average temperature lift is summer is still higher. Thus, the performance factor drops down. An increase of performance correlating with an increase of the brine inlet temperature can be observed when a high demand of energy for space heating (from February to April) was recorded. Moreover, in DHW-only summer operation, the fraction of auxiliary energy for control in relation to the compressor energy is also higher.







Energy delivered and consumed in 2008



Seasonal performance factor (monthly profile and total value for 2008) and brine inlet temperature.

Performance indicators

Seasonal performance factors	
SPF heat pump (excl. backup heater):	**3.8**
SPF heat pump (incl. backup heater):	**3.8**
Minimal SPF (June 2008):	**3.0**
Maximal SPF (April 2008):	**4.0**

Operation times	
Heat pump total:	**2074**
Heat pump space heating:	**1614**
Heat pump for DHW:	**460**

Economy, Ecology and Costs

Environmental effects of the heat pump based on thermal energy produced*:

CO_2-eq. emission factor:	650 $g/kWh_{el.}$
CO_2-eq. emission***:	4011 kg
Primary energy factor:	2.65 $kWh_{prim.}/kWh_{th.}$
Primary energy:	16353 $kWh_{prim.}$
SPF based on primary energy:	1.43

Comparatively environmental impact of a condensing gas boiler based on thermal energy produced**:

CO_2-eq. emission factor:	252 $g/kWh_{th.}$
CO_2-eq. emission***:	5912 kg
Primary energy factor:	1.15 $kWh_{prim.}/kWh_{th.}$
Primary energy:	26942 $kWh_{prim.}$
Primary energy efficiency:	0.85

*values based on thesis made by Fraunhofer ISE, considering the whole process chain and the supply energy effort
**values based on GEMIS 4.5
***values based on thermal energy produced in 2008
**** based on a boiler efficiency of 0.97

Conclusion

The presented data confirms that a ground-.coupled heat pump with a floor emission system can achieve high performance. This does not only lead to savings concerning operating costs, but also with respect to the environment. The computed results of CO_2 emissions and primary energy presented above prove that the described heat pump affects the environment less than an alternative solution of a condensing gas boiler.

Imprint

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Date of Best practice sheet: February 2010

Literature

Website of the "WP-Effizienz" project
http://wp-effizienz.ise.fraunhofer.de

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Wärmepumpen im Feldtest
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(Project outline in German, download at www.annex32.net)

Marek Miara
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Best practice

Single-family house with two separate air-source heat pumps for space heating and domestic water production

Fraunhofer ISE

Fraunhofer Institut
für Solare Energiesysteme
Freiburg, Germany

Contribution of the German national project

Summary

The Fraunhofer Institute of Solar Energy systems (FhG-ISE) is carrying out a large field test of more than 100 heat pumps installed in low energy houses.
This best practice sheet presents field monitoring results of a heating system providing thermal energy for a newly built detached house. The house is equipped with two separate air source heat pumps. The heat pump for the space heating operation is located outside and uses outdoor air. The heat is emitted by a floor heating system into the heated space. Design temperatures of the emission system are designed to low values. Moreover, the space heating system contains a buffer storage. An exhaust air-to-water is used as heat source for the domestic hot water operation.
Measured monthly-averaged outdoor air temperatures reach values of -3 °C and 21 °C during the year, yielding an overall Seasonal Performance Factor of the Generator system SPF-G of 3.33 due to DHW energy share of 9%. The fraction of auxiliary energy used is with 4% slightly lower than the average value.
Due to the good overall seasonal performance factor, the system reaches CO_2-emission savings of 26% and primary energy, savings of 34% compared to a condensing gas boiler with an efficiency of 0.97 based on primary energy and CO_2-eq.-emission factors of the GEMIS 4.5 data base used in Germany.

Building data

- Location: Buchenbach, Baden-Württemberg, Germany
- 4 inhabitants
- Year of construction: 2008
- Heated area: 211 m^2
- Design heating load (EN 12831): 12.9 kW (61 W/m^2)

Introduction

“WP-Effizienz” (“Heat pump efficiency”) is a German monitoring project run by Fraunhofer ISE in Freiburg. The aim of the project is to collect real performance data from a large number of new buildings equipped with different types of heat pumps. The data of more than 100 buildings have been collected since 2006. The project has been run until 2010. The evaluation of the data allows to draw a wide range of conclusions including efficiency comparisons of different systems, the impact of different operation parameters on the performance, optimisation potentials, typical reasons for technical failures and system breakdowns as well as explanations for other phenomena. The described building is monitored as part of the “WP-Effizienz” project.

The domestic hot water exhaust air heat pump

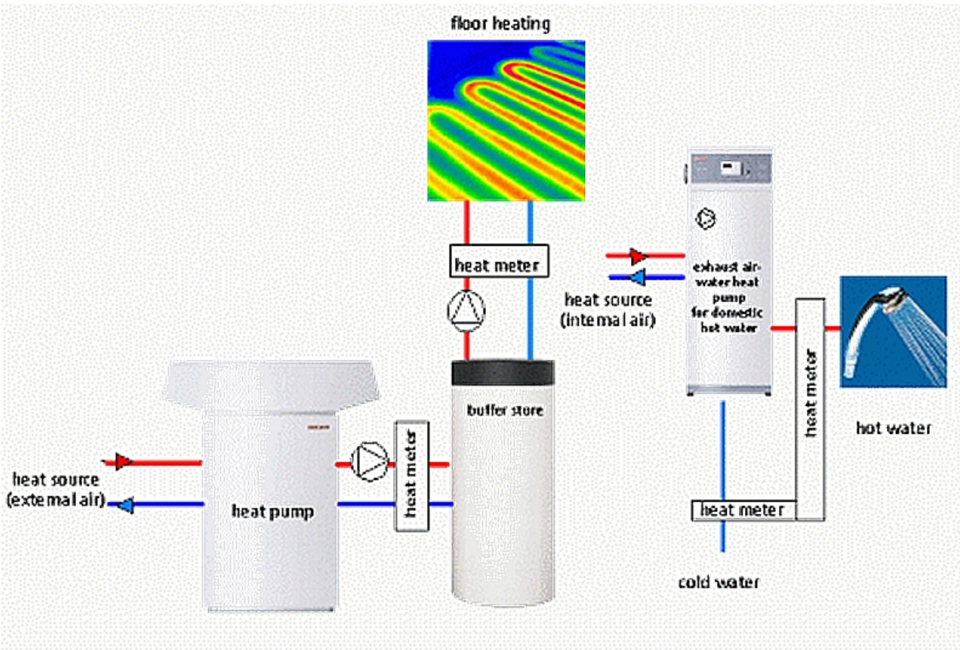
Technical concept

The building is equipped with two separate systems for space heating (SH) and domestic hot water production (DHW) with two separate heat pumps.
The air-source heat pump located outside the building supplies thermal energy for space heating. The electrical backup heater is supposed to support the heat pump when peak heating load occurs. The heat is distributed by a low temperature floor emission system with a storage buffer tank.
The energy for the domestic water heating is delivered by a compact unit with internal buffer tank. In this case, the energy source is exhaust air (ventilation energy recovery). An integrated fan sucks air from inside the building and blows cooled air out of the building after the heat recovery with the exhaust air heat pump. An integrated storage tank allows to minimise energy losses.
The two heating systems operate separately without a common control equipment. Both the SH and DHW unit can be considered as simple and robust systems, which reduce the risk of failures, control strategy errors and excessive electrical energy consumption.

The front view of the monitored building

Current market situation

Both types of heat pumps are being produced and are available on the market.



System sketch including the measurement concept of the installed SH and DHW heat pumps

Technical data of the unit

Heating unit:	**outside air-to-water heat pump, located outside**
Domestic water unit:	**exhaust air-to-water heat pump with ventilation heat recovery, located inside**
Energy emission system:	**low temperature floor system**
Heating capacity / COP(SH unit):	
A2/W35	**11.3 kW / 3.7**
A-7/W35:	**9.6 kW / 3.2**
Refrigerant (SH):	**R407C**

Field monitoring

The building is monitored within the scope of the “WP-Effizienz” project since October 2008 and will at least be monitored until the end of 2010. The monitoring period covers the period Oct. 2008 – Aug. 2009.

The temperatures, flows, powers and energies in the space heating and domestic hot water circuits are recorded once per minute. The consumption of the electrical energy by all system components is stored, as well. The collected data are transmitted to Fraunhofer ISE where automatic data quality control and further processing including data filtration, computation of sums, averages and other factors concerning day, month and year levels are performed.

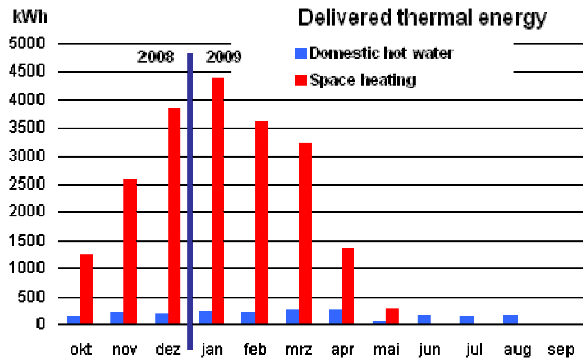
The thermal energy produced by the heat pump systems in the described period was 22458.7 kWh (corresponding to 106 kWh/ m^{2}a). The amount of energy needed for space heating was 91% (or ≈97 kWh/(m^{2}a)) which is above the normal value. Building drying and not finished building isolation works are responsible for this value. The corresponding electrical energy consumption was 6497.3 kWh of which 95% were consumed by the heat pump compressors.

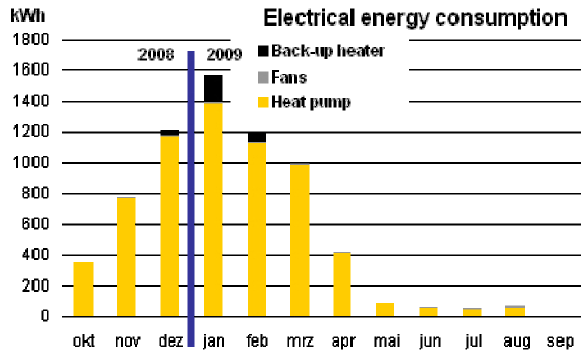
Additionally, 282.1 kWh (4% of total) was consumed by the electrical backup heater of the outside air-to-water space heating heat pump unit.

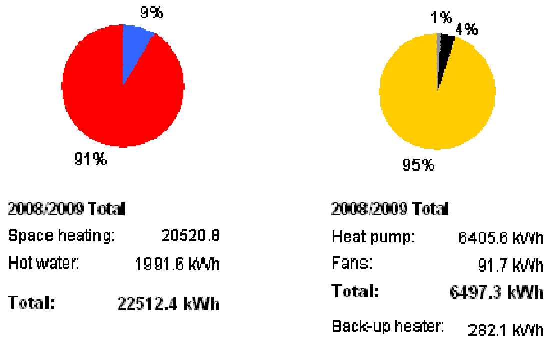
The energy amounts given above determine a Generator Seasonal Performance Factor of the generation system SPF-G of 3.3.

The domestic water heat pump unit uses air from inside the building as energy source. This guarantees a high and relatively constant temperature of the source which results in good performance.

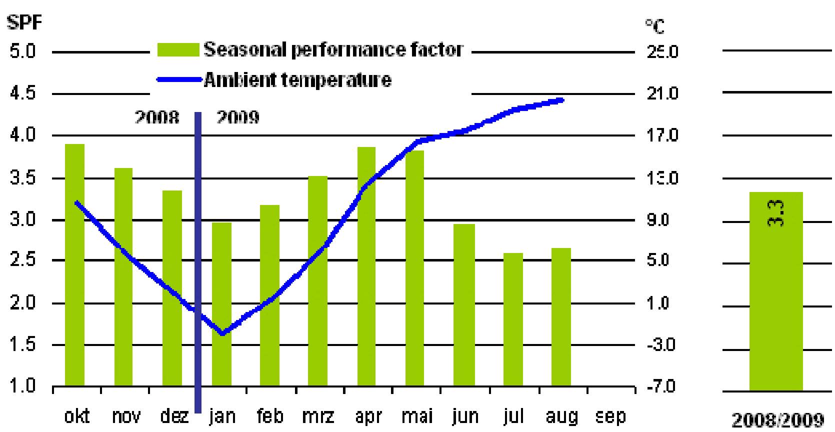
The performance of the space heating unit is linked to the outdoor air temperature. The air temperature significantly drops down in winter months which results in a decrease of the heat pump’s performance (low source temperature), which is depicted below. The monthly performance drops down in summer, even though the average ambient temperature rises. Since the main activity of the system in these months focuses on DHW delivery, the heat pump does not benefit from higher ambient temperatures.







Energy delivered in 2008/2009



Seasonal performance factor (monthly profile and total value for monitoring period) and ambient temperature

Performance indicators

Seasonal performance factors

SPF whole system (excl. backup heater): 3.4
SPF whole system (incl. backup heater): 3.3

Minimal SPF (whole system) July 2009 - 2.6
Maximal SPF (whole system): October 2008 - 3.9

SPF heating unit (excl. backup heater): 3.4
SPF heating unit (incl. backup heater): 3.3

SPF domestic water unit: 3.5

Economy, Ecology and Costs

Environmental effects of the heat pump based on thermal energy produced*:

CO_2-eq. emission factor:	650 $g/kWh_{el.}$
CO_2-eq. emission***:	4223 kg
Primary energy emission factor:	2.65 $kWh_{prim.}/kWh_{el.}$
Primary energy:	17218 $kWh_{prim.}$
Primary energy SPF:	1.24

Comparatively environmental impact of a condensing gas boiler based on thermal energy produced**:

CO_{2eq} emission factor:	252 $g/kWh_{th.}$
CO_{2eq} emission***:	5673 kg
Primary energy emission factor:	1.15 $kWh_{prim.}/kWh_{th.}$
Primary energy:	25889 $kWh_{prim.}$
Primary energy efficiency****:	0.85

*values based on thesis made by Fraunhofer ISE, considering the whole process chain and the supply energy effort
**values based on GEMIS 4.5
***values based on produced thermal energy from 10/08 unti 07/09
****based on a boiler efficiency of 0.97

Conclusion

The presented data confirm that an air-to-water heat pump with floor emission can achieve high performance. Although ambient air is an energy source with low and not stable temperature, it can result in a high SPF combined with a low temperature emission. This does not only lead to savings as far as operating costs are concerned, but also with respect to the environment. The computed results presented above prove significant savings both regarding primary energy and CO_2 emissions.

Imprint

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Best practice

IEA HPP Annex 32

Economical heating and cooling systems for low energy houses

Single-family home with ground-coupled heat pump

Fraunhofer ISE

Fraunhofer Institut
für Solare Energiesysteme
Freiburg, Germany

Contribution of the German national project

Summary

The Fraunhofer Institute of Solar Energy systems (FhG-ISE) is carrying out a large field test of more than 100 heat pumps installed in low energy houses.
This Best Practice Sheet presents field monitoring results of an ground-coupled heat pump providing thermal energy for a newly built detached house.
One borehole of 130 m with double U-Tube heat exchanger is used as heat source. The space heating emission system is a floor heating designed to a supply temperature of 38 °C, which is connected to the heat pump by a heating buffer storage. DHW is produced alternately by switching the heat pump from the space heating operation to a DHW storage.
The source temperature reaches very high temperatures of 9 °C-15 °C during the year, yielding an overall Seasonal Performance Factor of the Generator system SPF-G of 4.11 despite the relatively high DHW energy share of 24%. The fraction of auxiliary energy is with 8% slightly higher than the average.
Due to the good overall seasonal performance factor, the system reaches CO_2-eq. emission savings of about 37% compared to a condensing gas boiler with an efficiency of 1.0. In terms of primary energy, savings of about 44% can be reached. The SPF-G based on primary energy yields a value

Building data

- Location: Neuffen, Baden-Württemberg, Germany
- Inhabitants: 5 persons
- Year of construction: 2006
- Heated area: 150 m^2
- Design heating load (DIN 4701): 7.5 kW (50 W/m^2)

Introduction

"WP-Effizienz" ("Heat pump efficiency") is a German monitoring project run by Fraunhofer ISE in Freiburg. The aim of the project is to collect real performance data from a large number of new buildings equipped with different types of heat pumps. The data from more than 100 buildings have been collected since 2006. The project will run until 2010. The evaluation of the data allows to draw a wide range of conclusions including efficiency comparisons of different systems, the impact of different operation parameters on the performance, optimisation potentials, typical reasons for technical failures and system breakdowns as well as explanations for other phenomena. The described building is monitored as part of the "WP-Effizienz" project.

The front view of the monitored building

Technical concept

The monitored system is designed for a low temperature floor emission system with buffer tank. A separate circuit for domestic water heating is equipped with a storage tank. The heat pump operate alternately in SH or the DHW mode and is switched between the modes.

The source energy for the heat pump is delivered by a borehole heat exchanger with a total length of 130 m. The electrical back-up heater is supposed to support the heat pump when peak heating load occurs.

The low heating circuit temperature with a design temperature of 38 °C combined with the relatively constant and high source temperature (9 °C -15 °C) provide good thermodynamic operating conditions for the heat pump. This leads to a high efficiency of the whole system.

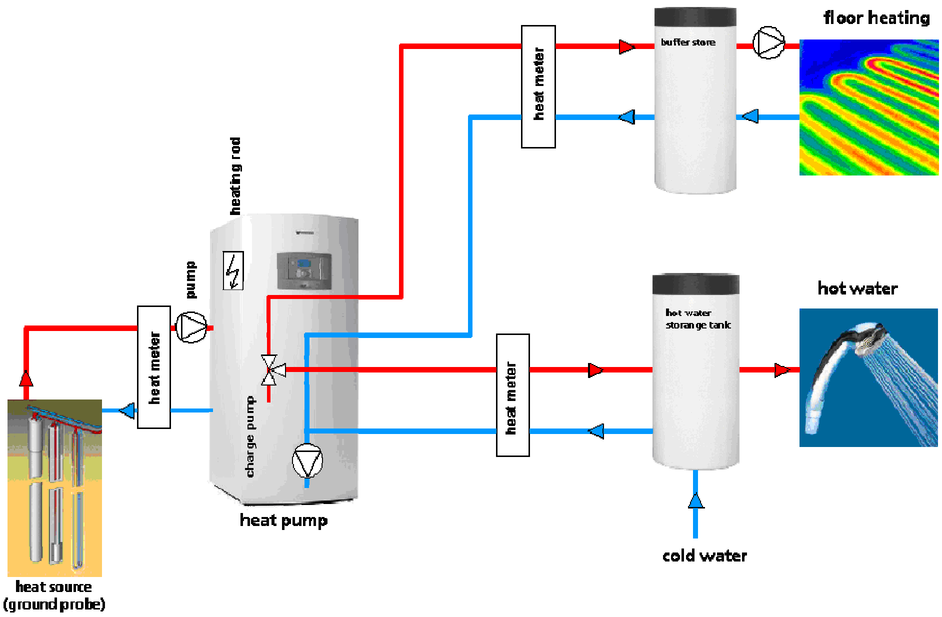
Performance is positively influenced by the fact that the concept of the heat distribution and the emission system is not too complex. The use of a limited amount of control equipment reduces the risk of failures, operation strategy errors and electrical energy consumption.

Another factor contributing to the generally high performance factors is the careful installation of the system. Well-designed and executed piping reduces the loss of pressure and energy which positively affects the general efficiency of the heating system.

The heat pump and the measurement equipment

Current market situation

The monitored system is available on the market.



System sketch of the monitored system

Technical data of the unit

Heat pump:	**ground-coupled heat pump for alternate SH and DHW operation**
Refrigerant:	**R407C**
Energy source:	**1 borehole of 130 m**
Defrosting agent:	**22% ethylene glycol**
Heating capacity / COP:	
B0/W35:	**7.3 kW / 4.1**
B0/W50:	**7.0 kW / 3.0**
Emission system:	
	low temperature floor heating
Design temperature:	
SH	**38 °C**

Field monitoring

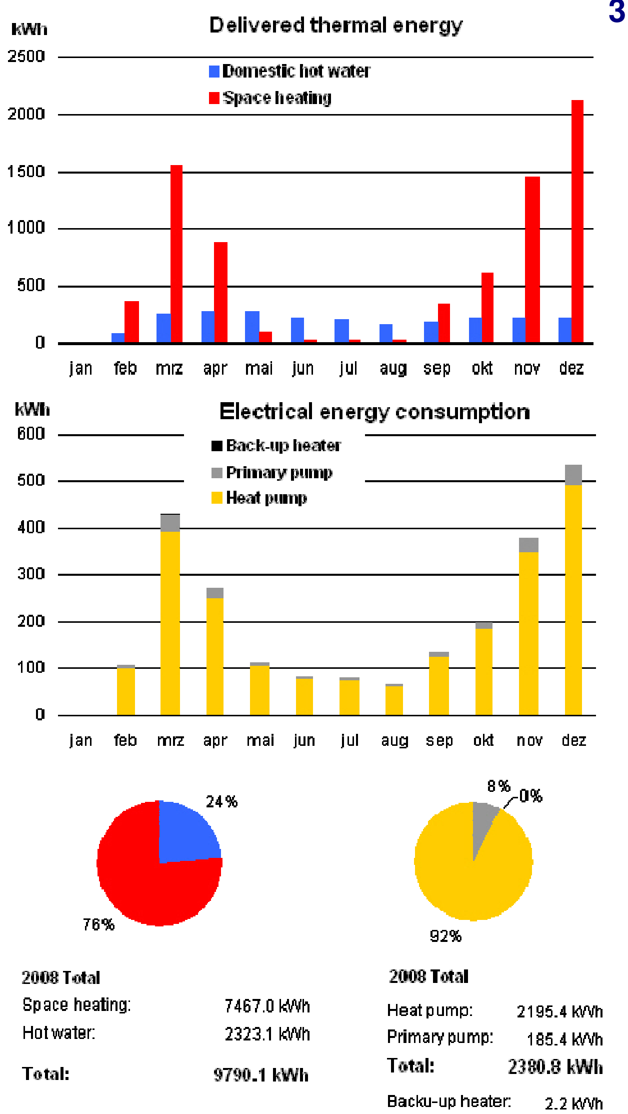
The building is monitored within the scope of the “WP-Effizienz” project since November 2007 and will at least be monitored until the end of 2010. The monitoring period covers the complete year of 2008.

The temperatures, flows, powers and energies in the brine circuit as well as space heating and domestic water heating circuits are recorded once per minute. The consumption of the electrical energy by all system components is stored, as well. The collected data are transmitted to Fraunhofer ISE where automatic data quality control and further processing including data filtration, computation of sums, averages and other factors concerning day, month and year levels are performed.

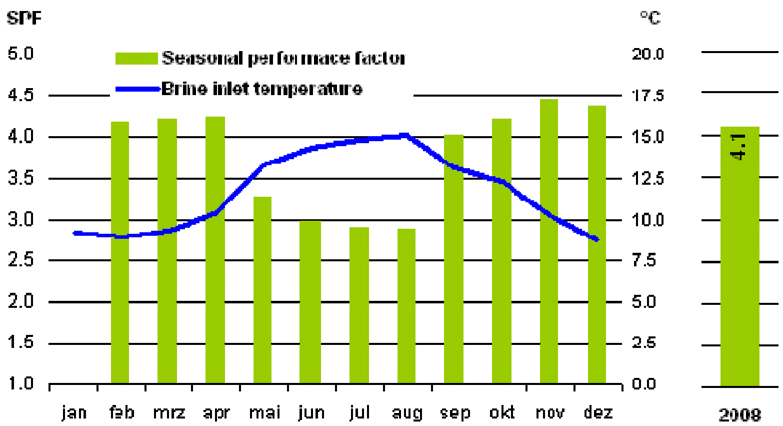
The thermal energy delivered by the heat pump in 2008 was 9790.1 kWh. The amount of energy needed for space heating was 76% or 7467 kWh (50 kWh/m^{2}a) which is below the standard value and at the upper limit of a low energy house. The corresponding electrical energy consumed was 2380.8 kWh (fraction of energy consumed by the heat pump 89%).

Consumption of electrical backup heater is negligible.

The energy amounts given above determine an overall Seasonal Performance Factor of the Generator system SPF-G of 4.11. A yearly profile of the performance factor and the brine inlet temperature is presented in the graph below. Times of lower system performance corresponds to months, in which no or very little energy for space heating was needed. The increase of the average brine inlet temperature which can be observed during these months does not compensate the increase of the average temperature of hot water delivered by the heat pump (≈35 °C for space heating and 52 °C for domestic water heating). Because when the average difference between the source and the output temperature is higher in summer, the performance factor drops. An increase of performance correlating with an increase of the brine inlet temperature can be observed when a high demand of energy for space heating (from February to April) was recorded. The amount of the non-productive electrical energy consumption (energy used by the heat pump for controlling without any compressor activity) is much higher in summer which also contributes to the observed decrease of system efficiency.



Delivered and consumed energy in 2008



Seasonal performance factor (monthly and total value 2008) and temperature of brine inlet

Performance indicators

Seasonal performance factors	
SPF heat pump (excl. backup heater):	**4.1**
SPF heat pump (incl. backup heater):	**4.1**
Minimal SPF (August 2008):	**2.9**
Maximal SPF (November 2008):	**4.4**

Operation times	
Heat pump total:	**1147 h**
Heat pump space heating:	**832 h**
Heat pump for DHW:	**314 h**

Economy, Ecology and Costs

Environmental effects of the heat pump based on thermal energy produced*:

CO_2-eq. emission factor:	650 $g/kWh_{el.}$
CO_2-eq. emission***:	1549 kg
Primary energy emission factor:	2.65 $kWh_{prim.}/kWh_{th.}$
Primary energy:	6315 $kWh_{prim.}$
SPF based on primary energy:	1.55

Comparatively environmental impact of a condensing gas boiler based on thermal energy produced**:

CO_2-eq. emission factor:	252 $g/kWh_{th.}$
CO_2-eq. emission***:	2467 kg
Primary energy emission factor:	1.15 $kWh_{prim.}/kWh_{th.}$
Primary energy:	11258 $kWh_{prim.}$
Primary energy efficiency****:	0.85

*values based on thesis made by Fraunhofer ISE, considering the whole process chain and the supply energy effort
**values based on GEMIS 4.5
***values based on produced thermal energy in 2008
**** based on a boiler efficiency of 0.97

Conclusion

The presented data confirms that a ground-coupled heat pump with a floor emission system can achieve high performance. This does not only lead to savings concerning operating costs, but also with respect to the environment. The computed results of CO_2-eq. emissions and primary energy presented above prove that the described heat pump affects the environment significantly less than an alternative solution such as a condensing gas boiler.

Imprint

Field monitoring
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Date of Best practice sheet: March 2010

Literature

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http://wp-effizienz.ise.fraunhofer.de

Marek Miara, Christel Russ, Rainer Becker
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KI Luft Kälte Klimatechnik, September 2007, p. 24-27
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Presentation Annex 32 Workshop, 9th IEA Heat Pump Conference, 19.-22. May Zurich, 2008
download at www.annex32.net

Marek Miara
Richtig geplant, wirklich gespart
Interim results WP-Effizienz IKZ Haustechik Heft 3/2009
(In German), download at www.annex32.net

IEA HPP Annex 32

IEA HPP Annex 32 is a corporate research project on technical building systems with heat pumps for the application in low energy houses.
The project is accomplished in the Heat Pump Programme (HPP) of the International Energy Agency (IEA).

Internet: http://www.annex32.net

Best practice

Economical heating and cooling systems for low energy houses

HVAC-System including a capacity-controlled ground-source heat pump installed in a low energy house in the cold region of Japan

北海道大学
HOKKAIDO UNIVERSITY

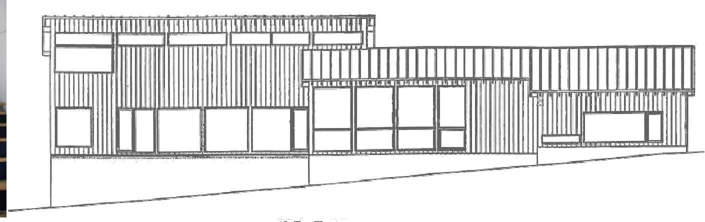
Contribution of the Japanese national project

Summary

This Best Practice Sheet describes the field-monitoring of a capacity-controlled ground source heat pump installed in a low-energy house built in the cold region of Japan (Hokkaido Island).
The building envelope consists of highly insulated walls and a floor with high thermal mass. The large window area is mainly oriented to the south. The overall heat loss coefficient (called Q-value in Japan) is 0.96 W/(m^2·K) and the effective clearance area (called C-value in Japan) is 0.4 cm^2/m^2. Both values are significantly lower than the standard values of the Japanese "standard for next generation" houses with a requirement of a Q-value < 1.6 W/(m^2·K) and a C-value < 2.0 cm^2/m^2.
For heating and cooling, two single U-tube borehole heat exchangers are connected to a Japanese fabricated ground-source heat pump unit with variable compressor speed. Thereby, the COP can be increased in part load operation compared to the full load COP. DHW energy is supplied by a Japanese air-source CO_2 heat pump water heater (EcoCute).
The heat from the GSHP is emitted to the room by a floor emission system. Supply temperature exceeded 35°C only for a few hours of the year. At these supply temperatures, indoor room temperatures are kept above 20°C.
The favourable part load operation leads to the measured generator seasonal performance factor (SPF-G) during the heating period of 4.45.
Compared to a fuel oil boiler, which is the conventional heating system of the region, and common building practice the CO_2-eq.-emissions are reduced by 59% in the low energy house with ground-source heat pump.
A 5.6 kW$_p$ PV system contributes 48% of the total electricity consumption.

Building Data:

- Location: Naganuma, Hokkaido, Japan
- Inhabitants: 2 persons
- Total floor area: 200 m^2
- Window area: 83 m^2, 63% south-facing
- Windows: Low-e triple glazing with Argon gas filling
  U-value: 1.3 W/(m^2·K)
- Heat loss factor (Q-value): 0.96 W/(m^2·K)



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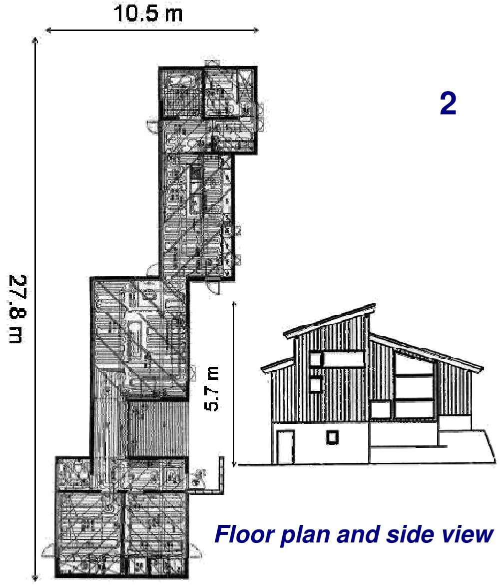


Floor plan and side view

Background

The heat load can be decreased in well-insulated and air-tight buildings. The use of heat pumps has been recognized to be a solution for further energy savings in low energy houses. In particular, floor heating systems using heat pumps may allow lower supply temperatures due to larger emission areas, thus improving the efficiency of heat pumps. However, common systems in the cold climate area in Japan, the Hokkaido Island, are fuel-oil boilers. In the frame of two field tests, the feasibility of the application of ground-source heat pumps in low energy houses in Hokkaido are evaluated. The results are compared to common system solutions for the climate zone.

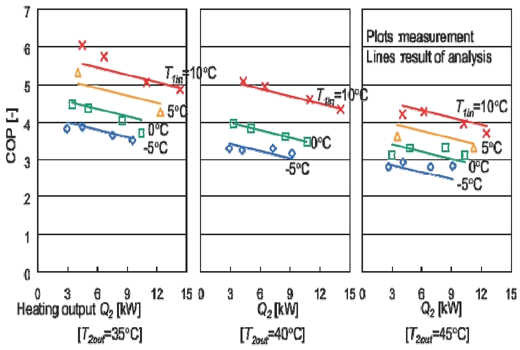
Technical concept

An inverter-controlled ground-source heat pump (GSHP) with rotary compressor of max. 10 kW heating capacity, which can vary the heating power by controlling the compressor speed, is used for heating and cooling. Two single U-tube borehole heat exchangers of about 100 m length, installed 5 m apart, serve as heat source. Measurements of the ground properties yielded a ground water temperature of 10.8 °C at a level of 14.7 m. The effective ground conductivity is 1.4 W/m/K evaluated by thermal response test. The heat produced by the heat pump is distributed to the room space by a floor emission system, which is designed to a flow temperature of 35 °C. Passive cooling with the borehole heat exchangers is also possible in summer and emitted to the rooms by fan coil units.

Moreover, the system includes an air-source so-called EcoCute system, a CO_2-heat pump water heater, which incorporates a 460 l DHW storage tank.

A mechanical ventilation system is installed to guarantee the required hygienic air exchange in the air-tight building. Average volume flow is 230 m^3/h or 0.5 h^{-1}. It is equipped with a ventilation heat recovery and a ground-to-air heat exchanger of 50 m length and 0.2 m diameter, which is buried 1.55 m deep in the ground in order to preheat and precool the ventilation air.

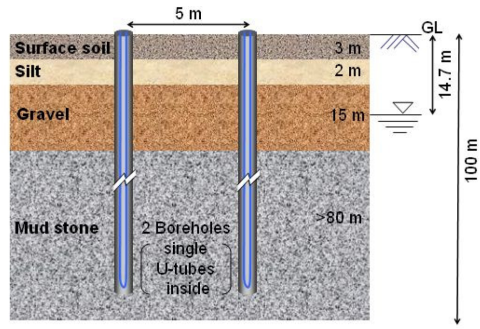
Furthermore, a 5.6 kW_p PV-system of polycrystalline modules is integrated in the metal roof.



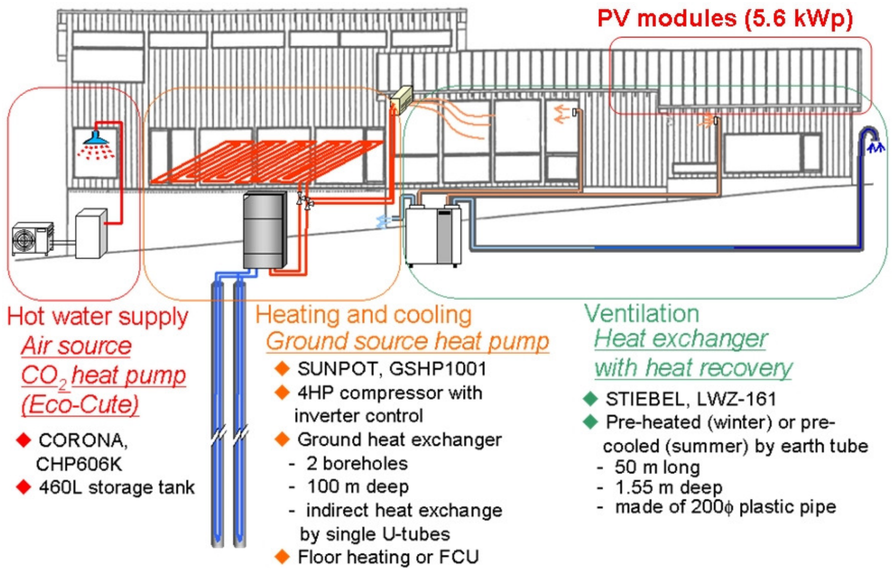
Measured heat pump characteristic

State of market introduction

The system is built-up of market available components, but has rarely been used in the cold climate region of the Hokkaido Island in Northern Japan, so far.



Geological structure of the soil for the ground-coupled heat pump



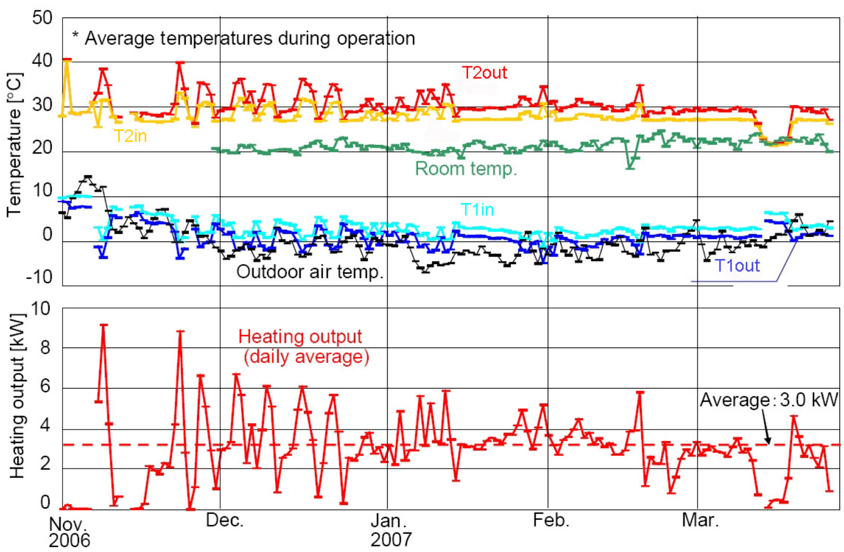
System configuration for the field test

Technical data of the unit

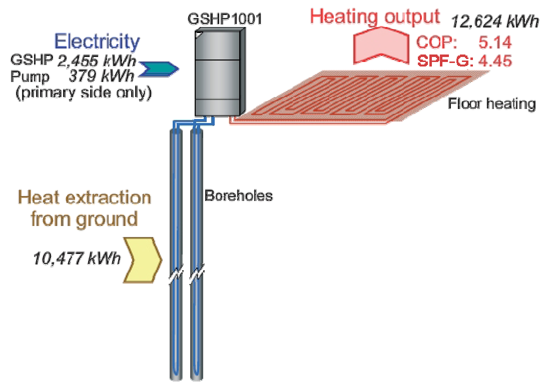
Type:	**inverter-controlled B/W-heat pump**
Source:	**2x100 m single U-tube borehole HX**
Heating capacity	**max. 10 kW (B0/W35)**
COP full load	**3.7 (B0/W35)**
COP part load	**up to 4.5 (B0/W35)**
DHW EcoCute:	**A/W, storage 460 l**
Ground-to-air HX:	**50m long, 1.6 m deep 0.2 m diameter**
Temp. change heat recovery	**90%**
Ventilation rate	**230 m^3/h**
PV-System:	**5.6 kW_p**

Field monitoring

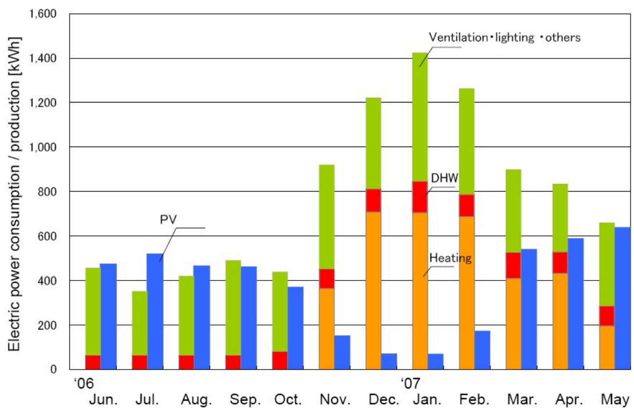
The year-round field monitoring took place between June 2006 and May 2007.
Measured supply temperatures mainly ranged between 30 ℃ and 35 ℃ with a max. of 40 ℃ for a few days. Ground temperature stayed relatively constant throughout the heating season and ranged around 0 ℃ with a minimum of -3 ℃., leading to effective temperature lift in the range of 35 K during the heating period.
Thus, the monitored seasonal performance showed quite high values. Moreover, the average heating power was evaluated to 3 kW. So, most of the time, the heat pump operates in part load. Hence, efficient inverter-driven capacity control, which increases the COP in part load, further contributes to the good seasonal performance factor. Considering only the heat pump, the SPF-HP (or average COP) is 5.14 in the heating period. On the other hand, the generator seasonal performance factor including also the source auxiliary energy yields an SPF-G of 4.45. The fraction of the auxiliary energy for the source pump is 13.4%.
Operation of the ground-to-air heat exchanger yielded minimum outlet temperatures above 2 ℃ and provides thereby an effective frost protection of the ventilation heat recovery. Outlet temperatures during the heating period range between 2 ℃ and 10 ℃ depending on the outdoor air temperature at the inlet. The average extracted power from the ground was evaluated to 200 W or 4.4 W/m installed tube, contributing a 14% reduction of ventilation losses.
The total annual electric energy consumption of 9379 kWh (47 kWh/(m^{2}a)) is modest and can be decomposed into 37% for heating, 10% for DHW, and 53% for other purposes (incl. ventilation). On the other hand, the PV-system generated an annual energy amount of 48% or 4534 kWh and was self-sufficient during the summer months May to October.
Winter indoor temperatures are above 20 ℃ in almost all conditions, so winter comfort can be guarantee also with the low flow temperature of max. 35 ℃. On the other hand, some overshooting of the temperature up to 28 ℃ occurred at high solar gains, which could be avoided by improved shading and additional thermal mass inside the building.



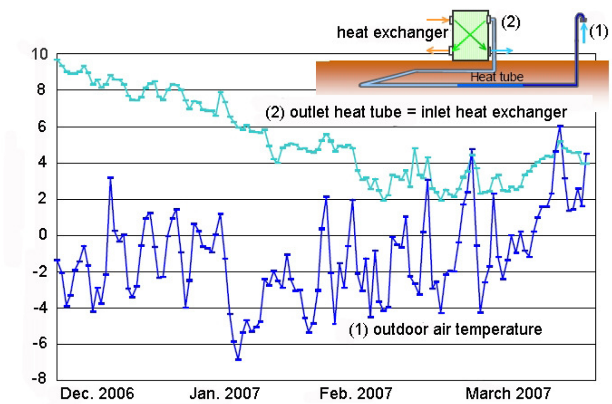
Average monitored temperatures in the winter period 2006/2007



Energy balance in the winter heating period



Electrical power consumption/production by PV system



Preheating of the outdoor air by the ground-to-air heat exchanger

Performance indicators

Seasonal performance factors

SPF heat pump (boundary COP)	**5.14**
SPF generator (boundary produced, heat, incl. source pump)	**4.45**

Fractional losses/consumption

Fraction auxiliaries (source pump)	**13.4%**

System performance and optimisation

An overall electrical energy consumption incl. household appliances of 47 kWh/(m^2a), leaving less than 20 kWh/(m^2a) for heating purposes, is very modest and characterises a good low energy house. A generator seasonal performance factor SPF-G in space heating mode of 4.45 is a good result for a ground-source heat pump.
However, fractional auxiliary energy of 13.4% for the source pumps seem high, since a rule of thumb states that efficient ground source pumps shall not consume more than 4% of the compressor electricity. Thus, either there is an optimisation potential concerning a higher pump efficiency, maybe also due to longer running times due to the continuous capacity-controlled operation. On the one hand, the high fraction of auxiliary energy could also be an indicator of the very efficient compressor operation consuming less energy due to good average COP of 5.14 by the capacity control.
In wintertime problems with the generated power of the solar PV system have been detected due to snow covering. Since PV is a technology of still high investment costs, solutions for a more efficient operation without the impediments of snow covering should be developed.
A second field test (see N-house project) shall address and evaluate further optimisation potentials:

- Further heat recovery from the exhaust air
- Passive pre-cooling/dehumidification with ground-to-air heat exchanger
- Control and operation (continuous/intermittent) of space heating

Economy, Ecology and Costs

Concerning the ecology the system has been compared to common fossil heat generators used in the region regarding CO_2-eq.-emissions. Compared to an oil boiler of the region with a boiler efficiency of 85%, about 2.3 ton CO_2 or 59% of CO_2-eq.-emissions could be saved
Compared to a gas boiler, the savings are lower, but still significant emission savings of about 1.7 ton or 45% based on the $CO_{2eq.}$-emission factors used in Japan*.

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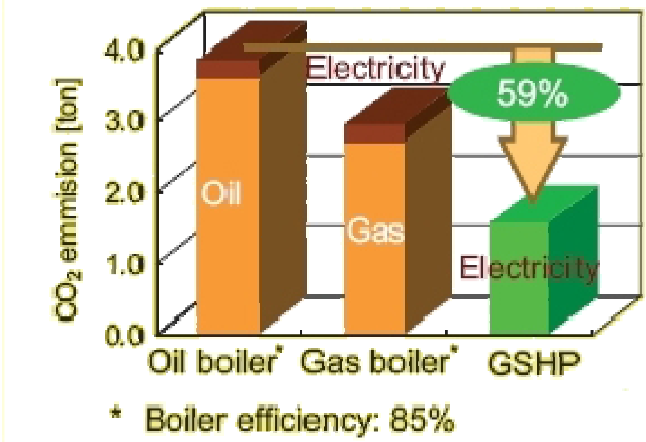
* CO_2-eq.-emission factors used in Japan:
Electricity:410 gCO_2/kWh_{el}, fuel-oil: 244 $kgCO_2/kWh_{th.}$



Environmental merit of the ground coupled heat pump in comparison to oil and gas boilers common in Hokkaido

Imprint

Field monitoring

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Fujiwara Environmental Science Institute
Takao Katsura, Ph.D.

Date of Best practice sheet: March 2010

Literature

Sayaka Takeda Kindaichi, Katsunori Nagano, Takao Katsura, Shogo Hori, Kazuo Shibata
System performance of an HVAC system in a low energy house in the cold region of Japan, IEA HPC Newsletter, volume 26, No. 3, 2008

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System assessment and field monitoring, IEA HPP Annex 32 Country report Japan, Task 3, Sapporo, May 2008

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Sayaka Takeda Kindaichi et al.
Annual energy consumption of an actual low energy house in the cold region of Japan, University of Tokyo, Japan IEA HPP Annex 32 Workshop, Kyoto, Dec. 2007, download at http://www.annex32.net

Best practice

Economical heating and cooling systems for low energy houses

B/W heat pump with capacity-control installed in a low energy house in the cold region of Japan (N-House project)

北海道大学
HOKKAIDO UNIVERSITY

Contribution of the Japanese national project

Summary

This Best Practice Sheet describes the field-monitoring results of a low-energy house built in the cold region of Japan (Hokkaido Island).
For heating and cooling, double U-tube heat exchangers are installed in boreholes and connected to two Japanese fabricated ground-source heat pumps (GSHP), one for space heating and one for DHW operation. Furthermore, the system is equipped with a 3 m^2 evacuated tube solar collector and a 3 kW$_p$ solar PV system. A ground-to-air heat exchanger, which includes a passive (de-)humidification chamber, is used for pre-heating and -cooling of the ventilation air. Moreover, a heat recovery of the ventilation exhaust air contributes to source heat for the heat pumps.
The heat from the GSHP is emitted to the room by a floor heating system. The system performance is also discussed. Moreover, the monthly electricity consumption and production by the solar photovoltaic (PV) system are compared, and finally the annual energy balance is evaluated.
The monitored space heating consumption was evaluated to 52 kWh/(m^{2}a) and the system reaches a seasonal performance factor of the generators of 3.8 in space heating, 3.7 in DHW operation including a 23% solar thermal contribution and an overall performance factor of 3.8.
Compared to a common house of the region of a Q-value of 1.6 equipped with oil boiler (85% efficiency), a reduction in CO_2 emission of 71% is reached, which stems to 45% from the insulation and 55% from the applied building technology. In terms of primary energy the reduction is 53%, which is caused to 60% by the insulation and to 40% by the building technology.

Building Data:

- Location: Sapporo, Hokkaido, Japan
- Inhabitant: 2 adults, 2 children, Total floor area: 223 m^2
- Walls: U-value: 0.12 W/(m^{2}K) (1st floor), 0.19 W/(m^{2}K) (ground floor), 0.15 W/(m^{2}K) (under floor)
- Windows: area: 117 m^2, 40% south-facing, Triple low-e glazing with Argon gas, U-value 1.2 W/(m^2·K)
- Roof: U-value: 0.097 W/(m^{2}K)
- Overall heat loss (Q-value): 0.94 W/(m^2·K)

International Energy Agency
Heat Pump Programme

Background

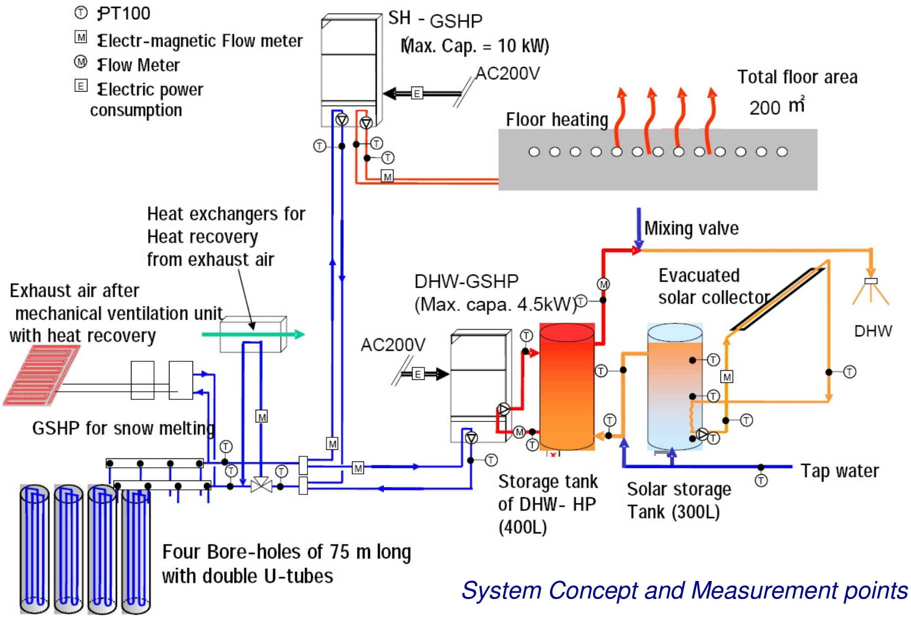
The heat load can be decreased in well-insulated and air-tight buildings. The use of heat pumps has been recognized to be a solution for further energy savings in low energy houses, in particular with floor heating. However, common systems in the cold climate area in Japan, the Hokkaido Island, are fuel oil boilers. In the frame of two field tests, the feasibility of the application of ground-source heat pumps in low energy houses in Hokkaido is evaluated. The results are compared to common system solutions for the climate zone.

Technical concept

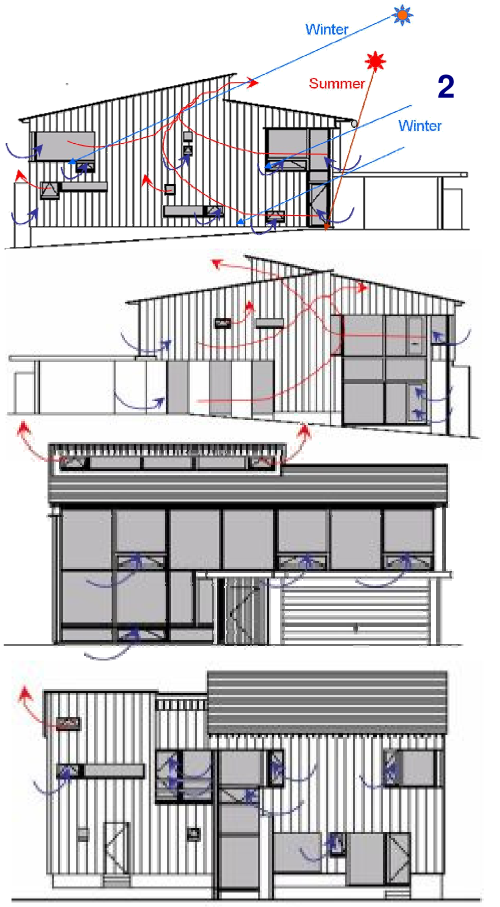
For use of passive solar gains in wintertime, 40% of the 117 m^2 glazing area is oriented to the south. Walls and floors are made of heavyweight reinforced concrete to store the gains. In summer time, balconies and the roof construction is used for sun protection to prevent overheating. The surface finishing of the walls contains a plastering of Wakkanai Siliceous Shale, which is capable to absorb and desorb water for passive internal humidity regulation.
The technical concept comprises 4 different brine-to-water (B/W) heat pumps. An inverter-controlled B/W heat pump of a maximum heating capacity of 10 kW is used for heating and passive cooling operation. While the space heating system is emitted by a 200 m^2 floor heating, additional fan coils units are used for passive cooling. The DHW is preheated during daytime with a 3 m^2 evacuated solar collector connected to a 300 l solar DHW storage. A different B/W heat pump is used for DHW reheating to a temperature of 65 °C during night-time, which is stored in a 450 l DHW storage. Two further heat pumps are integrated in the system for snow melting. Four boreholes, each 75 m, are equipped with double U-tube heat exchangers and serve as heat source for the heat pumps.
A ventilation system is equipped with a ventilation heat recovery and a 40 m long ground-to-air heat exchanger, which is buried 1.5 m in the ground.
After the ventilation heat recovery, an additional heat exchanger recovers heat from the exhaust air by a coupling to the source system of the heat pump.
Moreover, a 3 kW$_p$ solar photovoltaic (PV) system is installed on the metal roof.

State of market introduction

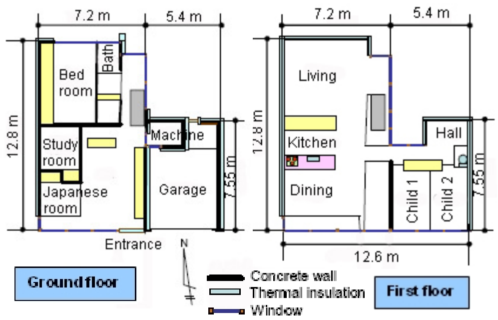
The system is built-up of components available on the market, but is seldomly used in this cold climate region of the Hokkaido Island in Northern Japan.



System Concept and Measurement points



Passive strategies of the N-House



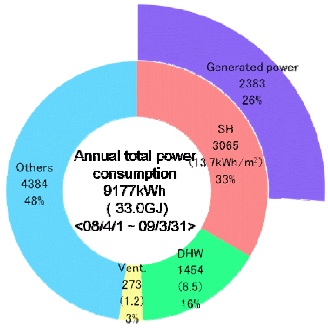
Floor plan of the N-house

Technical data of the system

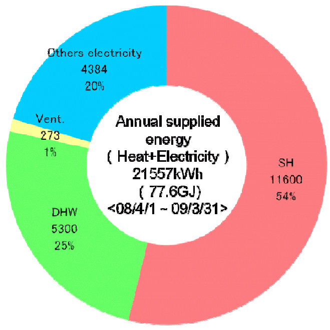
Type:	**B/W heat pumps**
Source:	**4x75 m double U-tube borehole HX**
Space heating part:	
Output capacity	**max. 10 kW (B0/W35)**
COP full load:	**3.7 (B0/W35)**
COP part load:	**up to 4.5 (B0/W35)**
DHW part:	
Output capacity	**max. 4.5 kW (B0/W35)**
Solar collector:	**3 m^2 evacuated tubes**
DHW storage:	**400 l**
Solar storage:	**300 l**
DHW temperature:	**65 °C**
Ventilation heat recovery	**80%**
PV Generator:	**3 kW$_p$**

Field monitoring results

For the year-round evaluation of the field monitoring the period 1. April 2008 until 31. March 2009 has been selected.
The total energy consumption of the house comprising heat and electricity can be assign to 54% (11600 kWh) to space heating, to 25% (5300 kWh) to the DHW operation and to 20% to other electric appliances, while the ventilation only requires 1% (273 kWh). The specific space heating consumption reaches a typical value for low energy houses of 52 kWh/(m^2a) based on total floor area.
The total electrical energy consumption of 9177 kWh can be broken down to a household consumption of 48% or 4384 kWh, while 52% or 4793 kWh are consumed by the building technology (3% ventilation, 33% space heating and 16% DHW).
26% of the total electrical consumption is generated on-site by the PV system, leading to a purchased energy of 30.5 kWh/(m^2a). Referring to the technical installations, about 50% of the electricity consumption is covered by the on-site electricity generation.
The resulting seasonal performance factors of the generators are 3.8 in the space heating mode and 3.7 in the DHW mode, which includes the solar contribution of 24% for the DHW heating by the evacuated tube collectors (in operation from mid of June). The evacuated tube collectors have a performance factor of 25 (ratio of produced heat to electricity input). The overall seasonal performance of the system is thereby 3.8.
As a new approach the ventilation heat recovery from the exhaust air is used as heat source for the ground source heat pump. This heat recovery contributes about 20% of the source energy for the space heating operation and about 30% of the DHW operation, in total about 25% of the source energy.
Moreover, and ground-to-air heat exchanger is installed, which contains a passive (de-)humidification.



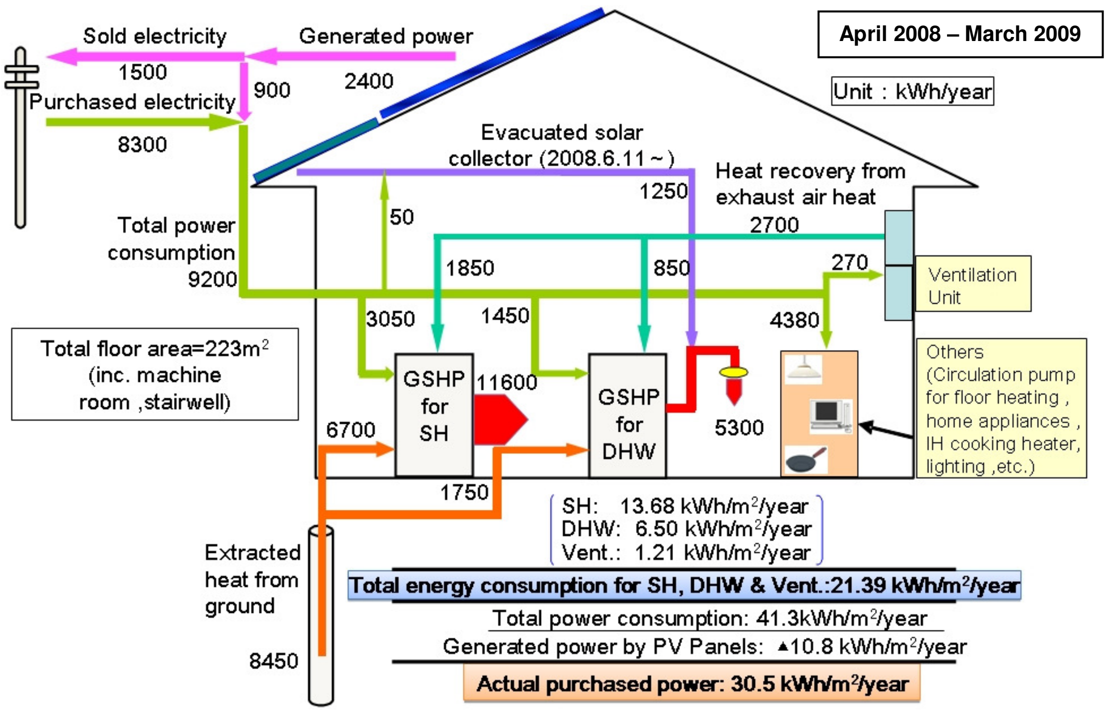
Breakdown of the electricity consumption



Breakdown of the total energy consumption (incl. heat)

Performance indicators

SPF heat pump SH (boundary COP)	**3.8**
SPF HP DHW	**2.8**
SPF-G DHW (incl. Solar)	**3.7**
Solar collector (vacuum tubes)	**25**
SPF overall (all system components)	**3.8**
Electricity generation on-site	**2363 kWh (26 %)**



Energy flow diagram and balance of installed components in the N-house

System performance and optimisation

The overall seasonal performance factor generator SPF-G of 3.7 is good for a ground-coupled heat pump and a solar collector in a cold climate region.
The single performance factors of the heat pump for space heating of 3.8 and for DHW of 2.8 correspond to the seasonal performance factors measured in other field monitoring projects.
The solar collector shows a good seasonal performance factor of 25, as well, yielding to an overall seasonal performance of 3.7 in the DHW mode, since the solar collector contributes only 24% due to the operation from June on.
The installed 3 kW_p solar PV system contributes about 25% of the overall electricity use of the house and about 50% of the consumption of the building technology. In the winter period, however, there have been times with snow cover, which causes a decrease of the electricity generation.
Further innovative technologies have been installed in the house. In the plaster of the walls Wakkanai Siliceous Shale is integrated for a passive humidity control. Moreover, the same stones are integrated in the ground-to-air heat exchanger as a pit with packed broken stones. Thus, in summertime, the natural hydroscopic stones can be used to extract humidity from the inlet air. In wintertime, dry outside air can be humidified while passing through the packed bed. Furthermore, a heat recovery from the exhaust air is used as second heat source besides the ground. However, a detailed evaluation of these innovative pilot technologies could not be performed in the time frame of Annex 32.

Economy, Ecology and Costs

Compared to a common houses of the region with a Q-value of 1.6 equipped with oil boiler (85% efficiency), a reduction in CO_2 emission of 71% is reached. This reduction stems to 45% from the insulation and 55% from the applied building technology, mainly from the space heating due to the higher energy demand. In terms of primary energy the total reduction is 53%, which can be assigned to the insulation with 60% reduction and to the building technology with 40%, as well mainly by the space heating part.

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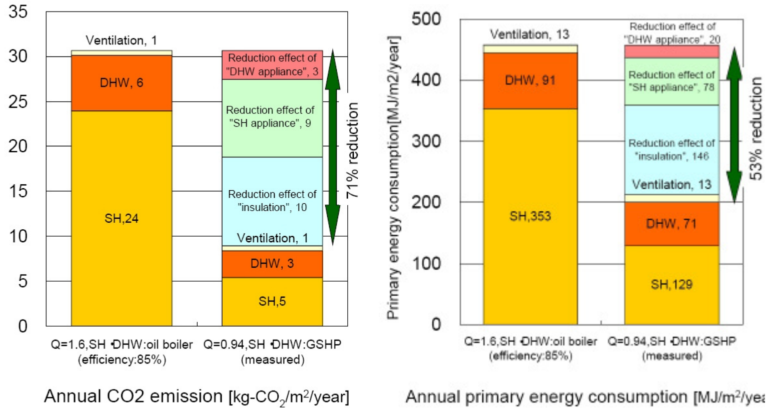
* $CO_{2eq.}$ emission factors:
Electricity:410 gCO_2/kWhel, fuel-oil: 67.8 $kgCO_2$/MJ

** Primary energy factors:
Electricity: 9.76 MJ/kWhel, fuel-oil: 36.7 MJ/l



Comparison of N-house system for SH, DHW and ventilation to conventional practice in terms of primary energy and CO_2-emissions

Imprint

Field monitoring

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Katsunori Nagano
Sayaka Takeda Kindaichi

Date of Best practice sheet: March 2010

Literature

Katsunori Nagano
System assessment and field monitoring, Country report Japan Task 3, IEA HPP Annex 32, Sapporo, May 2008

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Field test of ground-coupled heat pump for cold climate region of Japan, First and Second demonstration project heat pump system in Low Energy Houses, University of Hokkaido, Japan Workshop IEA HP Conference 2008, Zurich, May 19, 2008, download at http://www.annex32.net

Sayaka Takeda Kindaichi et al.
Annual energy consumption of an actual low energy house in the cold region of Japan, University of Tokyo, Japan IEA HPP Annex 32 Workshop, Kyoto, Dec. 2007, download at http://www.annex32.net

Best practice

Economical heating and cooling systems for low energy houses

Ground-source heat pumps in affordable low energy houses in Oklahoma City, OK, USA

Central Oklahoma Habitat for Humanity®

Contribution of the USA national project

Summary

Hope Crossing, a Central Oklahoma Habitat for Humanity (COHFH) project, features 3-bedroom, 2-bath single-family brick homes at about $85,000 each. A collaborative team consisting of a local ground source heat pump manufacturer, electric utility, and COHFH decided to make Hope Crossing a showcase large-scale demonstration of affordable low energy housing.

Oklahoma City is considered to be a mixed-humid climate, with homes requiring significant heating, cooling, and dehumidification throughout the year. In typical single-story COHFH houses, either a central forced-air gas furnace coupled with a split-system AC or split-system central air-source heat pump system is used for heating and cooling. The Hope Crossing homes, however, were built with high-efficiency geothermal heating and cooling systems (GHP).

All energy loads within the Hope Crossing homes are met with electricity. Additionally, many of the homes have energy-efficient insulation and low-e windows. Some homes also have solar capabilities, equipped with solar PV panels on their roofs.

The geothermal heat pump yielded up to 50% reduction of consumed annual site energy, corresponding to a reduction of 36% annual energy cost, and respective CO_2-eq.-emission savings. With additional low energy house construction energy savings could be increased to max. 75%. Both geothermal heat pump and low energy house construction proved to be cost-effective. PV panels can effectively provide summer peak electricity, but are less cost-effective at current PV panel prices.

Building Data (Hope Crossing Low Energy GHP)

- Location: Oklahoma City, OK, Climate: Mixed-humid
- Single-family homes; 240 units
- Total floor area: 110m^2 (1250 ft^2)
- Heating load: 5.3 kW, Cooling load: 4.7 kW
- U-value wall: 0.35 W/(m^2·K), floor: 1.99 W/(m^2·K)






Background

Air-conditioning is considered mandatory in all new Oklahoma City homes, making air-based distribution systems the norm. Most new homes use either a central forced-air gas furnace coupled with a split-system AC, or a split-system central air-source heat pump and supplemental resistance heat. In low-cost single-story houses typical of the COHFH homes, the central duct system is usually located in the unconditioned attic, perhaps the worst possible location from an energy-efficiency standpoint.

Technical concept

The ground source heat pump manufacturer and the local installer agreed to install the GHP system for the same price as the standard gas furnace/AC combination. The GHP manufacturer donated the heat pump units. To reduce installation costs, they integrated the ground-loop pumping and purging valves into the heat pump to save on space, equipment cost, and field labor. They also drilled a single 120m heat exchange bore directly underneath the floor slab instead of employing the typical practice of drilling two 60m heat exchangers in the lawn, which would require a separate excavation step and pipe routing into the house. The electric utility funded the incremental costs for the building envelope, lighting, and appliance upgrades. Both parties shared costs for the two homes equipped with solar PV systems.

COHFH has constructed four types of homes: the “Standard Gas” home, considered to be the standard until the more energy efficient construction began. The second type incorporated a GHP system into the otherwise “standard” type of home, thus designated “Standard GHP.” Later, the envelope, lighting, and appliances were upgraded, leading to the “Low Energy GHP” home. Finally, some homes have been equipped with solar PV systems sized with a goal of being zero-peak, or nearly “off-grid” during the utility peak load period. These “Low Energy GHP + PV” homes should not require any grid electricity (on a net basis) to operate the GHP system over the year.

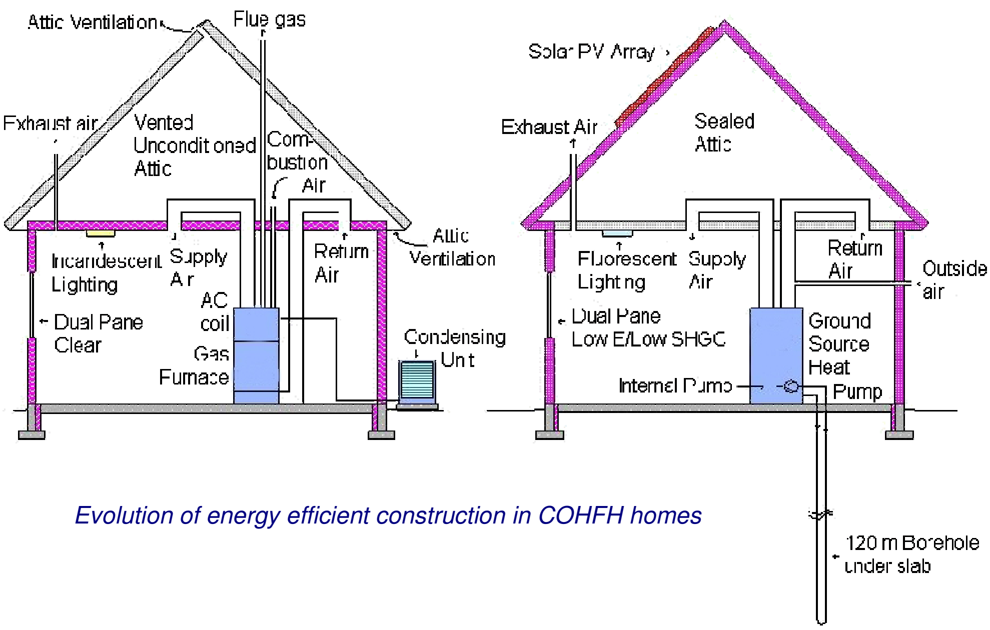
The figure below illustrates the major changes made to the homes in the progression from Standard Gas to Low Energy GHP + PV.

From bare slab with vertical bore GHX preinstalled. . .

to finished house, in 5 days!

State of market introduction

Geothermal (ground-source) heat pumps are one of the fastest growing applications of renewable energy in the world. Their main advantage is the use of normal ground or ground-water temperatures (between about 5 °C and 30 °C), which can be used all over the world. Annual growth in use is about 10%.



Evolution of energy efficient construction in COHFH homes

Technical data of the unit

Ground source heat pump

R410a refrigerant

Optional hot water generator with internal pump

Two-stage scroll compressor

Electronic variable speed fan motor

Cooling COP rating of 7.9 for Tranquility 27™ model

Five capacities: 7 – 21 kW

Extended range operation (-6.7 – 48.9°C EWT)

Flow rates as low as 0.027 l/s/kW

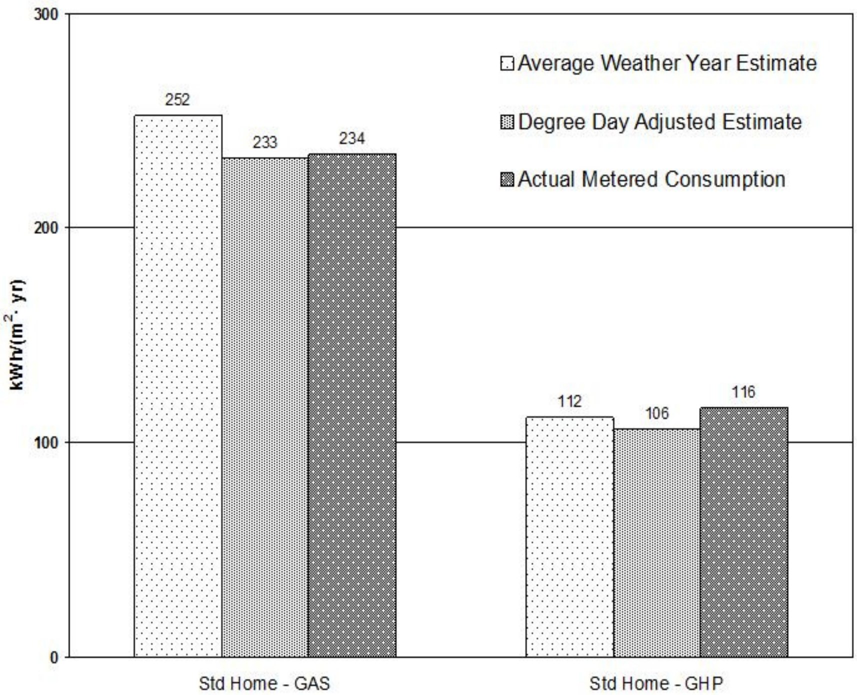
Field monitoring

Monthly energy consumption during 2007 was collected from utility meter data for 16 homes in a similar COHFH project (Spencer); 8 were standard gas type and 8 were standard GHP. For Spencer, the reduction in heating and cooling energy consumption of the GHP home type relative to the standard gas type was measured to be 66.3% and 48.8%, respectively.

For the GHP homes, all loads are met with electricity. For the standard gas homes using natural gas for heating, the water heater is also gas-fired, and estimates assumed that 75% of the ranges and 25% of the clothes dryers were also supplied by gas. (The remainder of the loads in the gas-heated homes is met with electricity.)

The figure below compares the estimated annual site energy use to average metered annual energy consumption during 2007 for the 16 Spencer project homes (~40% of gas home consumption was electric and the rest gas; GHP home consumption was all electric). The estimates are calculated using an average weather year for the locale. As can be seen, the estimated energy consumption for both home types is reasonably close to the actual consumption, deviating by less than 9% in the worst case after adjustment.

The above estimation procedure was used for the Hope Crossing project, to generate annual energy use estimates as part of the planning process in order to evaluate the benefits of GHP technology, low energy construction modifications, and integration of a grid-connected solar PV system. All typical end-use loads were considered in order to estimate the total energy consumption of the homes.



Estimated and metered total energy consumption

Tranquility 27™ Series geothermal heat pump

One of the heat pumps installed at Hope Crossing

Performance indicators

The Hope Crossing homes will also be LEED certified.

Many homes have energy-efficient insulation, low-e windows, and some have rooftop solar panels.

With all elements in place, including solar panels, energy consumption can be reduced by 75 percent.

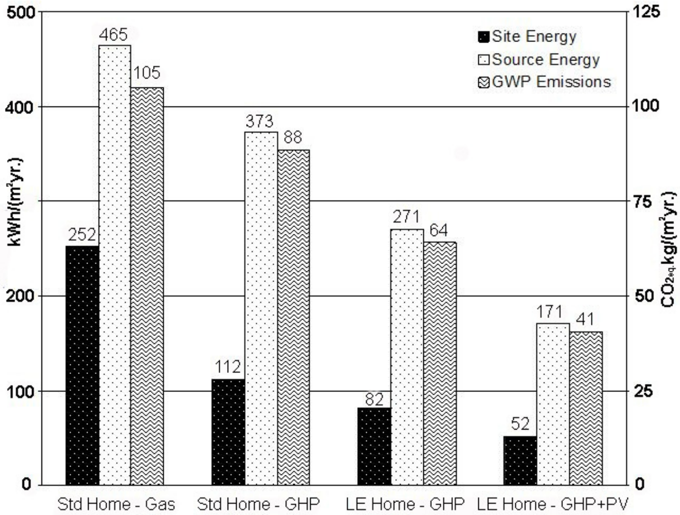
If more solar panels were used, the houses could function off the electrical grid.

System performance and optimisation

- The total site energy consumed by the typical new COHFH home can be reduced from 50-75% through the use of GHPs combined with low energy construction techniques
- Actual annual site energy savings of 50% were obtained using GHP systems in standard homes during the first phase of the project, which led to a 36% reduction in annual energy costs
- GHPs and low energy construction are both cost-effective, providing a return on investment in the 15% range, and both are generally available in the COHFH locale
- When the energy consumption of a home is brought to these low levels, relatively small solar PV systems can be incorporated that will nearly eliminate the summer peak load imposed on the electric utility, and that will provide all of the energy required to operate the GHP system
- By using a larger PV system, zero energy homes are feasible, but expensive
- As the energy consumption of the home is reduced, the appliance and plug load grows to nearly 50% of the total, creating a limit on further reductions

Economy, Ecology and Costs

The figure below shows a comparison of the total estimated site and source energy consumption and the associated carbon equivalent emissions, or global warming potential (GWP), for each COHFH house type. The 240 low energy GHP homes to be constructed in the Hope Crossing project will collectively save nearly 1,100 metric tons of CO_2 per year, or 22,000 metric tons over a nominal 20 year lifespan, compared to the standard gas homes that COHFH had been building. If all of the homes had the 2.3 kW solar PV option, another 12,000 metric tons could be saved over 20 years.
The GHP system and the low energy construction costs can provide a very favorable return on investment. The investment in solar PV is much more difficult to justify on energy cost savings alone. Providing financial benefits for the carbon emission reductions would improve the economics for all of these alternatives.
Note – CO_2-eq.-emissions based on US national average emissions factors for electricity and natural gas of 0.758 kg/kWh and 0.063 kg/MJ (0.227 kg/kWh), respectively.



Estimated total energy consumption and emissions

Imprint

Architecture and Design
Central Oklahoma Habitat for Humanity (COHFH)
Oklahoma City electric utility
ClimateMaster

Field monitoring
COHFH
Oklahoma City electric utility
ClimateMaster

Date of Best practice sheet: February 2010

Literature

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IEA HPC Newsletter, Volume 26, No. 3, 2008

Daniel Ellis
Field Experience with Ground-source Heat Pumps in Affordable Low Energy Housing
Presented at 9th IEA Heat Pump Conference, Zurich, May 2008, download at http://www.annex32.net/presentations.htm

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