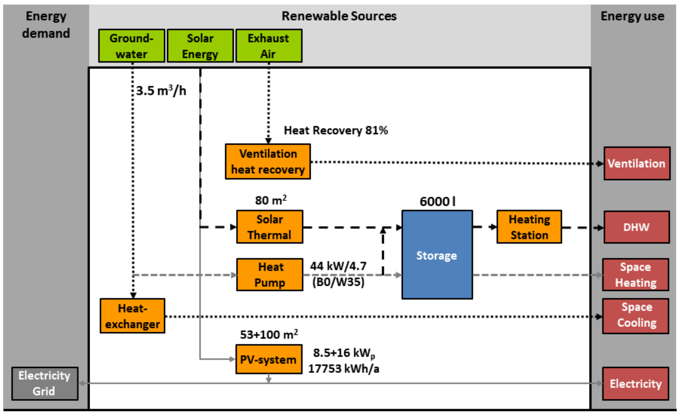
Vögelebichl Multi-Family Passive Houses

First Passivhaus Plus® compliant buildings

Summary

Vögelebichl multi-family houses are the first in the world responding to the Passivhaus Plus Standard. Furthermore, the buildings were designed to achieve the annual net-zero energy balance thanks to on-site renewable energy generation. The building system is equipped with a double-staged groundwater heat pump with 44 kW heating capacity (B0/W35), 80 m^2 of solar thermal collectors, PV panels with 24.5 kW peak power and 6 m^3 buffer storage. Ventilation with 81% heat recovery is implemented to always ensure hygienic air renewal, while minimizing energy consumption. The HP unit also features an additional heat exchanger (the de-superheater) with the purpose to produce hot-water simultaneously to low-temperature water, by cooling the superheated discharge gas exiting the compressor. Monitoring allowed to identify options for performance improvement and provided a base for system simulation to test alternative designs. Evaluation was performed applying monthly primary energy conversion factors to account for seasonal variation of renewable energy (RE) in the electricity mix.

Concept



Building Data

Location:	Innsbruck, Austria
Building Use:	residential, 26 flats
Energy ref. area (**N**orth/**S**outh)	1296/853 m^2
Walls (concrete)	0.11 W/(m^{2}K)
Roof	0.09 W/(m^{2}K)
Ground floor	0.11 W/(m^{2}K)
Windows (total/glass/frame)	0.92/0.6/1.1 W/(m^{2}K) triple glazing, g=0.6
Space heating demand (N/S)	11/14 kWh/(m^{2}a)
Design DHW demand (N/S)	19.6/24.5 kWh/(m^{2}a)

Background

Vögelebichl multi-family houses were built in Innsbruck in 2015 by the local social housing company, Neue Heimat Tirol (NHT). One heating central connects the two building blocks: the north (N) block has four floors and hosts sixteen flats; the south (S) block is just three floors high and hosts ten flats. It complies with the Passivhaus Plus certification, which, in addition to limiting the annual heating energy demand to 15 kWh/(m^{2}a), requires the building to have a bounded renewable primary energy demand of maximum 45 kWh/(m^{2}a) and to generate a minimum amount of renewable energy on-site (60 kWh/(m$_{gnd}{}^2$a)). The building was not merely designed to meet the highest energy performance requirements, but also to maximize the non-renewable primary energy saving by balancing the energy demand for heating, DHW, and ventilation with the on-site renewable energy, hence targeting to achieve yearly net-zero energy balance.

The facility is monitored by the Unit of Energy Efficient Building of the University of Innsbruck since the beginning of operation.

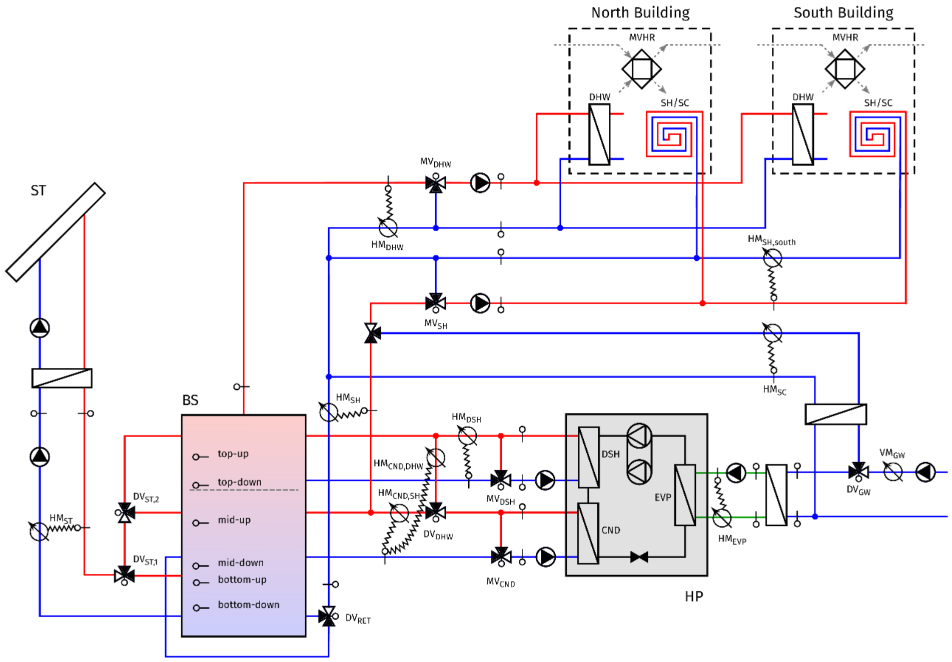
Technical concept

The building's HVAC system consists of two parts: the hydronic system and the ventilation system. The ventilation units ensure hygienic air renewal, whereas the hydronic system provides low temperature space heating (SH) and DHW preparation with decentral fresh water heat exchangers connected to a central heat pump (HP) and solar thermal (ST) collectors.

The HP is double-staged – allowing it to work at two levels of power – and provided with an additional heat exchanger, i.e. the de-superheater (DSH). The purpose of the DSH is to deliver heat at a high temperature level (e.g. heat for DHW) while not raising the condensation temperature (simultaneously delivering SH), thus at higher energy performance.

Heated system-water is stored in a combi-storage tank from which it is withdrawn for SH and DHW preparation. If stratification is properly ensured, combi-storages offer the possibility to save costs and reduce storage losses. The advantage of storing system-water rather than hot drinking-water, which is prepared in the flats by decentralized DHW heat-exchangers, reduces the temperature at which the water must be heated to avoid Legionella growth, allowing for better HP performance and thus energy savings.

The south building (S) roof is completely covered by PV, while the north building (N) is covered partly by ST and partly by PV panels to ensure the on-site electricity generation for achieving the net-zero energy balance.



HVAC system schematic with monitoring system

Design technical data

Heat pump

CTA Optiheat Duo OH 1-44e

Heating capacity (COP)

B0/W35	44 kW (4.7)
B0/W55	39 kW (2.9)

ST collectors

ST area (aperture area)	82 (74) m^2
Collector efficiency	0.77

PV panels

PV area (N/S)	53/100 m^2
Nominal capacity electric	8.5/16.0 kW$_p$

Storage

Storage volume	6 m^3
Diameter	1.6 m
Transmittance (average)	0.15 W/(m^{2}K)

Ventilation systems

Ventilation units (N/S)	2/1
Volume flow rate (N/S)	972/640 m^3/h
Specific Fan Power (N/S)	0.33/0.38 Wh/m^3
Heat recovery	81%

Abbreviations

BS	buffer storage
CND	condenser
DHW	domestic hot water
DSH	de-superheater
DV	diverting valve
EVP	evaporator
GW	ground water
HDD	heating degree days
HM	heat meter
HP	heat pump
MV	mixing valve
MVHR	mechanical ventilation heat recovery
PV	photovoltaic
SC	space cooling
SH	space heating
SPF	seasonal performance factor
ST	solar thermal
VM	volume flow meter

Field monitoring results

The focus of the monitoring was the measurement of the HVAC system performance and the approval of the NZE balance. In addition, the south building thermal comfort is monitored.

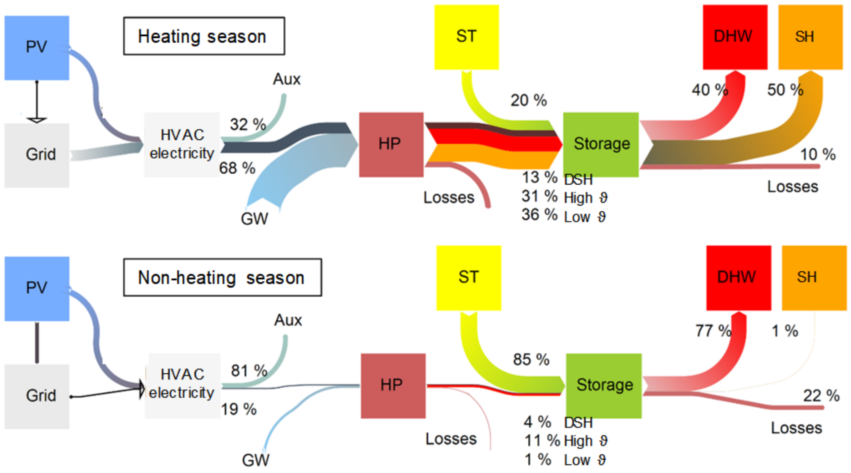
The monitoring period started in 2016 and it is still ongoing. In 2018 the space heating demand was with 17.9 kWh/(m^2 a) slightly higher than the design value. The first year of monitoring appears to be affected by the building construction moisture (concrete), resulting in the largest space heating energy demand so far, despite not being the coldest year in terms of maximum heating degree days (HDD). The energy demand for DHW represented the main component of energy consumption in 2017 and 2018, whereas in 2019 it was equal to the space heating demand.

In 2018, the indoor temperature was above the design heating setpoint of 20 °C, with a median value between 22 °C and 23 °C. The median of the relative humidity is above the too-dry limit of 35%.

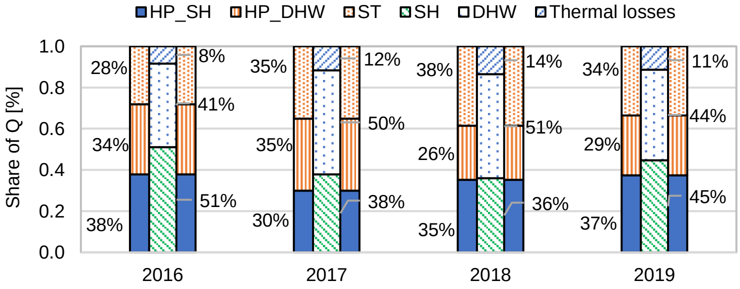
In none of the monitored years the on-site electric energy generation was sufficient to cover the HVAC energy consumption. Therefore, the net-zero energy balance has never been reached so far. One of the main reasons for that is the unexpectedly high auxiliary energy consumption.

The monitoring of the HP allowed to identify the share of the supplied heat by its components (CND, DSH) in the two working conditions (SH, DHW). For instance, in 2018, in SH mode the HP supplied heat was mainly in ‘stage I’ (34%), with ‘stage II’ covering only the 8% of the total supplied heat. Additionally, despite the scope of the DSH being the simultaneous preparation of DHW while in SH mode, in 2018 there was no evidence of this behavior.

The energy balances of the buffer storage present the share of the energy inflows and outflows. Noteworthy, the thermal energy delivered by the HP at low temperature (HP_SH) is lower than the required for SH. This difference is covered by the heat delivered at high temperature from either the HP in DHW mode or the ST collectors.



Energy flow diagram for 2018



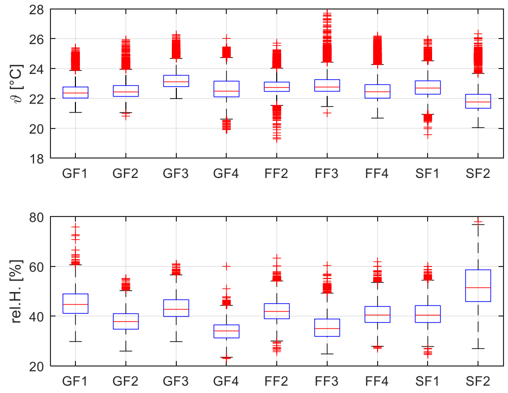
Thermal energy balance of the buffer storage

Performance in Field monitoring

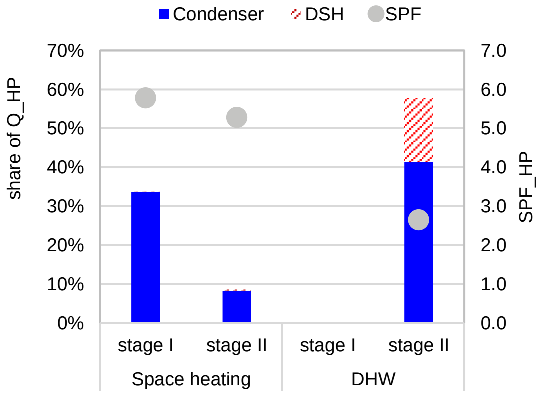
Energy demand (2018)	
Space heating (N/S/tot.)	**18.7/16.7/17.9 kWh/(m^2a)**
DHW	**26.0 kWh/(m^2a)**

Seasonal performance factors	
SPF heat pump (boundary COP)	**3.1**
SPF generators (HP and ST)	**4.9**
SPF system (all system components)	**4.2**

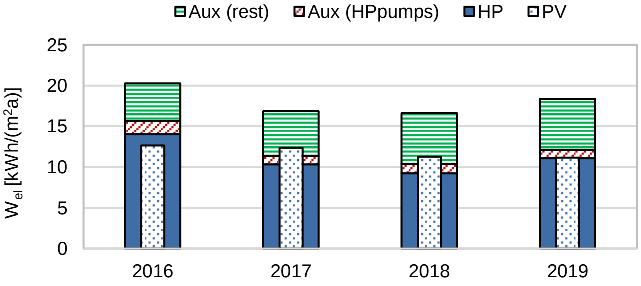
Solar System	
PV yield (electric energy)	**12 kWh/(m^2a)**
ST yield	**19.9 kWh/(m^2a)**



Box plot of indoor temperature and rH in 2018.



Share of supply heat by the HP in different modes



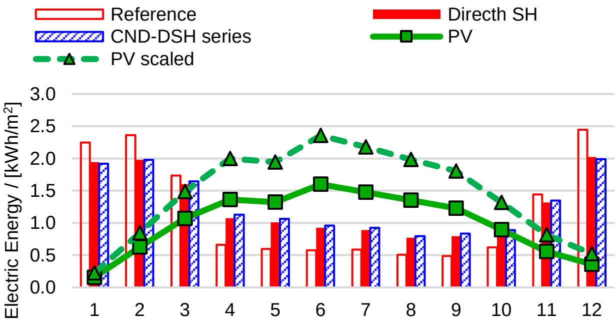
Electric energy balance

System performance optimization

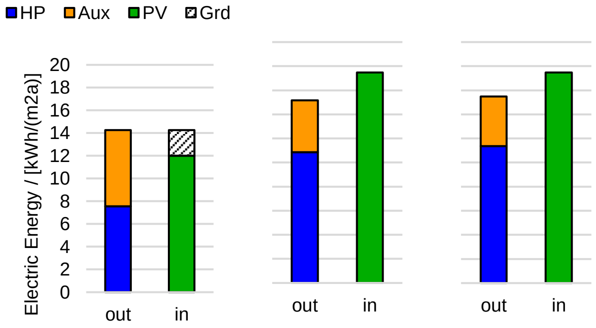
The monitoring analysis highlighted a sub-optimal control of the HP and large auxiliary energy consumption. Moreover, the solar thermal contribution during the heating season is negligible and there is a large surplus of PV generation during the summer. It is suggested to substitute ST by PV in order to reduce system complexity and thus reduce thermal losses and auxiliary energy consumption. PV self-consumption depends on thermal storage and the optimal configuration depends on the grid interaction.
Simulation-based optimization both at the component (i.e. buffer tank and heat pump unit) and system (heating system and building) level showed potential for energy performance improvement, particularly for the control of the DSH. Even larger performance improvement can be achieved simplifying the hydraulic design by directly connecting the HP to the SH loop (both cases) and by either having the DSH in series connection to the CND or disregarding the DSH. In both cases ST was not considered, resulting in a larger energy demand during the summer months, yet overly compensated by the PV yield.
The DSH could slightly improve the system performance, however, the potential is overall limited in buildings with low heating demand such as the Passive House.

Critical discussion on NZEB

Vögelebichl was designed as a net-zero energy building (NZEB), thus, to achieve the annual net-zero energy balance thanks to on-site renewable energy generation.
Although the balance has not been achieved in the monitored years, simulations showed the possibility to achieve it.
However, the net-zero balance would be obtained thanks to the large PV yield surplus during summer, which might be a problem for the grid stability and it is not so effective in reducing the building specific CO_2 emissions. Therefore, the net-zero balance on an annual basis might be a misleading approach to ensure low CO_2 emissions.
An alternative evaluation criterion to quantify the decarbonization effect of a building might be the annual non-renewable primary energy balance – neglecting surplus energy – obtained assuming monthly-dependent conversion factors as outlined in Ochs et al. (2018). This emphasizes the importance of maximizing the performance of the building during the winter months when on-site renewable energy generation is at its lowest, rather than considering beneficial the energy surplus during summer.



Electric energy consumption and PV yield of reference and optimization cases



Annual electric energy balance for reference, Direct SH and CND-DSH series.

Imprint

Building owner
Neue Heimat Tirol (NHT)
Design
Architect: Hanno Vogl-Fernheim
HVAC Planning: Alpsolar
General Contractor: Strabag
HVAC: Siko Energiesysteme (Heat Pump: CTA, Control Johnson Control, Stransky; Operator: IKB
Field monitoring
Unit of Energy Efficient Building, UIBK

The project was financially supported by NHT and Land Tirol

Date of sheet: 25.05.2020

Literature references

Dermentzis, G. et.. Lessons learned after four years of monitoring of two net-zero energy buildings in Austria". In preparation.
Franzoi, N. (2020). Simulation based optimization of a heating system in a high-performance building. Master's thesis.
Ochs, F., G. Dermentzis, and W. Monteleone (2019). Simulation-assisted optimization of the hvac system of nze multi-family buildings. In IBPSA Proceedings, Volume 16. University of Innsbruck.
Ochs, F. and G. Dermentzis (2018). Evaluation of efficiency and renewable energy measures considering the future energy mix. In Healthy, Intelligent and Resilient Buildings and Urban Environments. International Association of Building Physics (IABP).
Ochs, F., G. Dermentzis, and W. Feist (2014). Minimization of the residual energy demand of multi-storey passive houses energetic and economic analysis of solar thermal and PV in combination with a heat pump. Energy Procedia 48, 1124–1133.

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