ENERGY AND EFFICIENCY ANALYSIS OF HEAT PUMP SYSTEMS IN NON-RESIDENTIAL BUILDINGS BY MEANS OF LONG-TERM MEASUREMENTS

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Buildings and HVAC
Overview (1)

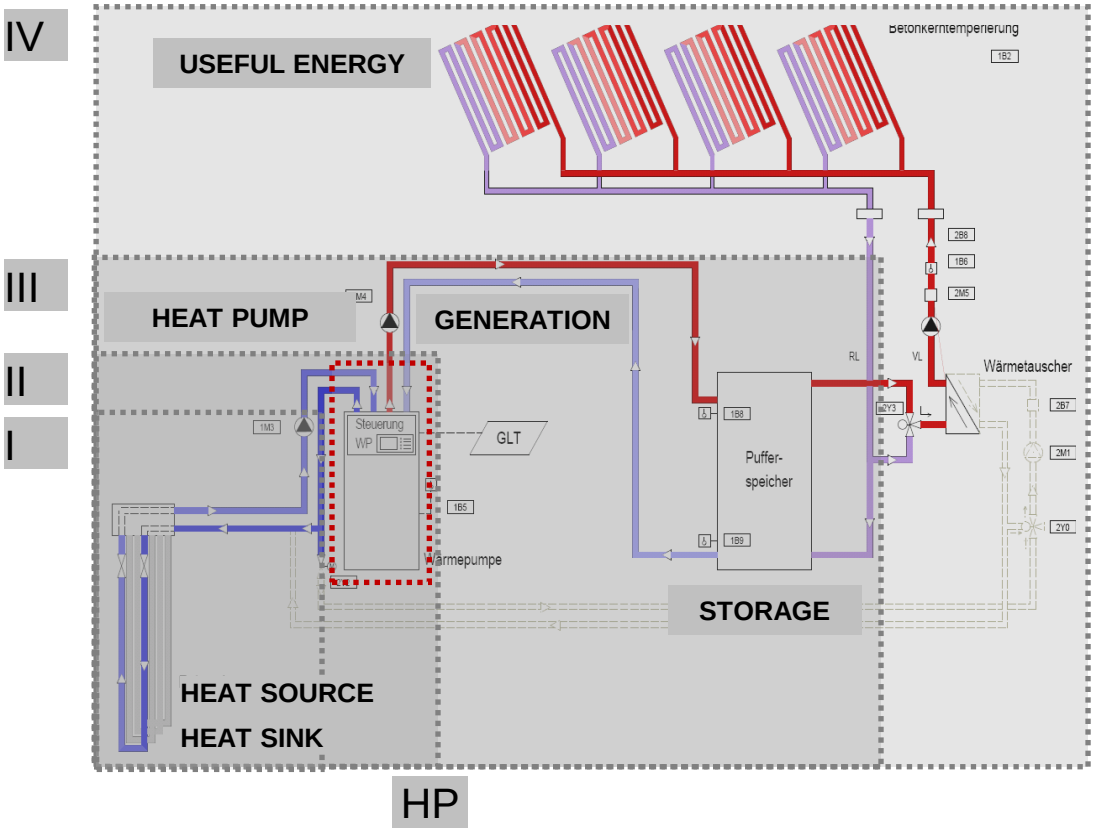
- **Buildings**:
  - Investigated projects: 16
  - Buildings: 15 new buildings, 1 refurbishment, 3 schools
  - Office buildings, schools: 1,600 – 17,700 m²
- **Heat sink/source**:
  - ground water (3), borehole heat exchangers (11), ground collectors / piles (2)
  - various dimensioning of the BHEX-field: 8 – 50 m/kW$_{therm}$ HP
- **Heat pump**:
  - electric compression-HP (13), absorptions-HP (3), power: 33 – 320 kW$_{therm}$
- **Heat supply**:
  - 5 monovalent, 11 bi-/ multivalent (biomass, gas, district heating, solar)
  - waste heat recovery in 6 projects (e.g. decoupling during cold production)

Buildings and HVAC
Overview (2)

- **Cold supply**:
  - primary usage of direct cooling
  - active cold generation via reversible heat pumps in 6 projects
- **Heat storage**:
  - available for all plants
  - very small dimensioning (11 – 25 liter/kW_{therm} WP)
  - different hydraulic connections
  - combi-storage tank in 4 plants (connected to multiple heat generators)
- **Cold storage**:
  - additional in 5 plants, 1 Heat-/cold storage
  - dimensioning between15 – 75 Liter/kW_{therm} WP
- **Heat and cold transfer**:
  - primarily thermo-active building system and heating/cooling ceiling: 23 – 30 °C
  - additional ventilation und in few cases radiators: 35 – 48 °C

Methodology for Analysis and Evaluation
Balance Boundaries I to IV

- Measurement data with high temporal resolution from demonstration projects over several operational years (1min - 10min increments)
- Standardized evaluation of the plants with Datastorage
- Analysis and evaluation according to operational modes: Heating, direct and active cooling, total operation
- Evaluation of 5 system boundaries
  - Energy and efficiency
  - Operational Performance



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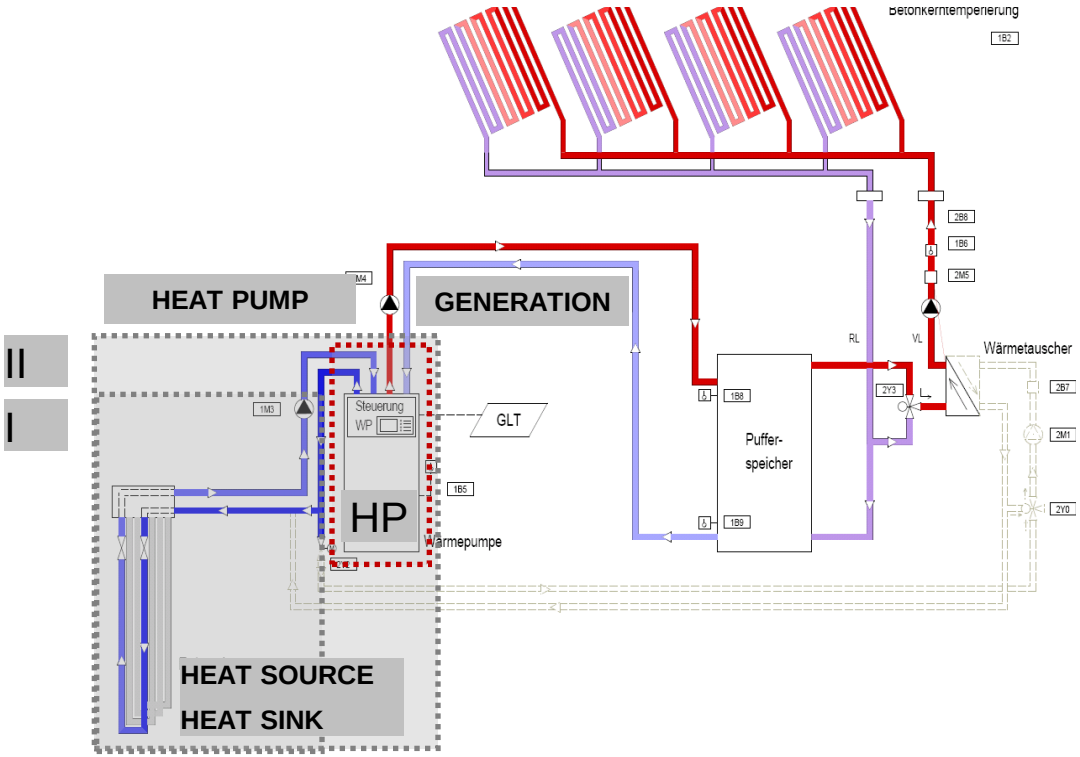
Methodology for Analysis and Evaluation

Balance Boundaries II and HP



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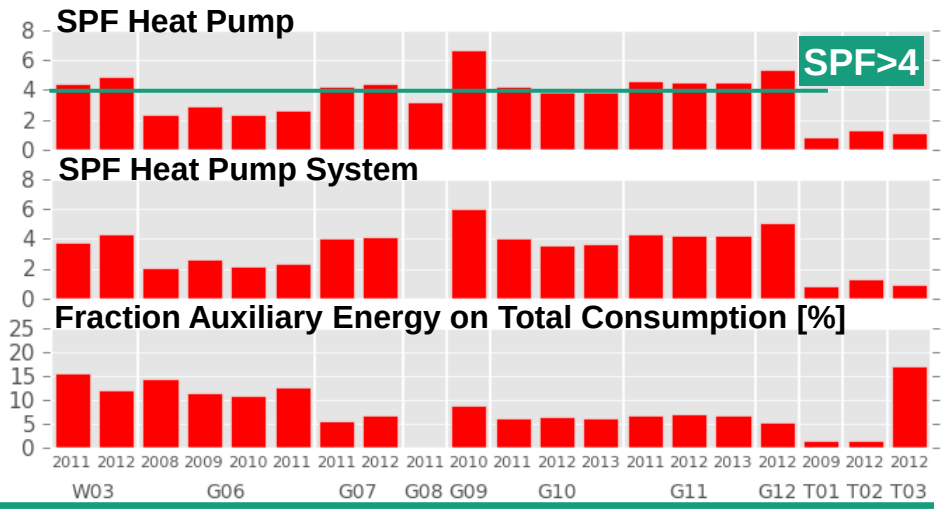
Heat Pumps in Heating Mode
Analysis of Efficiency

- **Efficiency of heat pump**
  - Electric HP: 2.4 – 6.6
  - No clear difference between monovalent and multivalent operation
  - Thermal HP: 0.8 – 1.3*



* SPF according VDI 4650, Page 2 (ultimate energy based, thermal and electric input)

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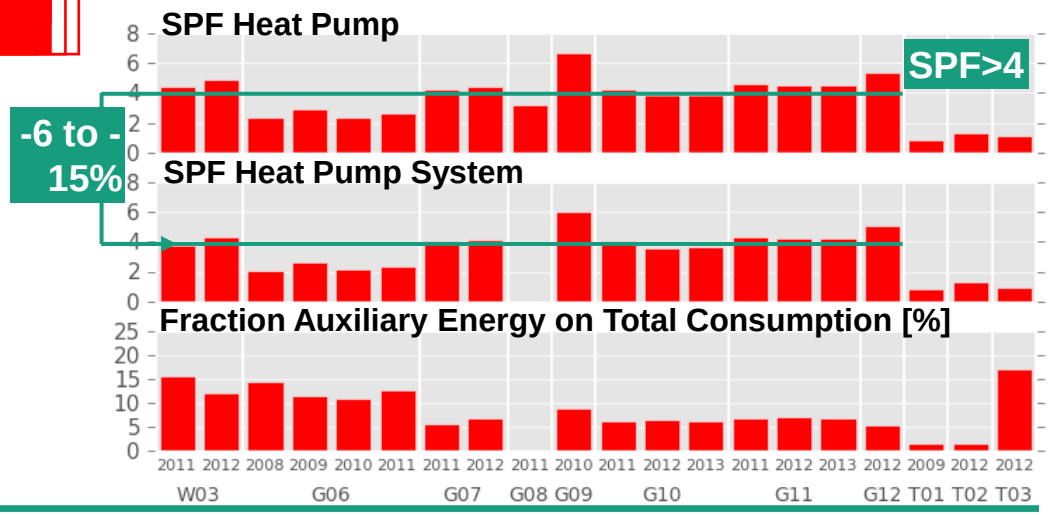
Heat Pumps in Heating Mode
Impact of Auxiliary Energy

- **Efficiency of heat pump**
  - Electric HP: 2.4 – 6.6
  - No clear difference between monovalent and multivalent operation
  - Thermal HP: 0.8 – 1.3*
- **Efficiency of HP system**
  - Electric HP : 2.1 – 6.1
  - Obvious reduction of SPF of 6 – 15% in some cases
  - Efficiency of system determined by HP and auxiliary energy



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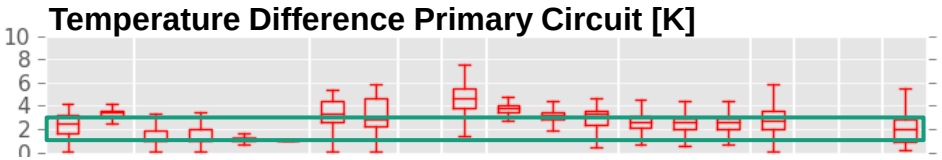
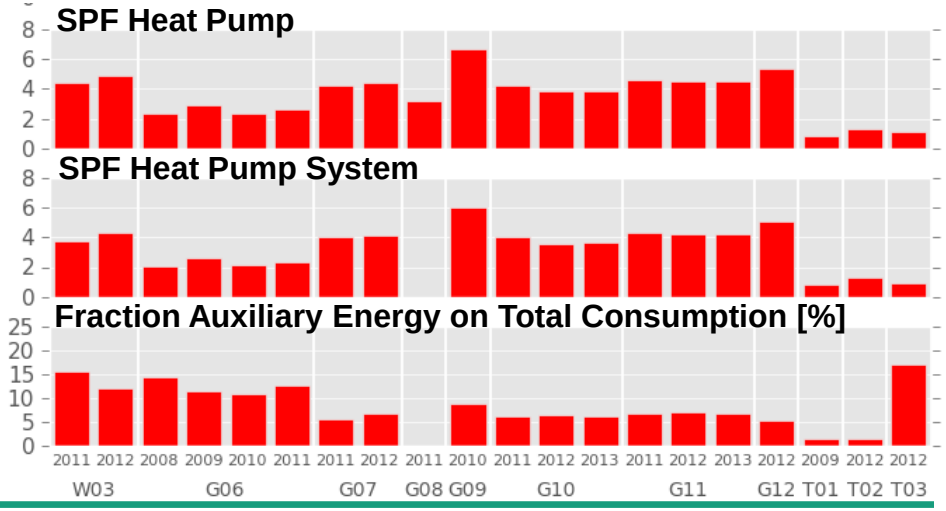
Heat Pumps in Heating Mode

Analysis of Operation



- Low temperature difference in the primary circuit, often 1 – 3 K



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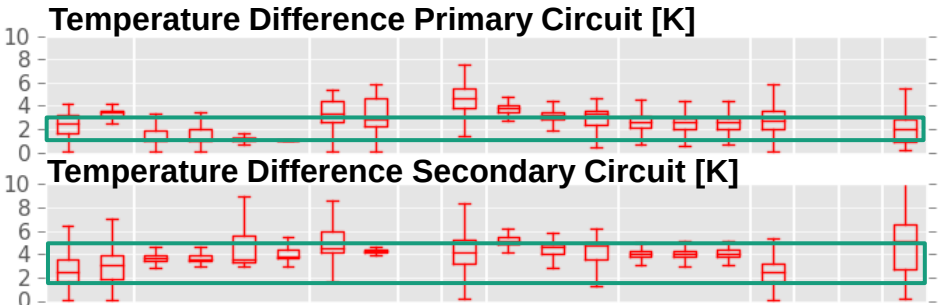
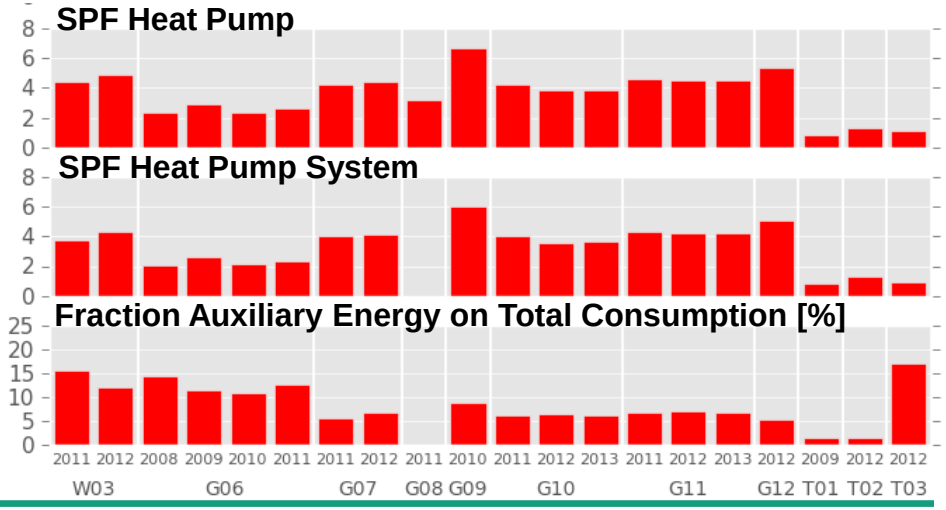
Heat Pumps in Heating Mode

Analysis of Operation

- Low temperature difference in the primary circuit, often 1 – 3 K
- Temperature difference in the secondary circuit between 2 and 5K





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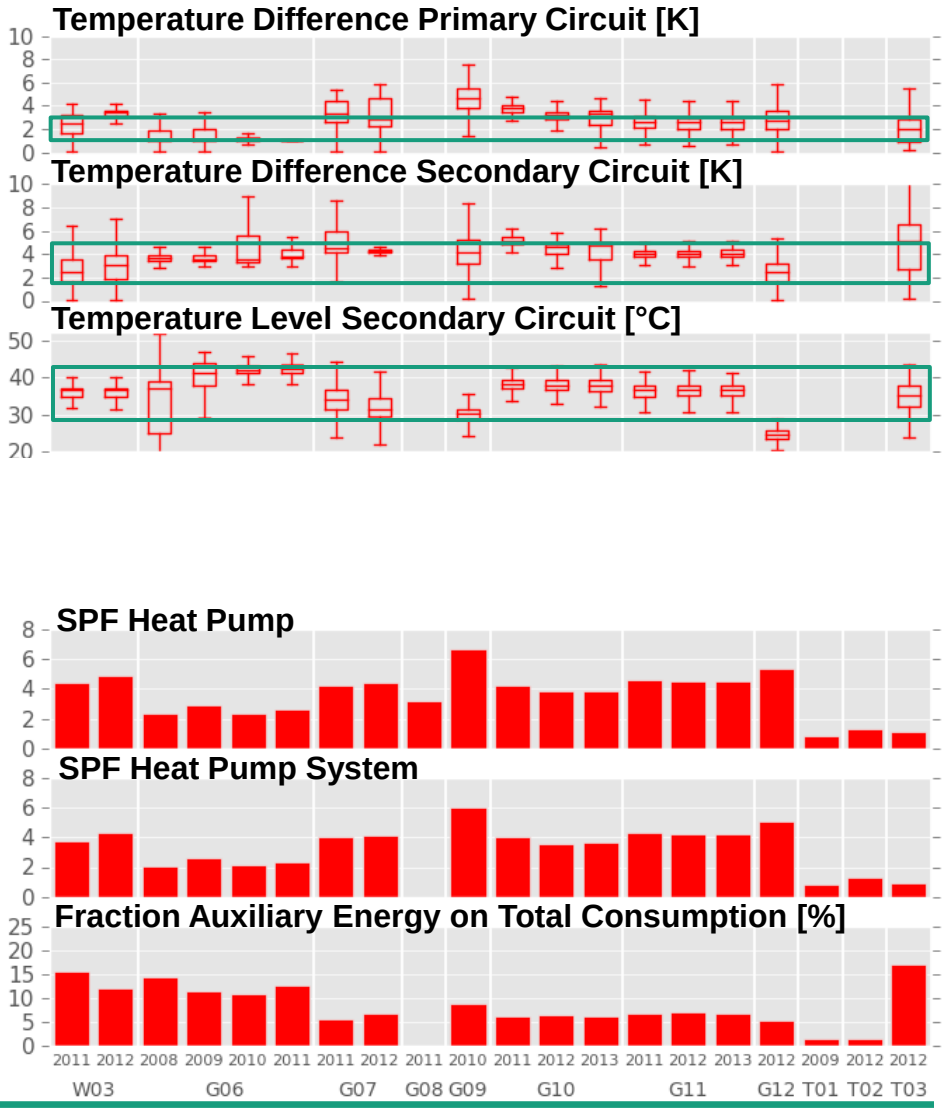
Heat Pumps in Heating Mode

Analysis of Operation

- Low temperature difference in the primary circuit, often 1 – 3 K
- Temperature difference in the secondary circuit between 2 and 5K
- Temperature level in the secondary circuit depends on the heat delivery system
  - Ventilation and surface-near systems: 35 – 45°C
  - TABS: 28 – 35 °C



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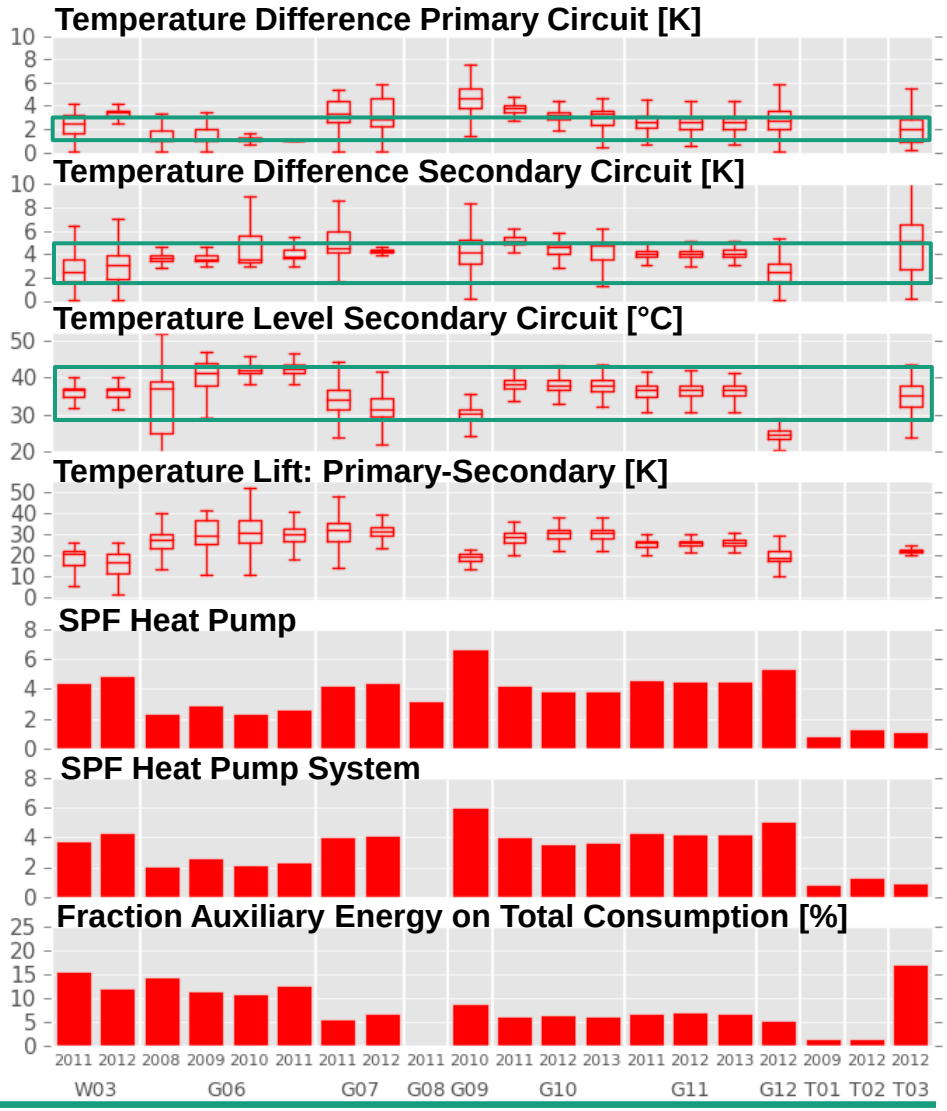
Heat Pumps in Heating Mode

Analysis of Operation

- Low temperature difference in the primary circuit, often 1 – 3 K
- Temperature difference in the secondary circuit between 2 and 5K
- Temperature level in the secondary circuit depends on the heat delivery system
  - Ventilation and surface-near systems: 35 – 45°C
  - TABS: 28 – 35 °C
- Big temperature lifts between primary and secondary circuit in some cases → reduced efficiency



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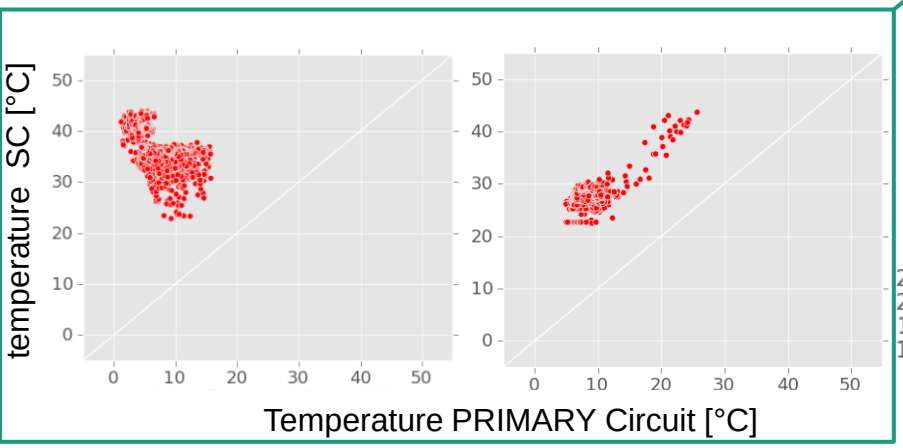
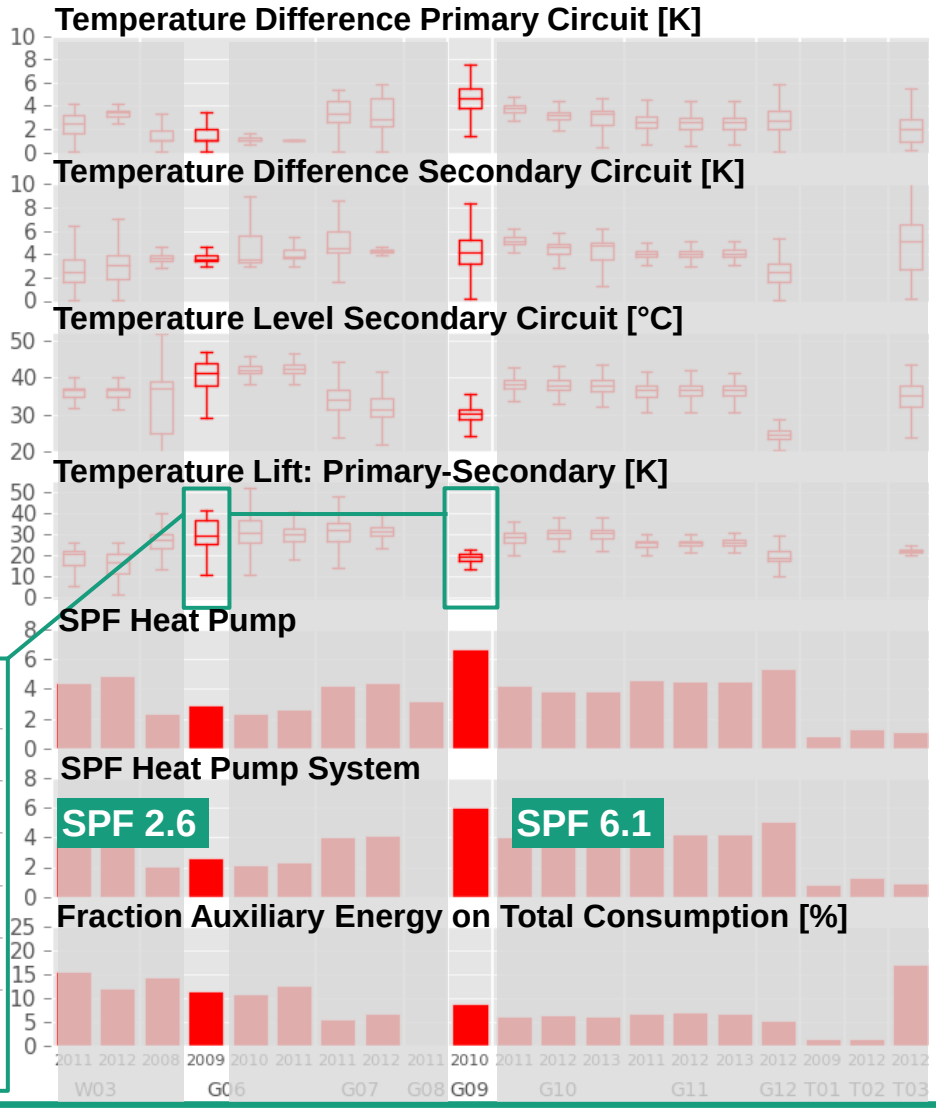
Heat Pumps in Heating Mode

Efficiency and Temperature Level





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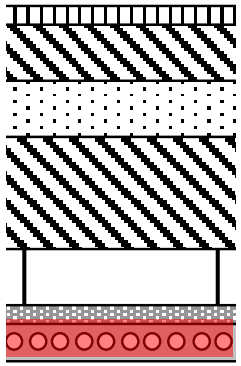
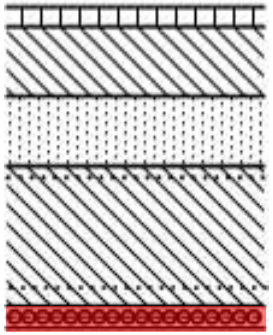
Heat Pumps in Heating Mode

Heating Delivery Systems

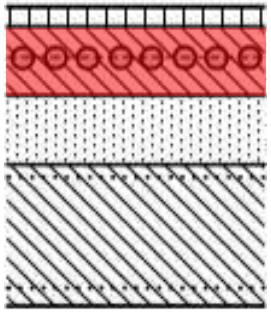
CEILING SUSPENDED PANELS



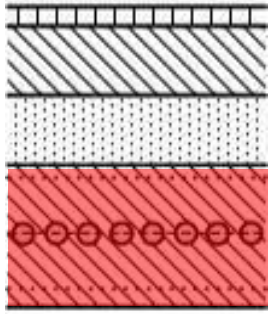
SURFACE-NEAR CONDITIONING



FLOOR CONDITIONING



CONCRETE CORE CONDITIONING



retrofit — new construction

decreasing temperature level

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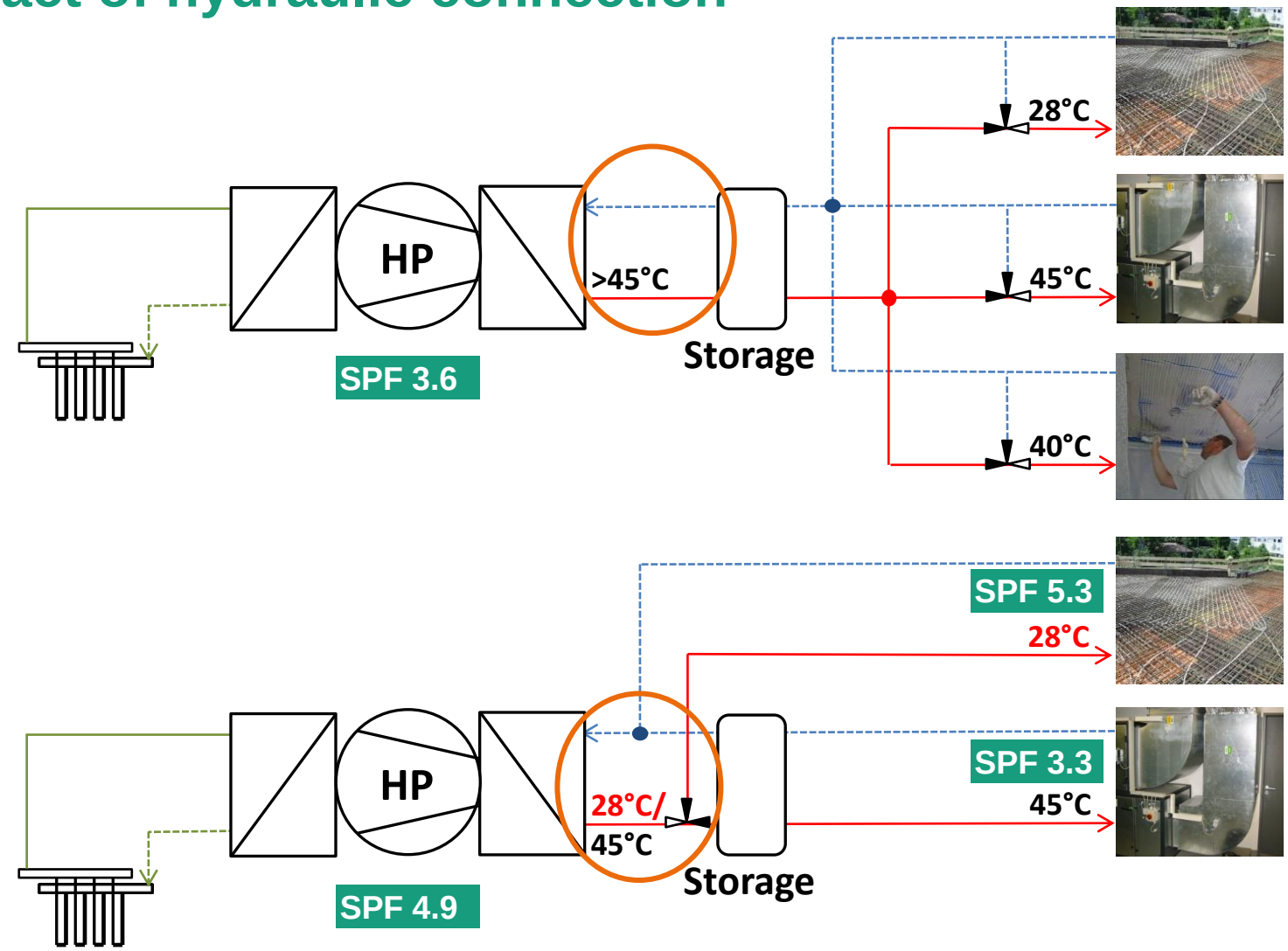
Heat Pumps in Heating Mode

Impact of hydraulic connection



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Heat Pumps in the Future Energy System

Why do we study demand response with buildings?

Why demand-response?

- The increasing share of Wind and PV in the German energy system causes strong fluctuations in electricity availability
- Demand response is an affordable way to reduce the demand for
  - Electric storage capacity
  - Electric storage power

Why use buildings?

- The collectivity of heat pumps and chillers has a high electric power
- The collectivity of buildings has a high thermal storage capacity
- ➢ The electricity load for heat and cold generation can be shifted, storing the energy as heat or cold

Benefits

- ➢ It can be fully automated. Ideally, the user doesn‘t even notice
- ➢ Low hardware investments required (only controllers, no storages)
- ➢ Small temperature differences due to high thermal mass

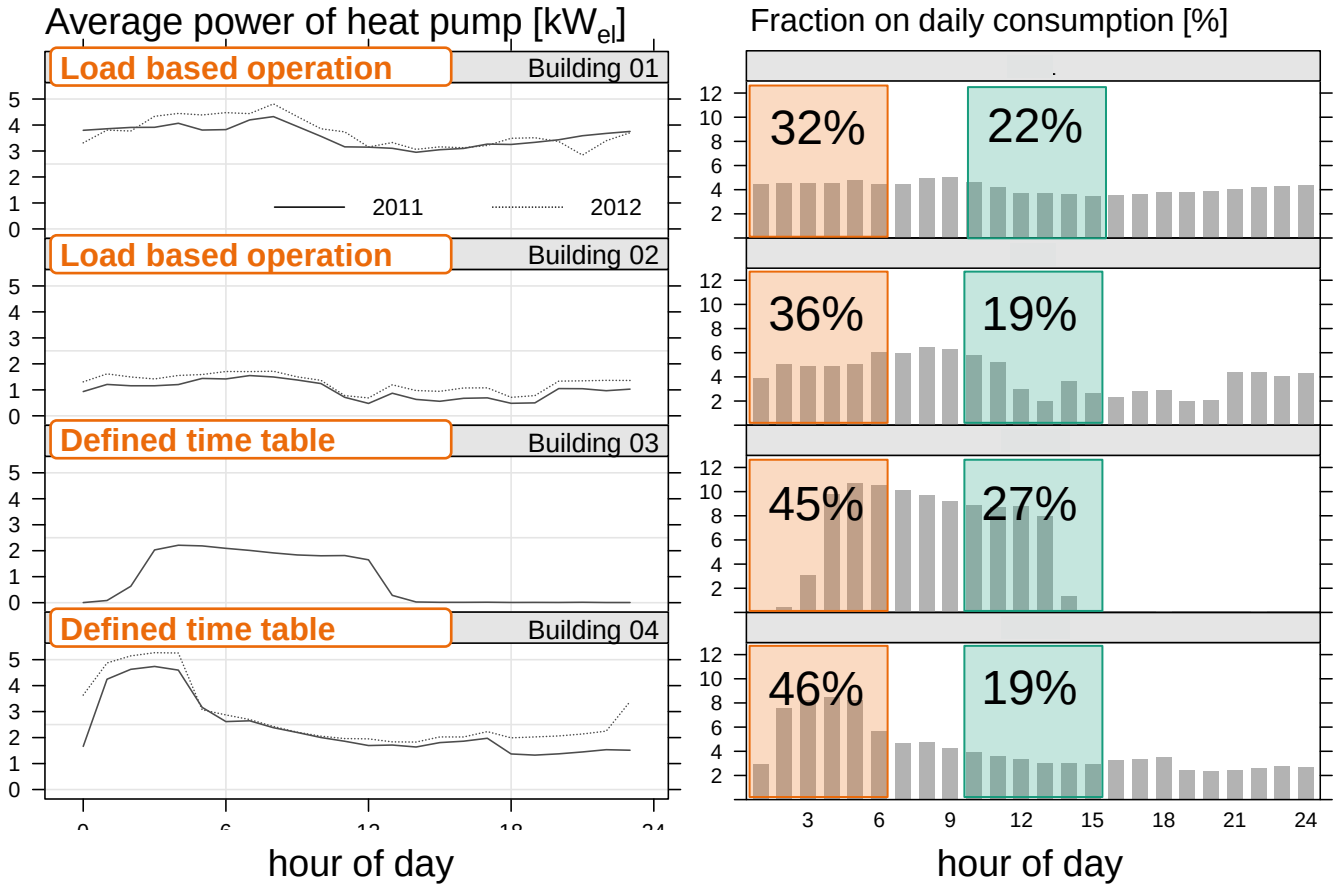
Heat Pumps in the Future Energy System

Towards grid-optimal operation of heat pumps

Consumption with **low** fraction **wind+PV**

Consumption with **high** fraction **wind+PV**

- Different operation modes
  - Load-based
  - Time tables
- Heat generation mostly during night-time → Low fraction of wind + PV



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Summary and Conclusion
Performance evaluation of heat pump systems

- Long experience monitoring and optimization of demonstration buildings
- Performance evaluation of 16 heat pump systems
  - Seasonal Performance Factors between **SPF 2.3 and 6.1 kWh_{therm}/kWh_{el}**
  - High impact of **auxiliary energy**
  - High impact of **hydraulic system design**
- Analysis of **heat pumps in the future energy system**
  - Significant increase in installed heat pump capacity
  - Opportunity of demand side management

Outlook
Heat pump systems in the electrical grid

- Buildings leave a lot of their **potential for grid-support** untapped.
- The easiest way to improve grid-interactivity is to reduce electricity consumption in the morning and the evening.
- In order to make buildings highly grid-interactive, large thermal storage capacities are required, i.e. activation of the thermal mass. This requires sophisticated control strategies in order to retain thermal comfort.
- Further information:
  - Annex 67: Energy Flexible Buildings
  - German Project: Grid-supportive Buildings and Communities (www.netzreaktivegebaeude.de)

Thank you for your attention!

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