Design and integration of heat pumps for nearly Zero Energy Buildings

Case Study IEA HPT Annex 49

Technische Universität Braunschweig · IGS · Steinbeis-Innovationszentrum energie+ · Federal Ministry for the Environment, Nature Conservation and Nuclear Safety · Federal Institute for Research on Building, Urban Affairs and Spatial Development · Forschungsinitiative Zukunft Bau

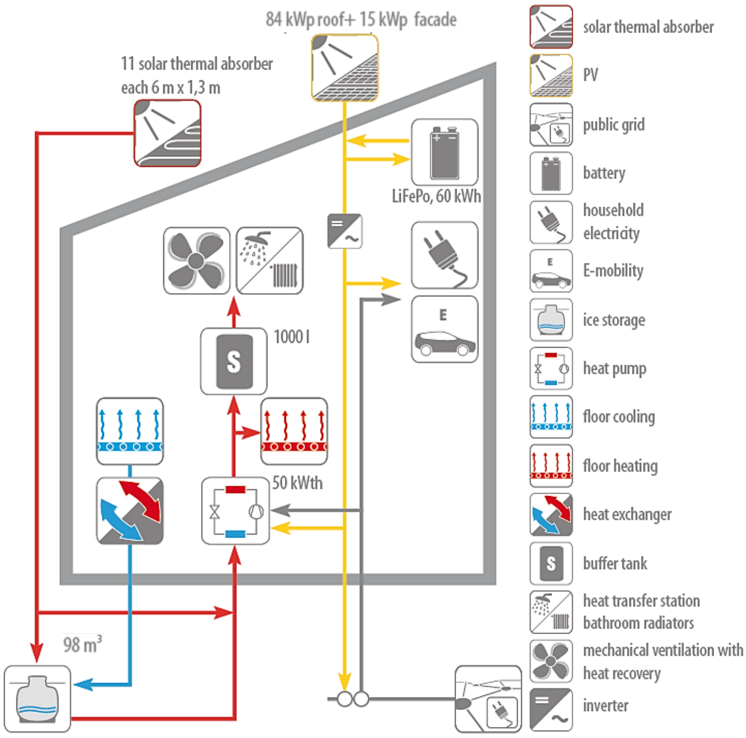
nZEB multi-familiy house

Riedberg, Germany

Summary

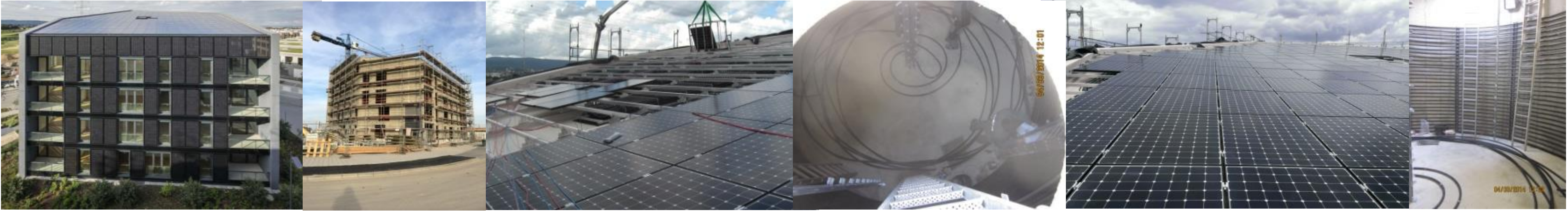
In August of 2015 the five-storey multi-family residential building (17 apartments) was commissioned. The all electric building is equipped with a 50 kW_{th} electric brine-water heat pump that uses a total of 85 m^2 of solar absorber in addition to an ice storage as heat source. 84 kW_p PV modules are installed on the roof and 15 kW_p in the façade to provide an annual surplus of electricity for the plus energy balance. Moreover, a mechanical ventilation system with 84% heat recovery is installed. The "Efficiency House Plus" standard has not been reached in the years of operation due to an increased consumption of heating energy as well as increased distribution losses compared to the planning. The heat pump only achieved SPF-values of 1.7–2.6 due to excessively high return temperatures. System optimization included the integration of an additional buffer tank as a hydraulic diverter and adjusting the setpoint for switching between solar absorbers and ice storage and support to the heat supply by electric instantaneous water heaters.

Concept



Building Data

Location:	Frankfurt a. M., Germany
Building Use:	multi-family house
Energy ref. area	1,600 m^2
Walls	0.12 $W/(m^2K)$
Roof	0.13 $W/(m^2K)$
Ground floor	0.12 $W/(m^2K)$
Windows	0.8 $W/(m^2K)$, g = 0,53
heating demand:	8.24 $kWh/(m^2a)$
DHW demand	10.63 $kWh/(m^2a)$



Background and current market state

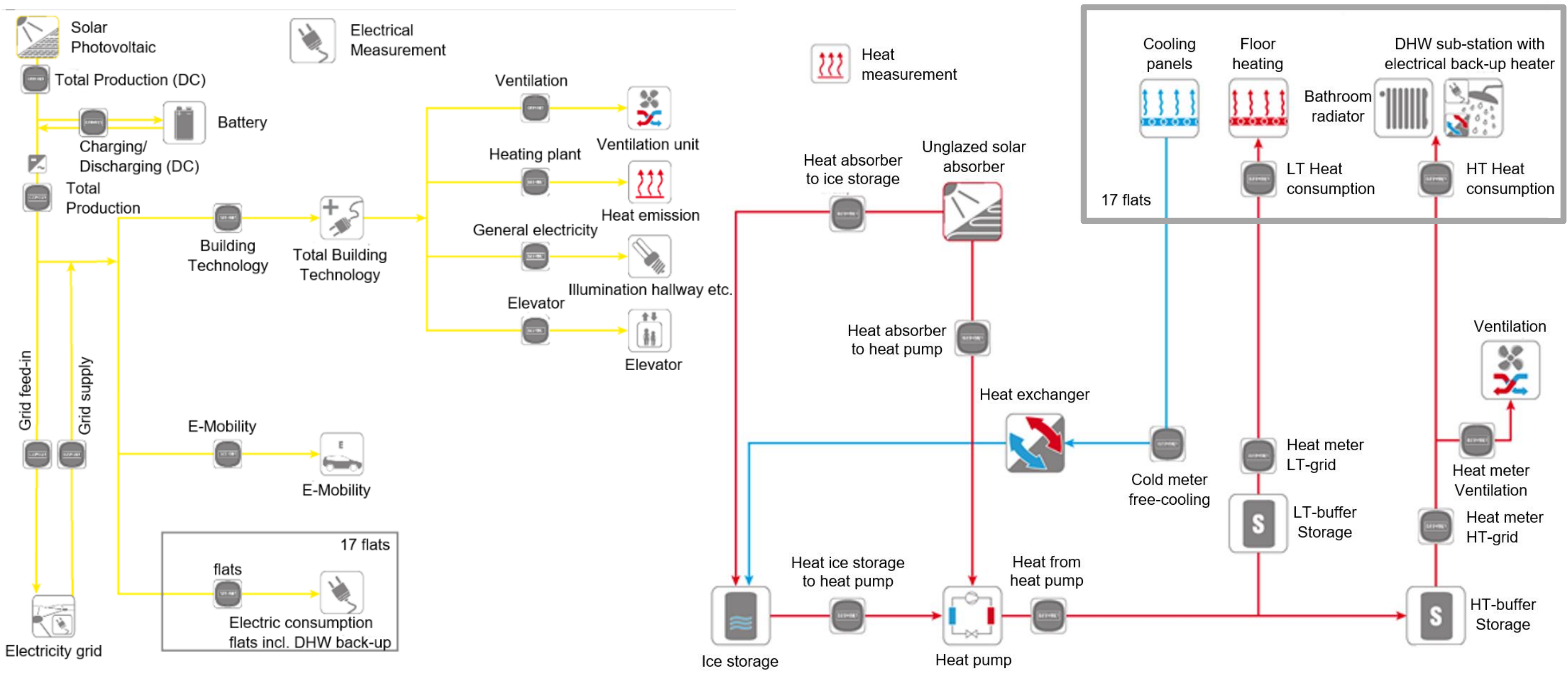
The German Federal Ministry of Transport, Building and Urban Development created the term “Efficiency House Plus”, and defines the standard by achieving a negative annual primary energy demand as well as a negative annual final energy demand. All further requirements and calculations named by the Energy Savings Act (EnEV), such as the protection against overheating in the summer have to be met, as well.
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 and subject of intensive monitoring.

Technical concept

A photovoltaic system with an installed capacity of 99 kW_p (84 + 15 kW_p) was installed on the roof and the south façade. The PV surplus can be used to charge a lithium-iron phosphate battery with a nominal capacity of 60 kWh. The coverage of the additional electricity demand for household and technical equipment is guaranteed by a connection to the public grid.
The use of solar energy is supplemented by a solar thermal system in form of solar air absorbers with an area of 85 m², which is installed under the PV modules. The provision of heat for the low-temperature floor heating system and hot water preparation (apartment transfer stations per apartment) is carried out by a brine-to-water heat pump. An ice storage of 98 m³ and the solar air absorber on the roof serve as the heat source. Depending on the temperature level and availability, the heat source is the solar thermal absorber on the roof or alternatively the ice storage tank. The regeneration of the ice storage takes place by the absorber and free cooling in the summer.
There are two networks for the heat distribution in the building, a low-temperature net for the floor heating and a high-temperature net with a storage tank of 1,000 l. The high temperature net supplies the domestic hot water preheaters in the apartment transfer stations, the bathroom radiators and the heating register of the ventilation system.
Occurring ventilation heat losses in winter are reduced by a central mechanical ventilation system with heat recovery and the living comfort is to be increased by the system. The possibility of natural ventilation is always available.

Technical data of the unit

Heat pump	
Simaka Simatron WP50	
Heating capacity/COP	**50 kW/4.5**
Ice storage	**98 m³**
Solar absorber	**85 m²**
Solar PV system	
Modules roof and façade integrated	
Total PV area:	**553 m²**
Peak power:	
Roof	**84 kW_p**
Façade	**15 kW_p**
Electrical efficiency	**20.1 %**
Storages	
Heating buffer storage	**1,000 l**
Battery	**60 kWh**
Ventilation systems	
Max volume flow rate	**1600 m³/h**
Heat recovery	**84%**



Measurement concepts for electricity (left) and heating (right)

Field monitoring results

The operating years 2016 to 2019 show a significantly higher electricity consumption compared to planning values. The reason for the higher energy consumption is not only the higher user consumption, but also the building services components.

The total annual electricity consumption is about 50.6 kWh/(m²a) (122,200 kWh/a). The heat pump accounts for approx. 36%, household for approx. 64% of the annual energy consumption.

The annual heating energy consumption (heating, DHW) is about 63.4 kWh/(m²a) (153,300 kWh/a). The room heating accounts for approx. 69%, DHW, storage and distribution losses for approx. 31% of the annual energy consumption. The area-related heating energy consumption in the operating years of 2016 to 2019 ranges from 60 to 65 kWh/(m²a). Between 145 and 158 MWh/a of heat is generated.

Therefore, the share for domestic hot water production (20.6 kWh/(m²a)) is well higher than the energy efficiency requirement of 12.5 kWh/(m^2_{NGF}a) required by the EnEV.

The balanced annual energy yield calculated from the measured data exceeds the planning values. Compared to the calculated electricity yield of 86,400 kWh/a from the PV system, approx. 99,500 kWh/a were delivered, around 15 % more than assumed in the planning. In the last four years of operation, the PV system has delivered around 386 MWh of solar energy in total. This results in a mean specific yield of approx. 975 kWh/kW$_p$.

Due to the increased consumption, the goals of the Efficiency House Plus standard could not be met, so that no balanced avoidance of final and primary energy as well as CO_2 emissions could be achieved. From 2016 to 2019, a primary energy deficit of ~ 12.7 MWh/a was calculated in the first years. 2018 and 2019 a primary energy surplus of 12 MWh/a was reached due to asymmetric weighting factors, since there was a final energy deficit, but values between 21.2 MWh/a and 29.0 MWh/a could be generated. Regarding CO_2 emissions, CO_2 equivalents of 527 g/kWh are used for both electricity savings and grid purchases. This results in a CO_2 deficit of 11 to 15 t/a.

The faulty implementation is reflected firstly by the solar absorber, since flows were not completely guaranteed and heat generated was not available to the calculated extent. Furthermore, there were problems during the four years of operation with regard to ventilation and hydraulics. Excessively high return temperatures resulted in unfavorable heat pump cycles, resulting in suboptimal temperature levels around the condenser, with monthly performance factors of only 1.7 – 2.6.

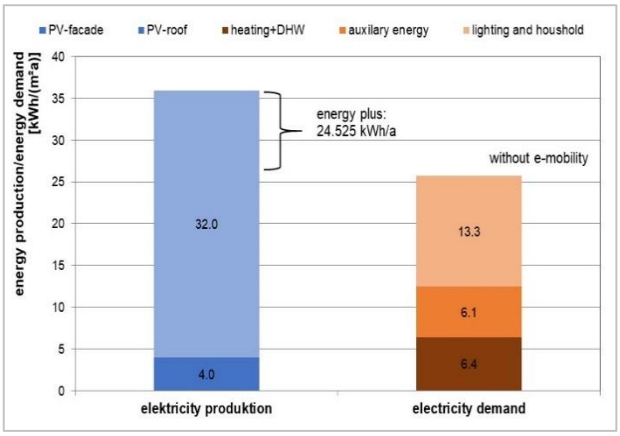
Performance in Field monitoring

Seasonal performance factors	
SPF heat pump (boundary COP)	2.2 (4.5)

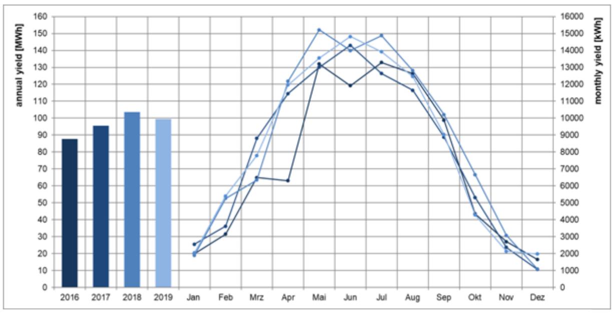
Solar PV yield	
Solar PV system	99,560 kWh (975.5 kWh$_{el.}$/kW$_p$)

nZEB balance (acc. "Efficiency House Plus")	
final energy	+ 10.6 kWh/(m²a)
primary energy	+0.2 kWh/(m²a)

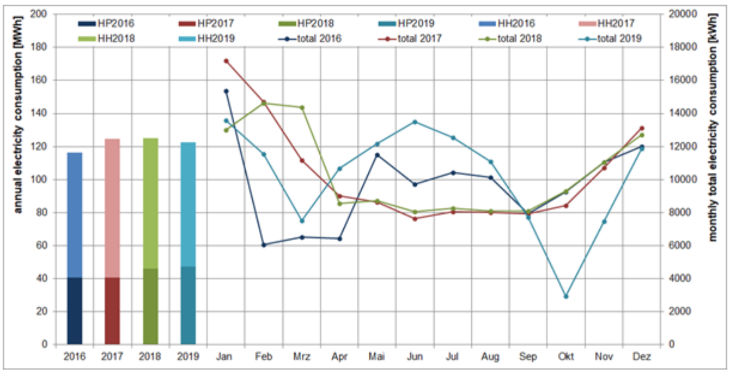
Temporal characteristic	
(annual on 15 min step basis)	
Demand cover factor (self-consumption)	42 %
Supply cover factor (self-generation)	53 %



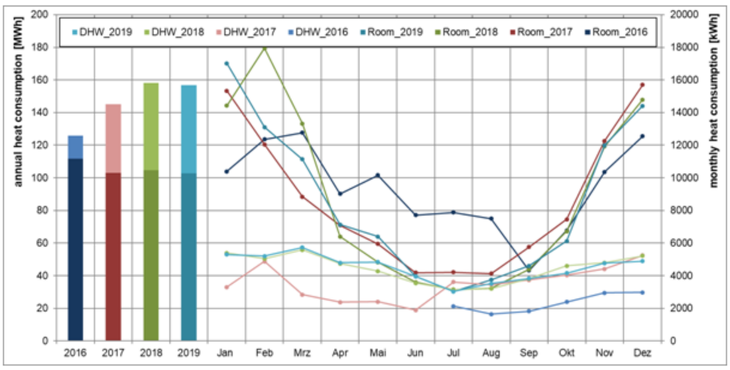
Calculated annual comparison consumption & production



Electric yield of the solar PV system, 2016 - 2019



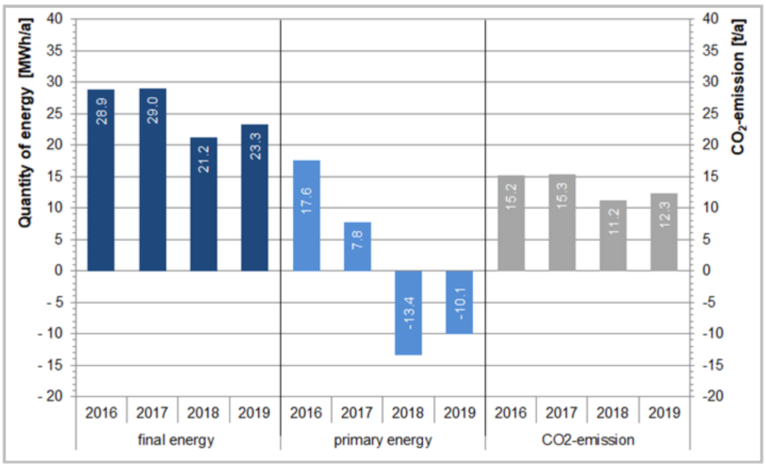
Annual and monthly electricity consumption, 2016 - 2019



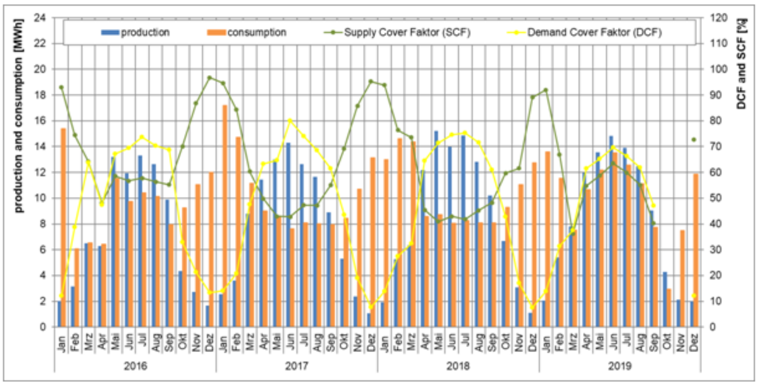
Annual and monthly heat consumption, 2016 - 2019

System performance and optimization

The first step of the system optimization involved the integration of a buffer as a hydraulic diverter in the low-temperature net. This was done due to the very high clocking of the heat pump.
Furthermore, the setpoint temperature for switching between solar absorbers and ice storage has been optimized, as well as adjusting pump delivery heads to increase the volume flows and thus increase the temperature level on the source side.
Due to findings that the performance of the solar absorbers were insufficient too early in the course of the year for operation as a heat source and the ice storage was used as a source, there was a temporary support to the heat supply by electric instantaneous water heaters in the heating period 2016/2017.
In the course of 2017, three instantaneous water heaters were permanently installed in the high-temperature network with a capacity of 9 kW each. Furthermore, dummy modules were removed from the roof to ensure a better flow around the solar absorber.



Final energy, primary energy and CO_2-emission, 2016l - 2019



Load / supply cover factor for the boundary building technology

Ecology and self-consumption

For the multi-family house no plus energy according to planning could be proven. The average annual electricity deficit is about 25,600 kWh/a (about 20 % of the electricity consumption). Over the period under consideration, about 53% of solar energy was used in the house itself, the rest being fed into the public grid. The load cover factor (LCF) varies between 39% and 45% over the years, reaching an average of 42% over the four years. In the monthly view the supply cover factor (SCF) runs from 36 % to 97% and the LCF from 7% to 80%.

Imprint

Building owner
Nassauische Heimstätte
Wohnungs- und Entwicklungsgesellschaft mbH

Design
HHS Planer + Architekten AG, Kassel

Field monitoring
TU Braunschweig
Institut für Gebäude- und Solartechnik

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Literature references

Rosebrock, Plesser, Fisch:
„Effizienzhaus Plus, FFM Riedberg EnergiePLUS im Geschosswohnungsbau", Final report, Forschungsinitiative Zukunft Bau des Bundesinstitutes für Bau-, Stadt- und Raumforschung Aktenzeichen: PEH – A3-12 10 01 / 12.19). TU Braunschweig Institut für Gebäude- und Solartechnik, 2018

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