

Design and integration of heat pumps for nearly Zero Energy Buildings



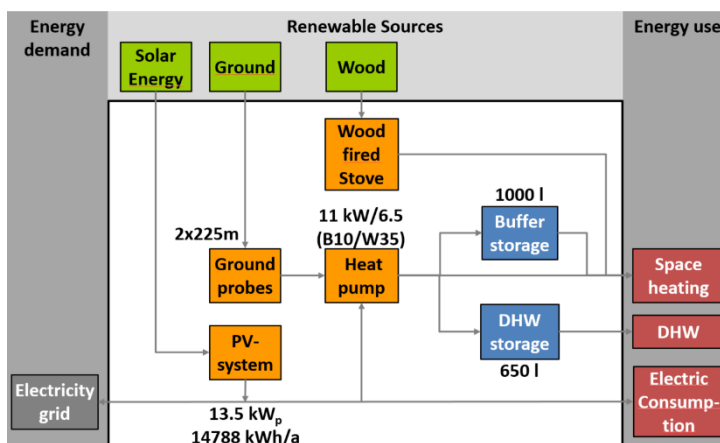
nZEB multi-family plus energy building Allmendholz 4 family building with low temperature lift heat pump in Horgen

Summary

The multi-family house has four apartments and is equipped with a geothermal heat pump with two boreholes of 225 m each for space heating and DHW production. Moreover, a 13 kW_p PV system is installed on the roof. The heat pump has a speed control by inverter and is optimised for low temperature lift. Additionally, wood stoves are placed in the apartments, which could deliver back-up heat in winter, but are not only used for heating reasons, but also to create a cosy atmosphere in the apartments. The heat pump shows high monthly performance factors up to 7, particularly in wintertime, which is due to the oversized geothermal probe, which is operated with water. Thereby, a plus energy balance is reached by the good PV yield of 1112 kWh/kW_p, but also due to the energy-conscious behaviour of the residents with 647 kWh/p electricity use.

The integrated monitoring system uses internal measurements of the heat pump and allows for an optimisation in operation of the control system. The following evaluation is based on data that is recorded by default which enables cost-effective monitoring.

Concept



Building Data

Location:	Horgen, Switzerland
Building Use:	residential, 4 flats
Energy ref. area	500 m ²
Walls (Wood)	0.18 W/(m ² K)
Roof	0.13 W/(m ² K)
Ground floor	0.12 W/(m ² K)
Windows	1 W/(m ² K)
	triple glazing
Space heating demand	40 kWh/(m ² a)

June 2020



International Energy Agency

Heat Pumping Technologies



Background

The apartment building was built in 2017 by the Allmendholz housing cooperative. The wooden element construction, mostly made of local wood, was built as a replacement for an older single-family house and thus yields an inner densification in the neighbourhood. In addition to ecological building technology, the residents have also committed to car-free living. The 4 apartments are inhabited by 8 persons.

Technical concept

The building technology was implemented according to the principle of "simple but efficient". A mechanical ventilation system was deliberately avoided, as the building is located in a quiet residential area. The heat pump system corresponds to the current standard, but with an optimized design. The two geothermal probes were drilled around 30% longer than required by SIA 384/6, with the aim of operating the probe at high temperatures in order to avoid use of antifreeze fluids. The capacity-controlled heat pump from BS2 was specially developed for systems with high source temperatures and low temperature lift. It has an integrated monitoring system, which simplifies the optimization of operations. Although not absolutely necessary with a capacity-controlled heat pump, a heating buffer storage is installed in this system. Reasons are on the one hand the low thermal mass of the wooden structure and the wall heating, and on the other hand it was intended to increase the self-consumption from the on-site generated PV-electricity.

The 13.3 kW_p solar PV system on the roof is optimised for high yield with a south-east orientation and 7° of inclination.

The hot water preparation is conventionally produced by the heat pump with an integrated DHW storage. For legionella protection, the storage tank is first heated up to 53 °C twice a week with the heat pump (operating limit of the heat pump at 60 °C, 7 K temperature difference of the internal heat exchanger in the storage), and then up to 60 °C with a direct electric back-up heating.

Additionally, each apartment has a small wood stove, which creates a cozy atmosphere in winter. The heat input from the wood stoves is taken into account in the evaluation using the estimated wood consumption.

Low temperature lift heat pump

The author of this report lives in the building himself and during his employment at BS2 AG managed the development of the low-lift heat pump and supported the building technology planning.

The heat pump is optimized for systems with high source and low sink temperatures. The complete system control, including solar circuit control for the geothermal probe regeneration (which is not required in this system) is integrated. In addition, all measured values can be read out and analyzed with the "BS2 Cockpit". Flow sensors are installed in both hydraulic circuits. These not only provide valuable information, but also protect the primary circuit from freezing if antifreeze is not used.

Design technical data

Heat pump

BS2 NHWP 6-20 (Inverter)

Heating capacity (COP)

B10/W35 (2500 RPM) 11 kW (6.5)

B10/W55 (3000 RPM) 12 kW (3.8)

Borehole heat exchanger

2x225m DN40 duplex

PV panels

PV area (SE, 7°) 74 m²

Nominal capacity electric 13.3 kW_p

Storages

Heating buffer storage 74 m²

DHW storage 13.3 kW_p

Back-up heating

Wood stove in the flat

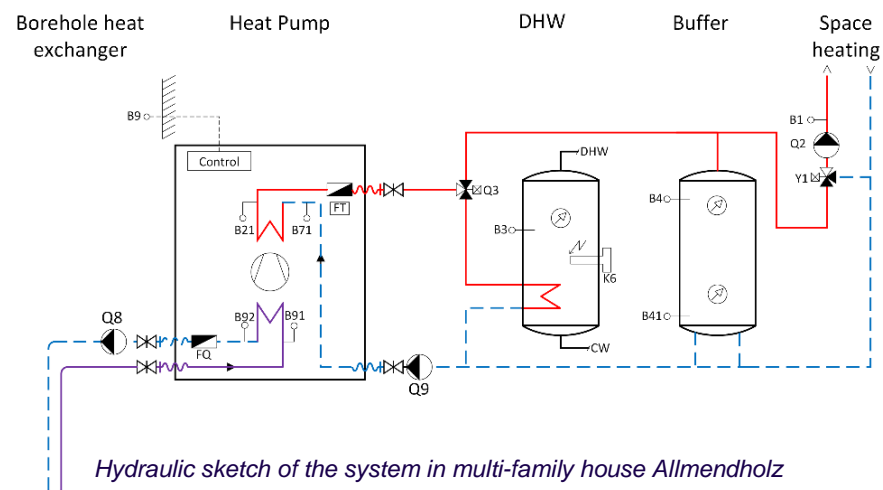
Heating Capacity 4x4 kW

Monitoring and "BS2 Cockpit"

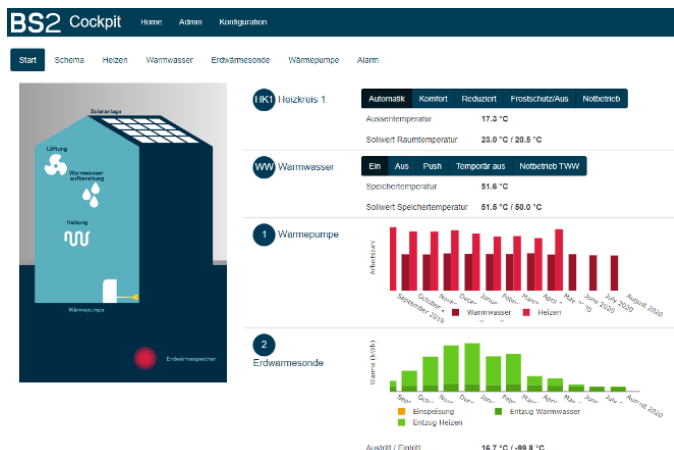
All data for evaluating the efficiency of the heat pump are collected by the heat pump controller. The integrated software "BS2 Cockpit" calculates the SPF on a monthly basis and allows to monitor many other relevant data in different time resolution (minutes or daily base) e.g. all measured temperatures, number of compressor starts, detailed energy values etc.

Combined with data from the solar inverter, thermal energy and water meter in the flats and electric energy meters, they allow detailed monitoring of the whole system. Twice a year the meters are read out. A combined excel tools calculates the service charge for each apartment and evaluates the system efficiency.

Actually, due of the high efficiency and the electric energy sold back to grid, the monthly energy costs are less than CHF 5 for each apartment.



Hydraulic sketch of the system in multi-family house Allmendholz



Interface of the BS2 cockpit energy monitoring system



Field Monitoring

With the exception of the electricity meter for the direct electric heating element, which was also installed as part of the SFOE project "Keeping hot water energy consumption under control" [1], it was possible to rely on existing measuring devices:

- Internally measured and calculated values from the heat pump
- Heat meters, hot and cold water meters in the individual apartments
- Electricity meter for the individual apartments
- PV inverter with Smart Meter

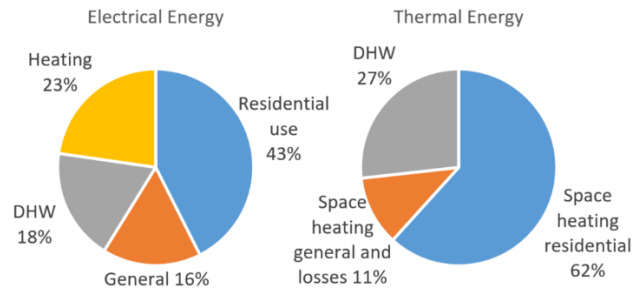
The energy monitoring is evaluated every six months by the recording of incidentals. The information on self-consumption is determined by the PV inverter and is based on 5 min values. The values were recorded for the entire building and not broken down to the individual apartments or building technology fractions.

The building was commissioned in November 2017 and the system settings were optimized in the first winter. The monitoring has been in operation since July 2018 and has been evaluated over 2 years. The illustrations refer to the first year of operation (July 2018 to June 2019), as this was the year with slightly lower outdoor temperatures. However, the numbers do not differ much in the two years, which confirms that the system is running stable.

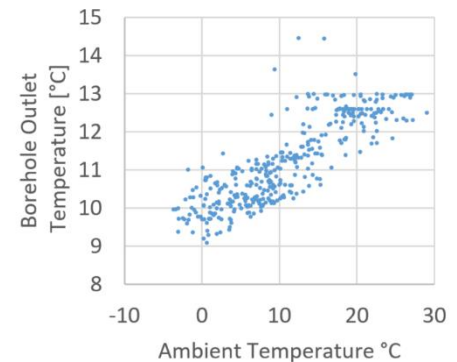
The heating demand is around 30 kWh/(m²a), of which about 20% or around 5 kWh/(m²a) are covered by the wood stove. 4 kWh/(m²a) of electricity are required for the heating provided by the heat pump, which corresponds to an SPF_{HP} in heating mode of 6.5 which is due to the high source temperature, which are mainly in the range of 10 – 14 °C and never decline below 9 °C even in wintertime. Despite the good building envelope U-values, the space heating demand is the dominating heat demand and the DHW fraction is only 27%, which is also due to a lower occupancy than of 62.5 m²/P compared 50 m²/P according to standard values or expressed as DHW demand 11.3 kWh/(m²a) vs. 19.8 kWh/(m²a) according to standard values. Due to higher temperatures in DHW operation, the SPF_w is with 3.5 significantly lower, but the overall SPF of 5 is still very high.

The electricity consumption of the entire building is 8732 kWh/a (including household electricity) corresponding to 1100 kWh/P or 17.5 kWh/(m²a), respectively. The PV yield is with 1112 kWh/kW_p very high and yields 29.6 kWh/(m²a) or slightly more than 50% surplus. The supply cover factor is 46% including the load management with the heat pump, i.e. almost 50% of the electricity requirement can be met directly from the roof.

Performance in Field monitoring		
Energy demand kWh/(m ² a)	Designed Benchmark	Measured
Space heating	40 D	30
DHW	19.8 B	11.3
Accommodation and general	35 B	10.3
Solar PV system		
PV yield (electric energy)	29.6	kWh/m ² a
Load cover factor	27	%
Supply cover factor	46	%
Seasonal performance factor		
SPF heat pump heating		6.3
SPF heat pump DHW		3.5
SPF overall		5

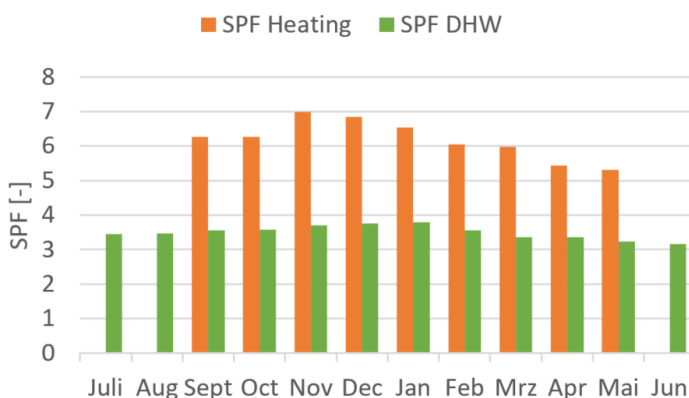


Thermal and electric energy fractions

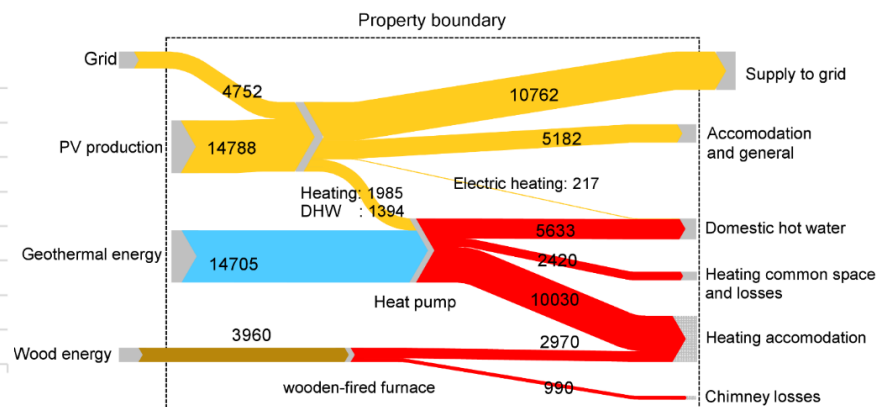


Borehole outlet temperature vs. outdoor air temperature

Weighting	Energy [kWh/(m ² a)]
Unweighted (annual balance)	-4.2 (Positive Energy Building)
Weighted acc. to Minergie-A®	5.5 (barely reached)
Weighted acc. to Muken 2014 (without considering PV)	18.3 (limit: 35)



Monthly performance factor of the heat pump for SH and DHW



Sankey diagram of the multi-family house Allmendholz



System evaluation and optimisation potential

The overall seasonal performance factor for heating and DHW (incl. electric heater) is 5. For space heating only, the system achieves an SPF of 6.3, which is an extremely good value. The high system efficiency is mainly due to the oversized geothermal probe as well as a consistent optimization in operation. The heat pumps proved to be slightly oversized. With an optimally design heat pump, the efficiency in heating operation could be increased by another 5-10%. The additionally installed wood stove in the flat would allow a rather small design of the heat pump since at highest heat loads in winter, the wood stove back-up could be operated.

The benefits of a heating buffer tank has been confirmed in this system. The main reason, however, is the oversized heat pump, which was done for two reasons:

- According to the heat load calculation, 10.5 kW, plus 2 kW for hot water preparation and some reserve due to the cut-out times of the electric utility, would be required. By the measurements, it was evaluated, that an output of approx. 8.5 kW would have been sufficient.
- The BS2 low-temperature lift heat pump has a peak output of 20 kW, which is still reasonably within the framework of the original dimensioning. This heat pump was chosen because the author of this report, who lives in the house himself, developed the device himself and thus has good opportunities for optimizing operations.

The operational experience has shown that the heat pump often runs at the minimum speed and starts to cycle quickly, even on cold days. Thanks to the large buffer storage, it was possible to increase the average running time from 55 minutes to 80 minutes by reducing the minimum speed. This results in approx. 1500 compressor starts per 2000 operating hours per year. It should be noted, however, that the control for increased self-consumption also increases the number of compressor starts. However, since the load management proved to have a limited effect, a much smaller design of the heat pump may even increase the SPF due to higher COP values in part load operation and would increase the life time of the heat pump due to reduced cycling. With this design, the heating buffer storage could be avoided and with smaller heat pump design, also system costs could be reduced.

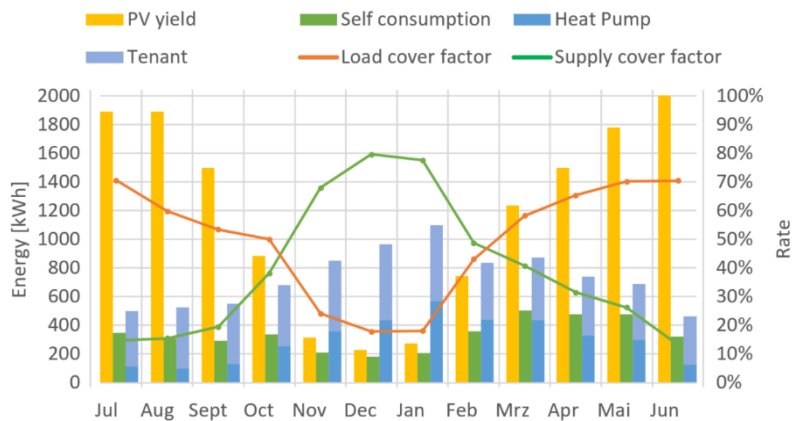
Increase of self-consumption

In the annual balance, the PV system generates 50% surplus electricity compared to the use in the building. Thanks to the self-consumption tenant can profit from the self-produced and cheap solar electricity.

It is remarkable that the monthly averaged SPF in the coldest months is higher than in transitional period. This is a consequence of the increased self-consumption. When there is power from solar PV system, the heating storage tank is charged up to 50 °C. Because of the high lift, the COP is reduced. This can be seen particularly in April and May. During space heating demand, the storage is hardly affected at night; if the storage was kept at the high temperature level, an unfavourable COP and increased storage losses resulted. To counteract this phenomena, in the second year the overcharge value is changed from time to time manually.

The hot water storage tank is charged in the afternoon by default. It is only charged at other times if there is enough solar PV yield. Since the heat pump already reaches the upper temperature limit in normal charging mode, overcharging, as with the heating storage tank, is not an option for the DHW storage.

Even though the self-consumption optimization by the buffer storage (over)charging could not be evaluated in detail, it is assumed, that the effect is relatively small [2]. Thus, probably a smaller design of the heat pump and entirely avoidance of the heating buffer storage could save investment cost and increase operation and performance of the heat pump.



Imprint

Building owner

Wohnbaugenossenschaft Allmendholz

Design

Architect: Haerle Hubacher, Zürich

HVAC: Fischer-Käser AG, Lotzwil / BS2 AG, Schlieren

General Contractor: Schär Holzbau

Field monitoring: Christoph Meier

Date of sheet: June 2020

Literature references

[1] W. Hässig, J. Staubli, C. Wemhöner. 2019

Managing DHW, Final report research project, Energieschweiz

[2] M. Cavegn. 2019

Betrieb von leistungsgeregelten Wärmepumpen, Semester project, HSR

Photos: Rita Palanikumar Fotografie / Haerle Hubacher / Christoph Meier