Design and integration of heat pumps for nearly Zero Energy Buildings

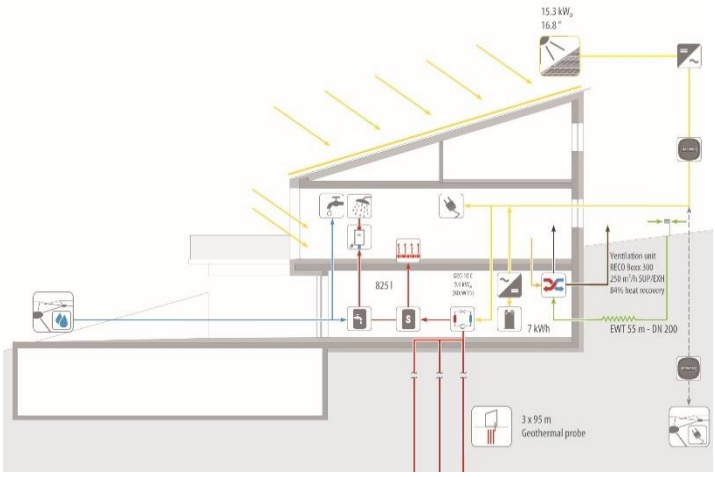
nZEB single family house

Berghalde, Germany

Summary

In 2010 in Leonberg-Warmbronn (Germany) finished one of the first residential buildings of a new type of building, which generates more energy than it consumes. It has been monitored for more than six years. The all electric building is equipped with a 10 kW_{th} ground-coupled heat pump and a 15.3 kW_p PV-system. Moreover, a mechanical ventilation system with 90% heat recovery is installed. The ground is used for free-cooling in summer operation, too. The " Efficiency House Plus" standard has been reached in all years of operation. The ground-coupled heat pump achieved an SPF up to 5.1 in space heating and domestic hot water (DHW) mode. Optimization to increase the share of self-consumed electricity with the aid of an adapted control of the heat pump led to an increase of electricity self-consumption from 18 to around 25 %. Due to an additional battery, the self-generated electricity use from the PV production could be increased.

Concept since 2012



Building Data

Location	Leonberg-Warmbronn, Germany
Building Use	single family house
Energy ref. area	260 m^2
Walls (brick/concrete)	0.15 W/(m^2K)
Roof	0.15 W/(m^2K)
Ground floor	0.3 W/(m^2K)
Windows	0.6 – 0.8 W/(m^2K)
	triple glazing, g=0.35 – 0.48
Space heating demand	50.1 kWh/(m^2a)
DHW demand	5.1 kWh/(m^2a)

May 2020

International Energy Agency
Heat Pumping Technologies

Background and current market state

The German Federal Ministry of Transport, Building and Urban Development coined the term “Efficiency House Plus”, and defines the standard by achieving a negative annual primary energy demand as well as a negative annual final energy demand. All further requirements and calculations named by the Energy Savings Act (EnEV), such as the protection against overheating in the summer have to be met.
The “Efficiency House Plus” principle was able to demonstrate its practical suitability as part of a research promotion program from 2011. A total of 37 buildings have been developed by various research institutions subjected to an intensive monitoring program.

Technical concept

The building was designed as a "power only house", which means that the sole source of energy to meet the useful energy demand is electricity. Energy sources include the public power grid, a fully roof PV system (15.3 kWp) and near-surface geothermal energy. A brine-water heat pump (10 kW_{th}) with three vertical boreholes (3 x 95 m) serve for heating and hot water preparation. For the energy storage the thermally effective building masses, a buffer storage (water, 825 l) and several electrical storages (7 and 20 kWh) are used. The heat is distributed in the house over the floor heating, only the two bathrooms have additionally radiators installed. In the summer months cooling can be enabled by the floor, in which the water from the borehole heat exchanger and the pipe network is circulated (free cooling). Flow heaters are installed additionally at the tapping points for decentralized reheating.
The entire building is ventilated through the windows. During the heating season and in midsummer, the mechanical ventilation system with heat recovery is switched on and supplies the living areas with fresh outdoor air. A ground heat exchanger additionally preconditions the outside air.

Technical data of the unit

Heat pump

Stiebel Eltron WPF 10E	
Heating capacity/COP	9,6 kW/4.6
Geothermal heat exchanger	3x 95 m

Solar PV system

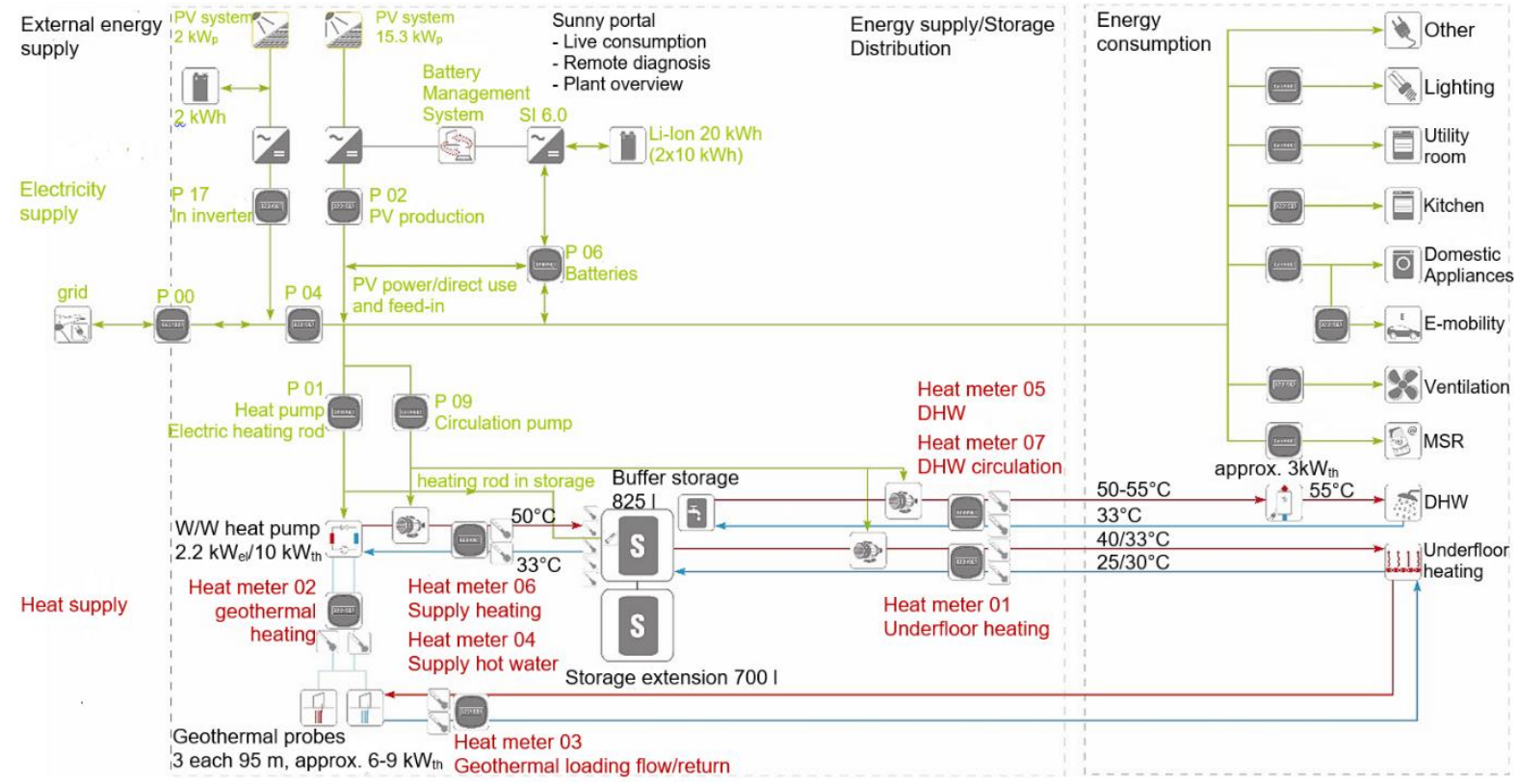
90 modules on the south-facing roof	
Total PV area:	120 m^2
Peak power:	15,3 kW
Electrical efficiency	13.5 %

Storages

Heating buffer storage	825 l
Battery	2 x 10 kWh Li-Ion

Ventilation systems

Max. volume flow rate	250 m^3/h
Heat recovery	90 %



Measurement concept

Field monitoring results

The objectives of the field monitoring are the evaluation of the "Efficiency House Plus" requirements. As further aspect the proportions of heat generation (heat pump), heat distribution (buffer storage / distribution) and heat transfer (heating and domestic hot water) are investigated in terms energy efficiency requirement by the EnEV. In this context, also the use of battery storage is of interest as a way to increase self generated electricity use from the PV production.

The monitoring period lasts from 2014 to 2019. During the summer months, the heat pump is used exclusively for hot water with short operating times, but at a relatively high temperature level, resulting in a monthly seasonal performance factor of 4.5. During the heating season the monthly performance factor rose up to 6.0. The annual performance factor ranged from 4.7 to 5.1 in the past four years.

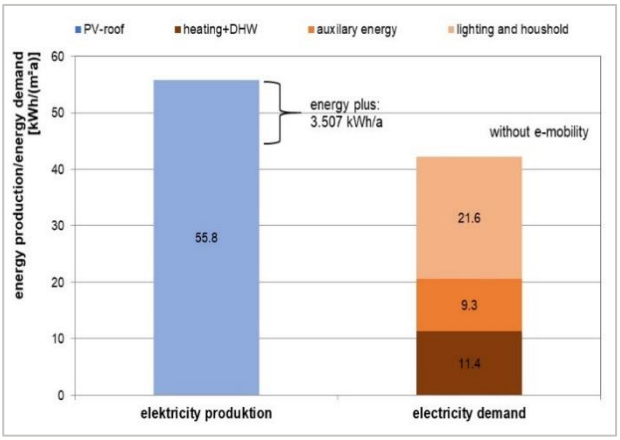
The total annual electricity consumption is about 30.6 kWh/(m²a) (7,970 kWh/a) The heat pump accounts for approx. 38 %, household for approx. 62 % of the annual energy consumption. The area-related electricity consumption in the operating years ranges from 27 to 34 kWh/(m²a). Between 7,200 and 8,900 kWh/a of electricity are consumed.

The annual heating energy consumption (heating, DHW) is about 50 kWh/(m²a) (1,290 kWh/a) The room heating accounts for approx. 85 %, DHW, storage and distribution losses for approx. 15 % of the annual energy consumption. The area-related heating energy consumption in the operating years ranges from 41 to 58 kWh/(m²a). Between 10,700 and 15,100 kWh/a of heat is generated.

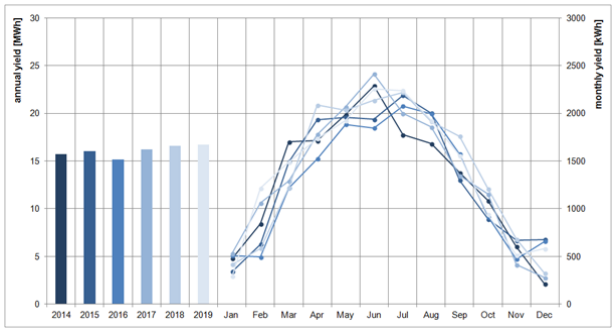
Compared to the calculated electricity yield of 14,500 kWh/a from the PV system, approx. 16,000 kWh/a were delivered. In the last six years of operation, the PV system has delivered around 96 MWh of solar power in total. This results in a mean installed capacity of approx. 1,070 kWh/kWp. The "Efficiency House Plus" requirements could be already reached in the years with a final energy balance of – 19.0 kWh/(m²a), i.e. a PV surplus of 19.0 kWh/(m²a) regarding the consumption of the building technology. The primary energy balance obtains a surplus of 77.5 kWh/(m²a).

Performance in Field monitoring

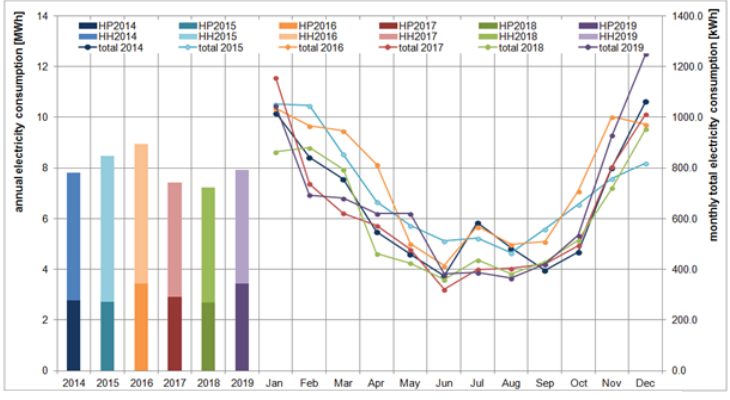
Seasonal performance factors	
SPF heat pump (boundary COP)	**5.1 (4.4)**
Solar PV yield	
Solar PV system	**16,000 kWh (1,070 $kWh_{el.}/kW_p$)**
nZEB balance (acc. "Efficiency House Plus")	
final energy	**- 19.0 kWh/(m²a)**
primary energy	**- 77.5 kWh/(m²a)**
Temporal characteristic (annual on 2 min step basis)	
Demand cover factor (self-consumption)	**41 %**
Supply cover factor (self-generation)	**33 %**



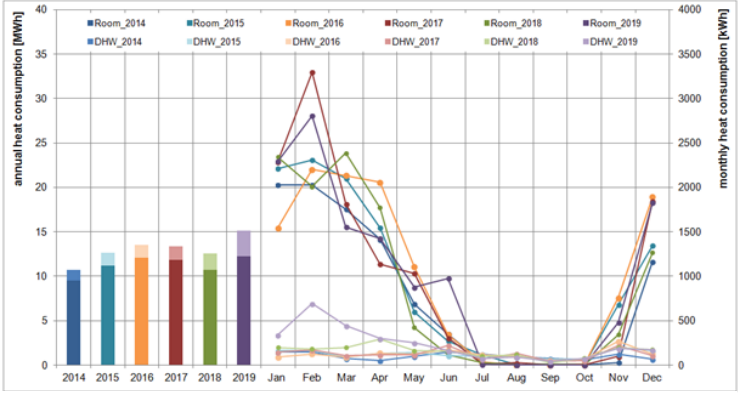
Calculated annual comparison of the consumption and production



Electric yield of the solar PV system, 2014 - 2019



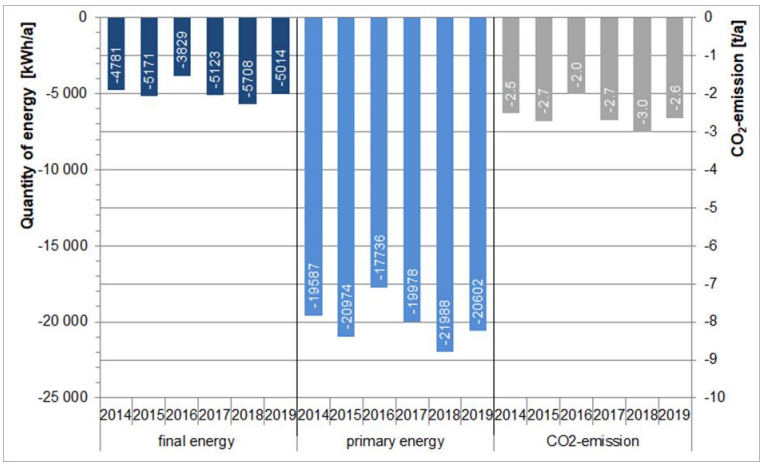
Annual and monthly electricity consumption, 2014 - 2019



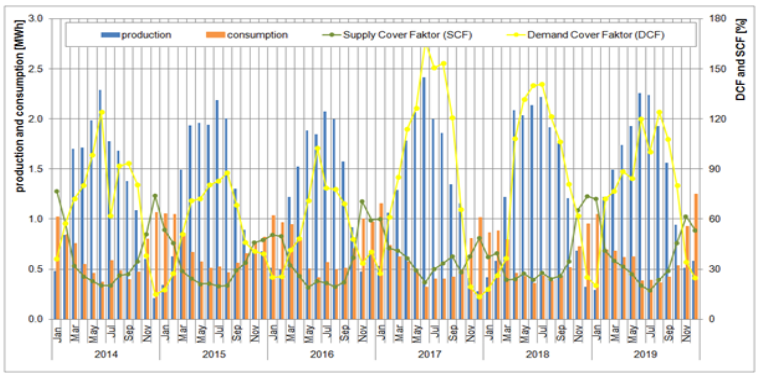
Annual and monthly heat consumption, 2014 -2019

System performance and optimization

The overall system performance of the system is with 4.9 in a good range for ground-source heat pumps.
Various measures were taken to increase the share of self-generated household electricity with the help of adapted control of the heat pump. Doubling the minimum downtime of the heat pump from 10 min. to 20 min. and increasing the hysteresis of the hot water supply from 2 K to 4 K to avoid overclocking of the heat pump in addition to an optimization of the heating curve and limiting heating temperature while maintaining user comfort led to an increase of the proportion of self-generated electricity from 18 % to around 25 %.
To increase the use of self-generated electricity, in December 2011, in addition to the existing battery with 7 kWh, another lead gel battery with a storage capacity of 20 kWh and max. 8 kW withdrawal power is integrated. Since June 2013, the added accumulator can no longer be accessed and thus no longer serves as an electrical storage. The proportion of self-generated electricity used from the PV production increased from 28 % in 2011 to 55 % in 2012 with the additional battery. Since the spring of 2018, initially a 10 kWh Li-ion battery and from autumn 2018 a second 10 kWh Li-ion battery entered into operation. As a result, the proportion of solar cover and the share of self-generated electricity used will increase significantly in comparison to recent years.



Final energy, primary energy and CO_2-emission, 2014 - 2019



Demand / supply cover factor for the boundary building technology

Ecology and self-consumption

The average annual electricity surplus is about 6,000 kWh/a (about 54% of the electricity consumption). Over the period under consideration, about 33 % of solar power was used in the house itself, the vast majority being fed into the public grid. The solar coverage ratio varies between 32 % and 49 % over the years, reaching an average of 41 % over the six years.

Imprint

Building owner
Univ. Prof. Dr. M. Norbert Fisch and Karin Fisch

Design
Berschneider + Berschneider,
Pilsach bei Neumarkt i.d. OPf.

Field monitoring
TU Braunschweig
IGS Institut für Gebäude- und Solartechnik

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Literature references

[01] Bockelmann, Fisch, Spika, Wilken: „Netto-Plusenergie-Gebäude mit Stromlastmanagement und Elektro-Mobilität“, Final report, Forschungsinitiative Zukunft Bau des Bundesinstitutes für Bau-, Stadt- und Raumforschung (Aktenzeichen: SF-10.08.18.7-11.32). TU Braunschweig Institut für Gebäude- und Solartechnik, 2013

[02] Bockelmann, Fisch, Kley, Wilken: „Betriebsstrategien für EnergiePLUS-Gebäude am Beispiel der Berghalde“, Final report, Forschungsinitiative (Aktenzeichen: SWD–10.08.18.7-13.33). TU Braunschweig Institut für Gebäude- und Solartechnik, 2015

[03] Bockelmann, Fisch: „Dezentrale, modulare Stromspeicher zur Eigenstromsteigerung in EffizienzhausPLUS Gebäuden“, Final report, Forschungsinitiative Zukunft Bau des Bundesinstitutes für Bau-, Stadt- und Raumforschung (Aktenzeichen: SWD–10.08.18.7-16.34). TU Braunschweig Institut für Gebäude- und Solartechnik, 2019

IEA HPT Annex 49

IEA HPT Annex 49 is a corporate research project on heat pump design and integration in nearly Zero Energy Buildings.
The project is accomplished in the Heat Pump Technologies (HPT) Technology Collaboration Programme (TCP) of the International Energy Agency (IEA).
Internet: http://www.heatpumpingtechnologies.org/annex49