Design and integration of heat pumps for nearly Zero Energy Buildings

Case Study IEA HPT Annex 49

nZEB - Residential Building D12 – Aspern / Vienna / Austria

Summary

The residential building “D12” is a block of 7 buildings with 4-6 storeys each, commercial use on the ground-floor (GF) with 8 shops on 900 m² and 213 flats on the upper levels. The (conditioned) gross floor area is about 20,600 (19,080) m². Two levels of underground car parking have been constructed, whereas the exhaust air of this parking is used as the source for one of the 7 heat pumps. The flats are heated with floor heating allowing for rather low heating powers and temperatures. The domestic hot water (DHW) is heated to 60 °C by fresh-water-modules which are supplied by the high-temperature (HT) ring, which is supplied by HT-heat pumps up to 70 °C.
The buildings’ heating and DHW system was specifically designed to support demand response with a multitude of different sources, namely thermal-, photovoltaic- and hybrid- solar collectors as well as seven heat pumps using ground water, waste air and shallow-surface geothermal heat storage. Hot water tanks are the short-term heat storage while the long-term ground storage is loaded by excess solar thermal energy. The buildings are in operation since March 2016.

Building data

Location:	Vienna/ Aspern Seestadt
Construction finished:	2016
Building Use:	residential/retail (GF)
Gross/Conditioned area:	20,600 m² / 19,080 m²
Non-residential area:	900 m²
#building blocks/storeys:	7/6
Space heating demand:	15.6 kWh/(m²$_{GA}$a)
Primary energy demand	87.4 kWh/(m²$_{GA}$a)
CO2-Emission	13.9 kg$_{CO2}$/(m²a)

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International Energy Agency
Heat Pumping Technologies

Background

The Aspern Smart City Research GmbH & Co KG (ASCR) is a joint venture between a network operator, an international technology company, an energy generation and supply company, and the City of Vienna. The testbed Aspern Smart City Research, located in the urban development area "Seestadt Aspern" outside Vienna, focuses on energy management, smart buildings, smart grids, smart ICT and smart users.

System concept

The innovative energy supply system of the D12 is using several heat pump technologies combined with various sources (air, soil, groundwater, solar) and storage technologies. The control strategy operates the combinations of heat pumps with the most efficient heat source (based on demand and the external boundary conditions) and loads the thermal storage system. The connection between those plant components of the heat supply and the heat consumers is realized with two loops for high and low temperature supply of a set point of 65 °C for domestic hot water (DHW) and 40°C for space heating (SH). Using a so called 'stratifier lance module' the solar heat can be fed into high, middle and low temperature level storages, so that collector operating time and performance is maximized.

The heat generation systems are located in 6 building service rooms, each with SH and DHW buffer storages (6 X 2,000 l) connected with the two loops. The electrical energy demand of the HVAC system is supplied by the PV collectors, hybrid collectors and the battery storage and, if not available, from the public electricity grid.

As SH emission system, a floor heating system is installed. It is connected to the low temperature water loop and consists of 228 heating circuits. 17 main pumps circulate water to the ascending major distribution pipes with a total mass flow rate of 95 m³/h. The DHW production is provided by 5 freshwater modules connected to the high temperature loop. Each of these plate heat exchangers has a maximum heat transfer capacity of 315 kW_{th}. The building complex is as well connected to the local district heating network with a capacity of 1.5 MW_{th}.

The heat system is operated in a holistic approach and the required/delivered energy is exchanged homogeneously over the hydraulic rings. However, the current water flow direction / frequency of the changes of direction cannot be determined explicitly. There are basically two operational modes depending on pressure difference:

1) Two or more active components operate the water network: The pumps produce the required pressure to direct the water flow, the pumps supply heat to the heating circuit and load the buffer tanks.
2) No heat generators running: The thermal water tanks are discharged and supply heat to the heating circuit.

Energy system data

Heat pumps

4 ground-water HP	
Capacity (W10/W55)	144.1 kW_{th}
COP (W10/W55)	3.57
2 brine/water HP	
Capacity (B5/W40)	65.1 kWh_{th}
COP (B5/W40)	4.47
1 Air/water HP	
Capacity (A5/W60)	57.8 kWh_{th}
COP (A5/W60)	3.00

Solar technologies

Solar thermal	90 kW_{th}
PVT	60 kW_{th}/ 16 kW_{pel}
Photovoltaics	20 kW_p

Storages

Ground storage	40 MWh_{th},
Hot water storages	6 x 2,000 l backup for SH and DHW

Calculated loads

Total SH load	306 kW_{th} 66 kW_{el}
Total DHW load	461 kW_{th}/ 119 kW_{el}

Demand response

A dynamic-thermal simulation study was performed using TRNSYS to get an estimation for the demand response potential of the building. The model was further used to develop and test control strategies and also to verify the demand response potential once validated with monitored data.

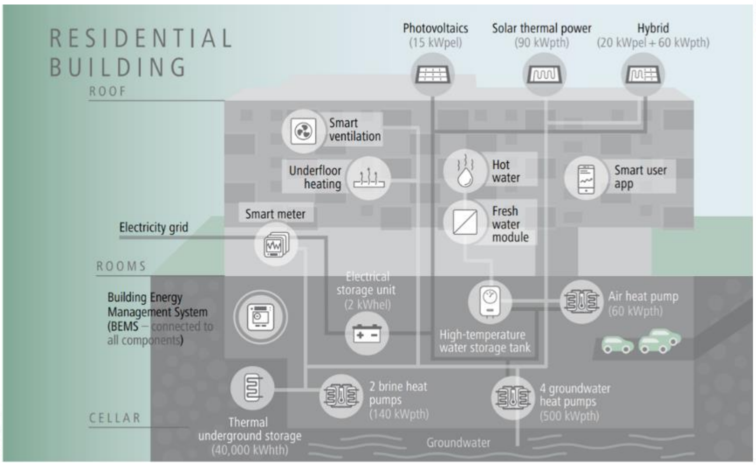


Figure 1: Schematic overview of the D12 building concept, Note: the low temperature storage tank is not shown (Source: ASCR)

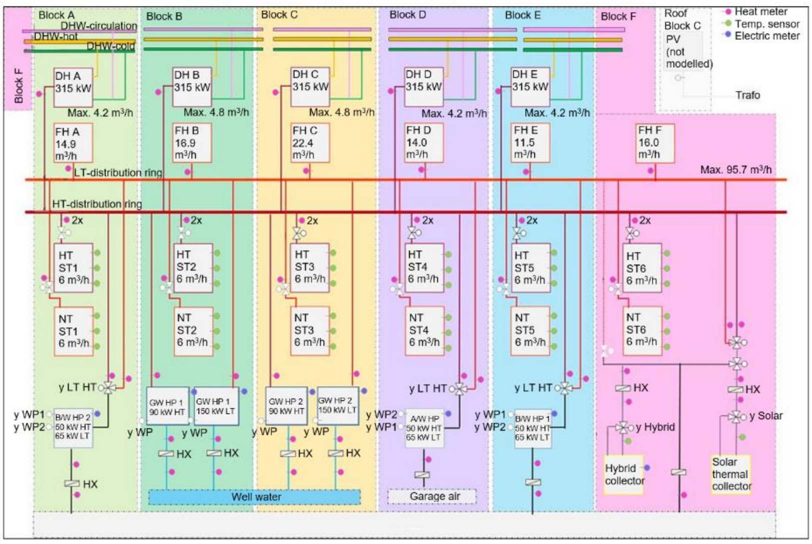


Figure 2: Scheme of the monitoring concept (ASCR).

Monitoring

An extensive monitoring campaign on the energy system and room level was conducted to study mainly the load shifting potential and occupant behavior. Figure 3 shows the monitoring concept of the heat generation and distribution system. Recorded and visualized monitoring data have been used to validate and to calibrate simulation models (building and system), see Figure 6.

The measured delivered heating (measured on room level, i.e. without distribution losses) is accounted to 26.7 kWh/m^2 (conditioned area) and higher than the target value. The increased window ventilation (rather than using the heat recovery forced ventilation) lead to higher heating demand above the heating limit temperature (T_ambient < 12°C) and more occupied hours than planned.

Figure 4 shows the split of delivered heat between the different heat sources for the first year of operation. The ground-water heat pumps delivered 52% of the required heat, the solar thermal system includes heat for the regeneration of the geothermal storage.

Due to both a) operation of various heat delivering systems and b) feeding delivered heat to two distribution water networks (Low and High temperature level), insufficient circulations and erroneous flows appeared in the beginning. This malfunctioning could be resolved by using non-return flaps and shut-off valves. Initially, it was expected that the system would suffer from relatively high distribution losses due to the complex hydraulic scheme. In fact, it was observed that the thermal losses are in the normal range.

In order to check the operational performance of the heat delivering and distribution system on the low temperature level, modelling and simulation work were carried out. Figure 5 displays the instantaneous heat fluxes (simulated and measured) on the low temperature level of the observation period from 02.02.2017 00:00 till 04.02.2017 00:00. Displayed heat fluxes are a) delivered heat from all heat pumps on low temperature level, b) heat taken and fed to the water storages and c) heat transferred to the floor heating system.

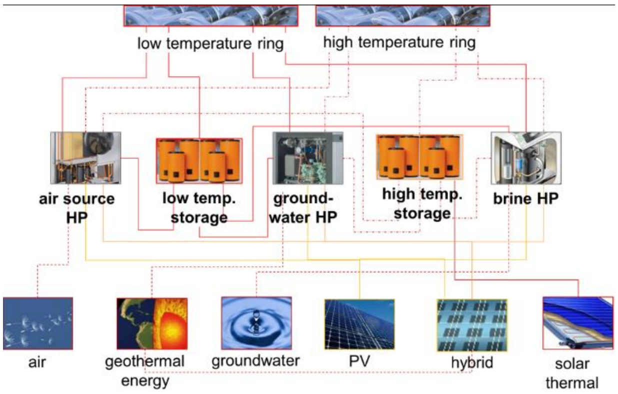
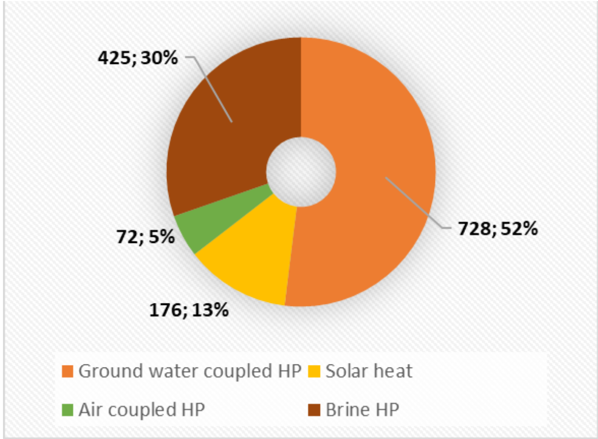


Figure 3: Simplified energy/mass flow diagram showing the connections among the various sources, generators, storages and loads.



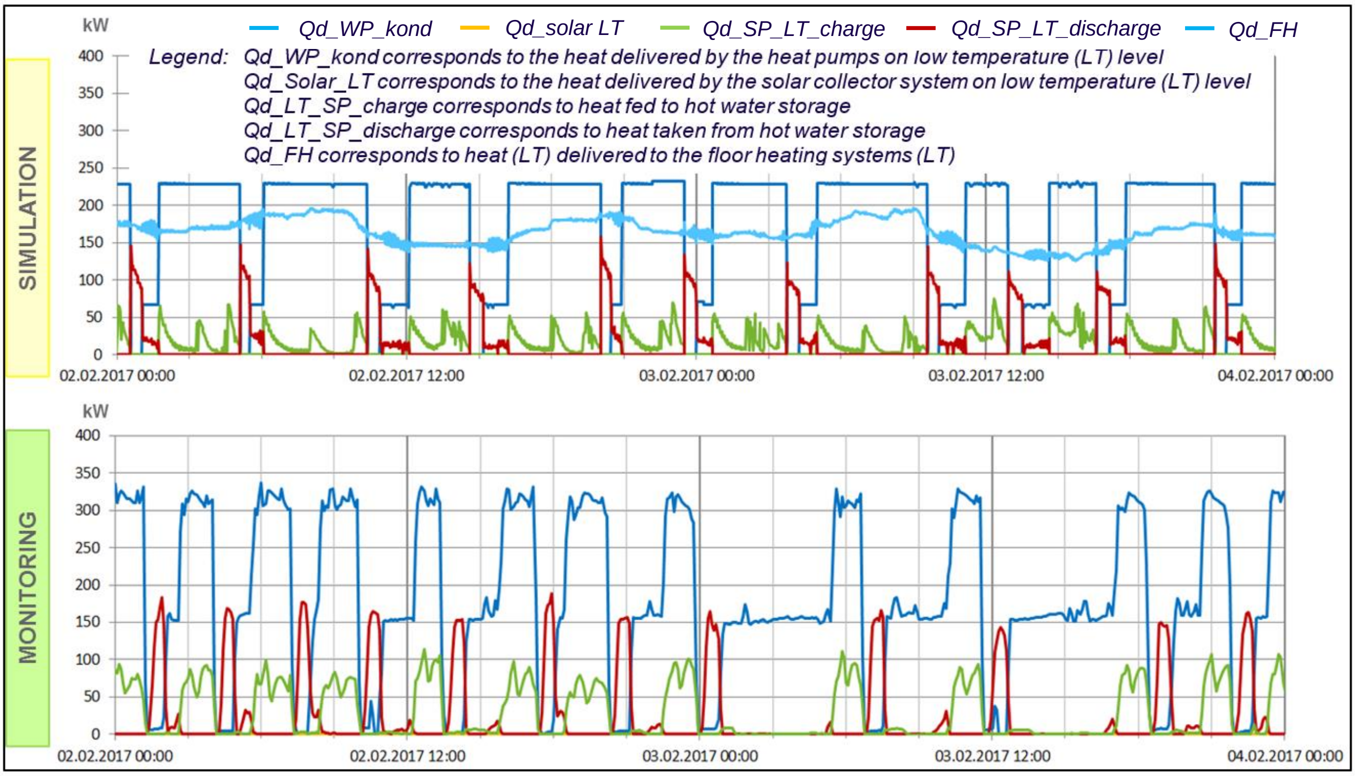


Figure 5: Comparison of simulation and monitoring data of heat delivered by heat pumps, as well as storage tank charging and discharging on the low temperature level, Observation period is from 02.02.2017 00:00 till 04.02.2017 00:00 (ASCR).

Evaluation by Simulation and Monitoring

By comparing heat capacity provided by the LT heat pump system, simulated values are lower than measured numbers – see dark blue line of Figure 5. As long as the first heat pump is sufficient to cover the heat load, only this heat pump is operated, and the residual heat is taken from the storage tanks (red line). If the water storage tanks are discharged, the second heat pump starts-up and heat surpluses are used to recharge the storage tanks (green line). In case the hot water tanks are fully charged, the heat pumps are switched-off and the hot water tanks are discharged (red line). In the considered period, no heat generated by solar collector system was transferred into the LT circuit, neither in the results of the simulation nor in the recorded values of the measurement equipment.

Energy performance data of the heat pump manufacturer for different flow and source temperatures were implemented in the heat pump models. Subsequently, the simulation results were compared with the monitoring data by taking the target parameter T_out_load. Figure 6 displays a table of relevant manufacture data and a scatterplot of simulated and measured values T_out_load. Based on the results of the scatterplot in Figure 6, it can be stated, that the defined heat pump model calculates the energy performance of the heat pump very well.

Vorlauf tVL (°C)	Wärmequelle Medium t1	(°C)	Q kW	P kW	COP
30	Brine (Sole)	-5	27,36	6,52	4,20
		-2	30,52	6,58	4,64
		0	32,89	6,64	4,95
		2	35,26	6,69	5,27
		5	39,31	6,80	5,78
	Groundwater (Wasser)	8	43,04	7,03	6,12
		10	45,34	7,07	6,41
		12	46,87	7,12	6,59
		15	48,52	7,16	6,78
35	Brine (Sole)	-5	26,77	7,29	3,67
		-2	29,83	7,36	4,05
		0	32,00	7,40	4,32
		2	34,37	7,44	4,62
		5	38,22	7,53	5,08
	Groundwater (Wasser)	8	41,68	7,76	5,37
		10	44,00	7,80	5,64
		12	45,57	7,82	5,83
		15	46,95	7,84	5,99
40	Brine (Sole)	-5	26,27	8,13	3,23
		-2	29,14	8,20	3,55
		0	31,21	8,24	3,79
		2	33,48	8,28	4,04
		5	37,14	8,37	4,44
	Groundwater (Wasser)	8	40,51	8,59	4,71
		10	42,66	8,64	4,94
		12	44,08	8,66	5,09
		15	45,55	8,64	5,27
		-5	25,78	9,04	2,85

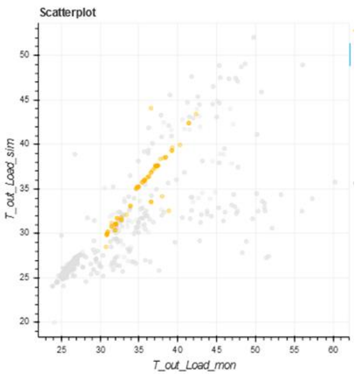


Figure 6: Scatterplot of the heat pumps sending temperature (monitoring vs. simulation) in part load operation (right) and manufacturers' performance data on the left.

Key Findings

- The ground and groundwater coupled heat pumps supply the lion's share of the heat, about four fifths of the total heat supplied was provided by these heat pump systems.
- Air source heat pump (parking garage) could be used mainly during summer to provide high temperature heat, whereas ground source heat pump mainly during winter (highest source temperature)
- The "multiple-heat source concept" of the overall energy system is approved to deliver a high redundancy and availability. Generally, no heat backup – like district heating – is required. Nevertheless, the district heating function as a thermal backup and guarantees high thermal comfort during heating season.
- Achieving both a) high solar fraction and b) no stagnation of the solar collectors, solar heat basically charges the geothermal storage or feeds the high/low temperature loop. Legionella-risk is not an issue due to the use of freshwater stations.
- Hybrid solar collectors well designed and chosen to regenerate the geothermal storage.
- Pressure management for high and low temperature water circuit is recommended, but difficult to manage and very tight dampers/valves are needed.
- Complex control strategies provoke to overburden the service and facility management personal.
- One central technical room rather than 6 would save costs. Enough space for such a large room should be planned.

Acknowledgement

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Literature reference

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Photos of the D12 building

IEA HPT Annex 49 is a corporate research project on heat pump design and integration in nearly Zero Energy Buildings.
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Internet: http://www.heatpumpingtechnologies.org/annex49