

Design and integration of heat pumps for nearly Zero Energy Buildings



Steinbeis-Innovationszentrum energie+

Supported by:



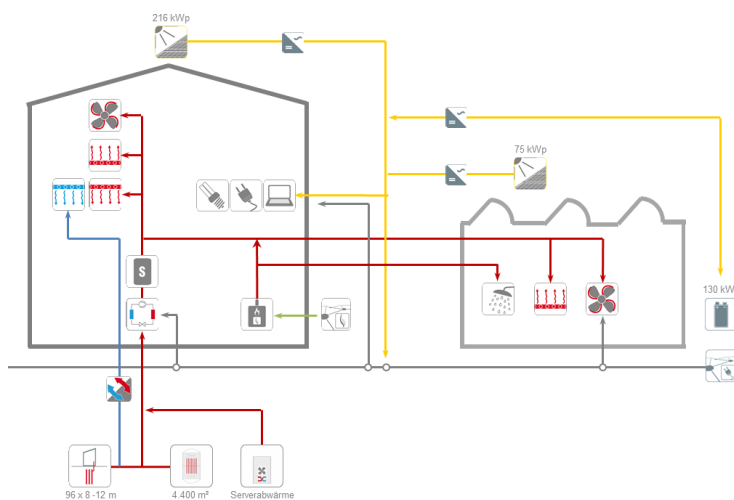
on the basis of a decision by the German Bundestag

nZEB with non residential use - school Willibald-Gluck-Gymnasium, Germany

Summary

In the town of Neumarkt, the Neumarkt district administration built in 2015 the new four-storey Willibald-Gluck-Gymnasium with gym for about 1,400 pupils. The energy concept includes regenerative energy generation via ground-coupled heat pumps (energy piles and agrothermal field) and a PV system on the roof of the gym and school (291 kWp) in combination with an electrical storage (130 kWh). All classrooms are ventilated both mechanically (85% heat recovery) and through the windows in a hybrid manner in order to ensure the indoor air quality. Night ventilation via the ventilation systems supports the cooling of the school during the summer months. Over the measurement period, very good seasonal performance factors of 4.7 to 5.2 were recorded. Approx. 59% of the solar power in the building itself was used. The solar coverage share of electricity consumption is around 47 % over the years. During the monitoring period, various optimizations were implemented in order to improve system performance and energy efficiency.

Concept



Building Data

| | |
|------------------|--|
| Location: | Neumarkt (i.d.Opf.), Germany |
| Building Use: | school with gym |
| Energy ref. area | 14,400 m ² |
| Walls | 0.15 – 0.17 W/(m ² K) |
| Roof | 0.14 – 0.15 W/(m ² K) |
| Ground floor | 0.08 – 0.09 W/(m ² K) |
| Windows | 0.7 – 0.9 W/(m ² K), g = 0.28 – 0.5 |
| heating demand: | 25 kWh/(m ² a) |
| DHW demand | 6.5 kWh/(m ² a) |

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

In addition to regenerative energy generation via ground-coupled heat pumps and a PV system on the roof of the gym and school (290 kWp), a Valadium Redox Flow (VRF) battery system forms the basis for the energy concept. The soil is accessed as a heat source and sink as well as thermal storage via activated energy piles (foundation piles) and a surface collector (agrothermal field) under the sports field. The peak load (30%) of the heating energy requirement is covered by a gas condensing boiler. The ground-coupled electric heat pumps generate the required heat for floor heating and concrete core activation as well as ventilation systems in the school building and for the floor heating installed in the gym and the radiators in the adjoining rooms. Cooling of the classrooms and IT/electrical rooms during summer is "passive" (pure circulation pump operation). All classrooms are ventilated both mechanically and through the windows in a hybrid manner. Heat recovery (approx. 85 %) is integrated to reduce ventilation heat losses, as is adiabatic exhaust air humidification for cooling in summer.

Through the integration of the VRF battery with a usable capacity of 130 kWh, the planning envisages that around 65 % of the solar yield can be used locally, while only 35 % is fed into the public electricity grid and thus lead to a solar coverage share of approx. 40 % of the total electricity requirement.

Technical data of the unit

Heat pump

Viessmann Vitocal 300

Heating capacity/COP max. 85,6 kWth

Agrothermal field 4,400 m²

Energy piles 96 piles

Solar PV system

~ 1,500 modules on the roof

Total PV area: ~1,600 m²

Peak power: 291 kWp

Roof school 216 kWp

Roof gym 75 kWp

Electrical efficiency 20.4 %

Storages

Valadium Redox Flow (VRF) 130 kWh

Ventilation systems

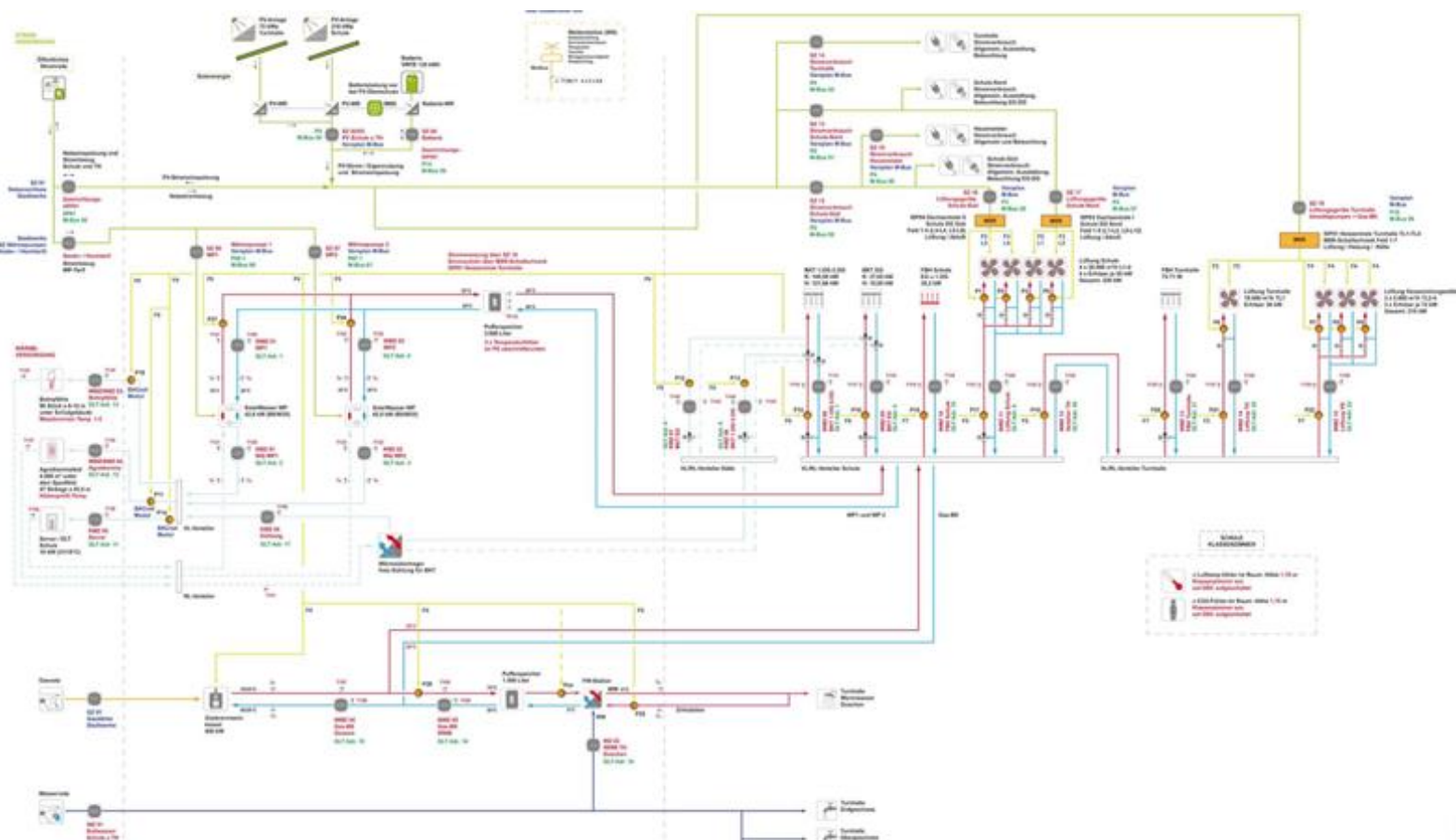
Max Volume flow rate 4x 20,000 m³/h

(school), 10,000 m³/h

(gym) and 3 x 5,000 m³/h

(meeting place)

Heat recovery 85 %



Measurement concept

Field monitoring results

The balance sheet annual energy production determined from measured data exceeds the planned values in the four operating years (2016 to 2019). Compared to the calculated electricity yield of around 243 MWh/a from the PV system, more than 275 MWh/a were delivered, i.e. around 13 % more than assumed in the planning. In the four operating years, the PV system delivered an average annual electricity yield of approx. 275 MWh/a and related to the installed capacity of approx. 975 kWh/kW_p (planning 919 kWh/kW_p).

The annual electricity balance broken down by heat pump and household (all other electricity consumption). By far the largest electricity consumer in the building is the general and user electricity for the school and gym with approx. 60 % of the total electricity consumption. Building conditioning (heating, cooling, ventilation) accounts for around 36 % of electricity consumption. The total annual electricity consumption is about 26.4 kWh/(m²a) (380 MWh/a) The heat pump accounts for approx. 10 %, individual consumption for approx. 90 % of the annual energy consumption.

The annual heating energy consumption (heating, DHW) is about 20.2 kWh/(m²a) (290.7 MWh/a). The room heating accounts for approx. 92 %, DHW, storage and distribution losses for approx. 8 % of the annual energy consumption. The area-related heating energy consumption in the operating years of 2016 to 2019 ranges from 18 to 22 kWh/(m²a). Between 270 and 320 MWh/a of heat is generated. Therefore, the share for domestic hot water production (1.65 kWh/(m²a)) is well lower than required by planning.

The monthly performance factors of the two heat pumps (excluding circulation pumps) for 2017 to 2019 are between 4.2 and 7.3. The annual performance factors are between 4.7 and 5.2 for the heat pumps. No SPF is recorded in the summer months, as the heat pumps are not in operation here and the building is conditioned via passive cooling.

From 2017 to 2019, a primary energy deficit of ~ 150 MWh/a was achieved. With regards to the final energy deficit, values between 135 MWh/a and 231 MWh/a could be generated.

For CO₂ emissions, CO₂ equivalents of 527 g/kWh are used for both electricity savings and grid purchases. This results in CO₂ deficit of 51 t/a.

Performance in Field monitoring

Seasonal performance factors

SPF heat pump (boundary COP) 5.4 (4.6)

Solar PV yield

Solar PV System 275,000 kWh (975 kWh_{el}/kW_p)

nZEB balance (acc. "Efficiency House Plus")

final energy + 15.0 kWh/(m²a)

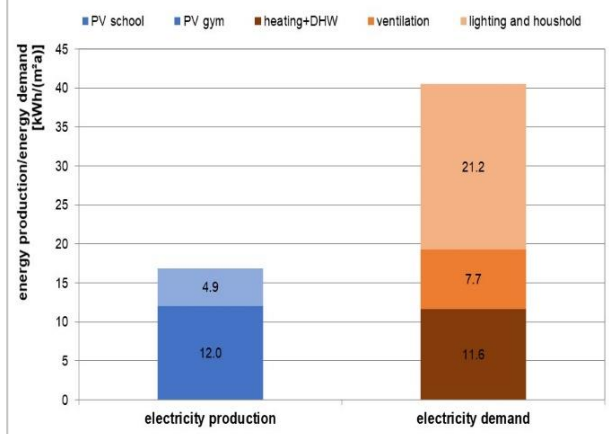
primary energy + 14.0 kWh/(m²a)

Temporal characteristic

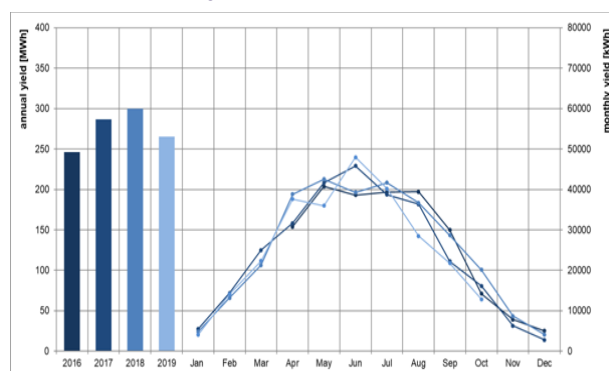
(annual on 15 min step basis)

Demand cover factor (self-consumption) 47 %

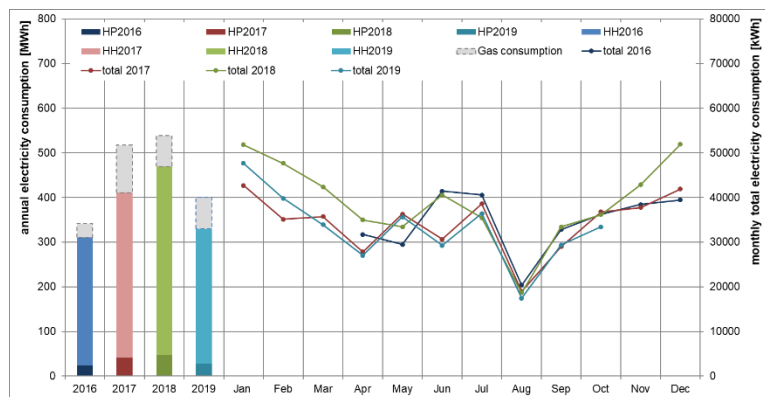
Supply cover factor (self-generation) 59 %



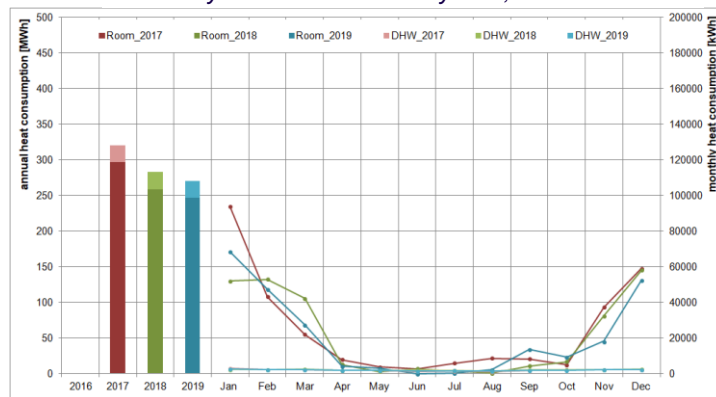
Calculated annual Comparison of the consumption and production planning



Electric yield of the solar PV system, 2016 - 2019



Annual and monthly electricity consumption, 2016 - 2019



Annual and monthly heat consumption, 2016 - 2019



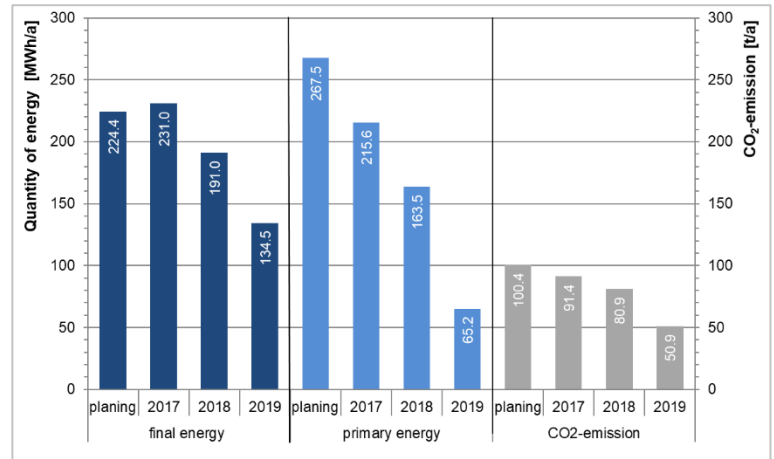
System performance and optimization

The following points could be recorded and optimized by the monitoring implemented since the plant was in operation and the continuous evaluation of the measurement data:

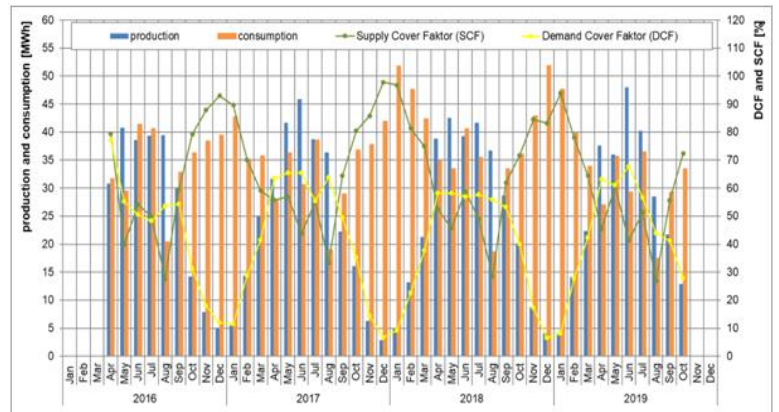
- In order to further improve the release of the adiabatic cooling, the supply air temperatures, the switchover between summer/winter operation and the control of the night ventilation were adapted to the actual room utilization and presence of the pupils.
- Settings and adjustments of the mass flow of the heating circuit to reach the target flow temperature.
- Missing shut-off valve in the flow distributor to the buffer storage.
- Based on the recorded brine inlet and outlet temperatures, adjustments have been made to the control strategies of both sources since the commissioning of the geothermal low-temperature sources and their heat exchangers. The year-round parallel operation was replaced by a previously manual adjustment via a priority distribution (activation / deactivation of one source). The switchover is based on the higher brine outlet temperatures per source system. During the heating period, the heat pumps primarily use the energy piles (higher brine temperature level). A reverse priority is planned for the cooling period. The agrothermal field acts primarily and then the energy piles are controlled in order, among other things, to ensure regeneration of the energy piles. An automatic switching of the sources depending on the brine temperatures is still to be implemented.

Ecology and self-consumption

Over the period under consideration, approx. 59% of the solar power in the building itself was used, the remaining part was fed into the public power grid. The solar coverage share of electricity consumption is around 47 % over the years. On a monthly basis, the SCF ranges from 27% to 98 % and the DCF from 7 % to 77 %.



Final energy, primary energy and CO₂-emission, 2016 - 2019



Demand/supply cover factor of first year for the boundary building technology

Imprint

Building owner
City of Neumarkt

Design
Berschneider + Berschneider
Architekten BDA + Innenarchitekten

Field monitoring
TU Braunschweig
Institut für Gebäude- und Solartechnik

The financial support of the BMWi for the field monitoring in highly acknowledged

Literature references

Kley, Bockelmann, Fisch, Hauck: „EnOB: Monitoring und Betriebsoptimierung des Willibald-Gluck-Gymnasiums in Neumarkt (i.d.OPf.)“, Final report, Bundesministerium für Wirtschaft und Energie (Aktenzeichen: 03ET1308 A / B). TU Braunschweig Institut für Gebäude- und Solartechnik, 2020

