SYSLAB - a research facility for future intelligent, active and sector coupled energy systems

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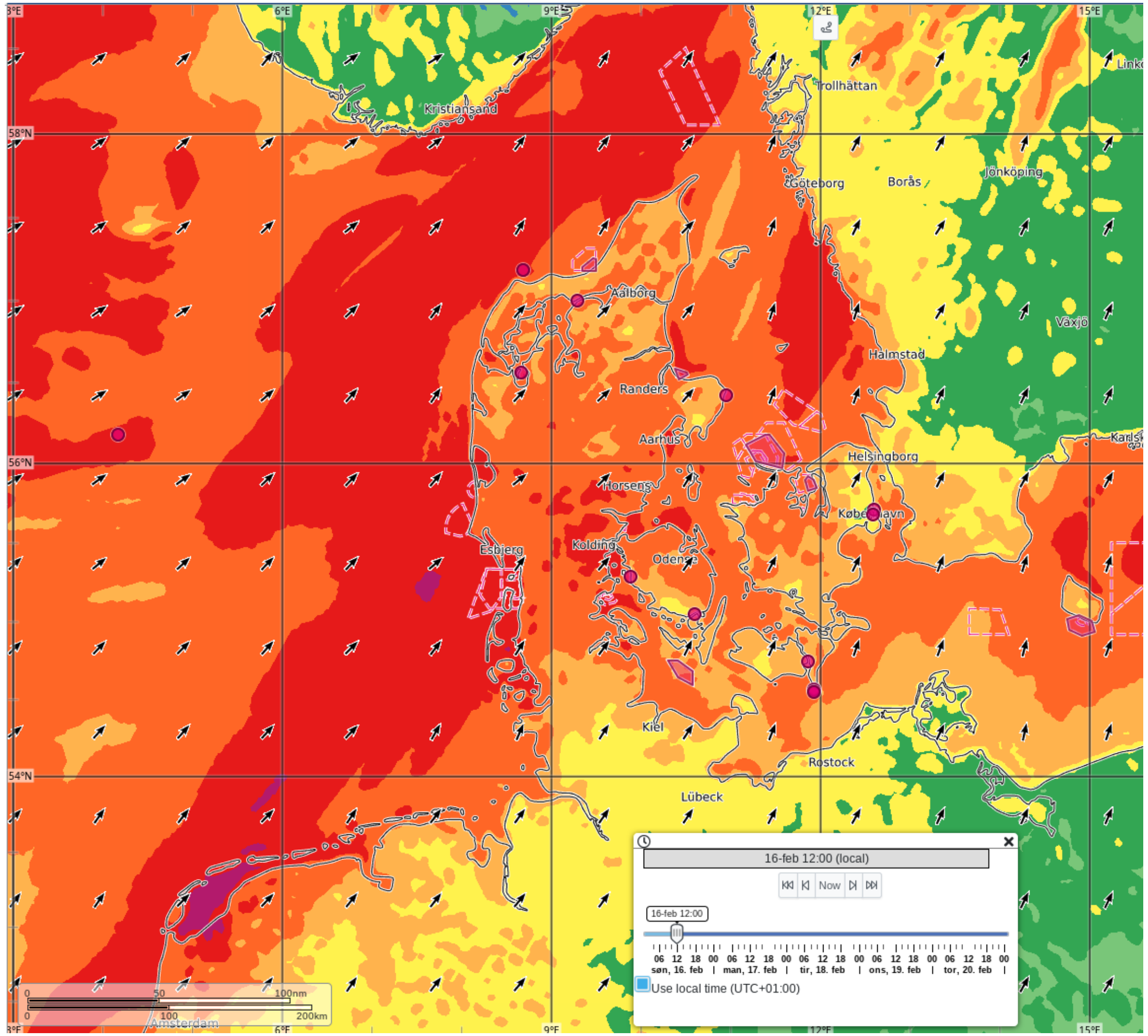
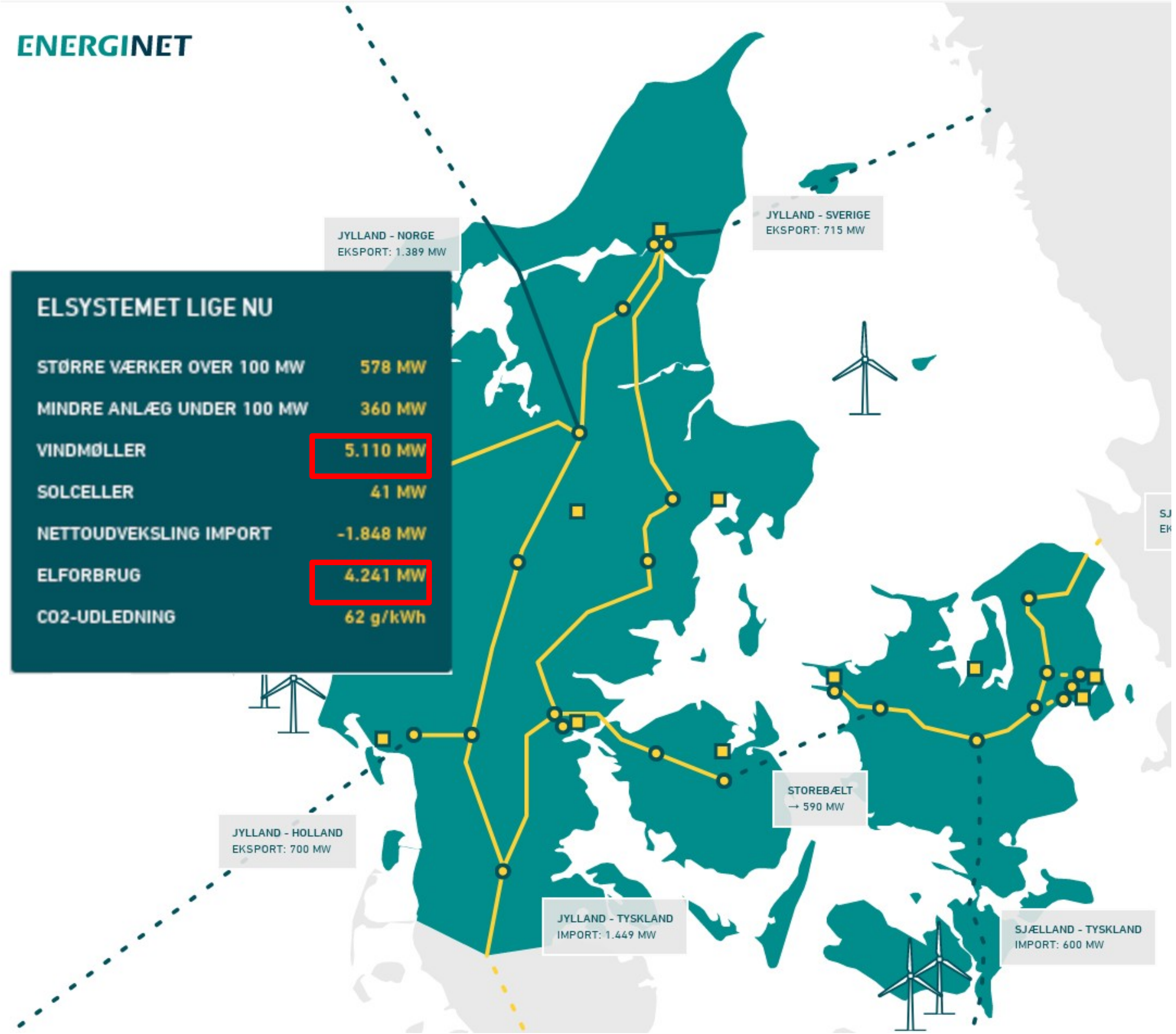
PowerLabDK

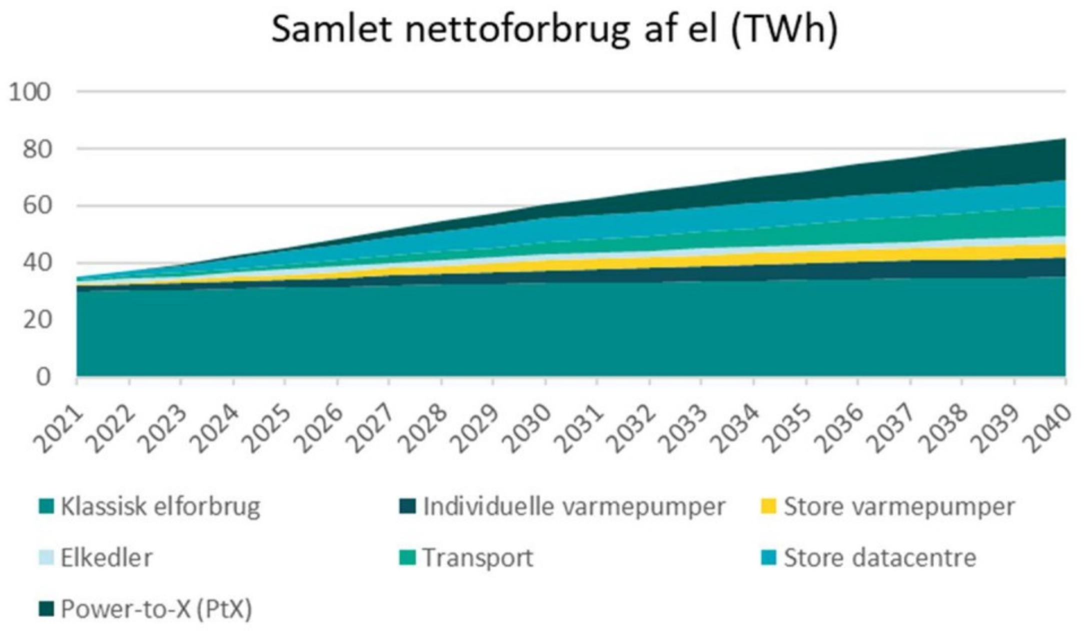
North Sea storm, 16/02/2020

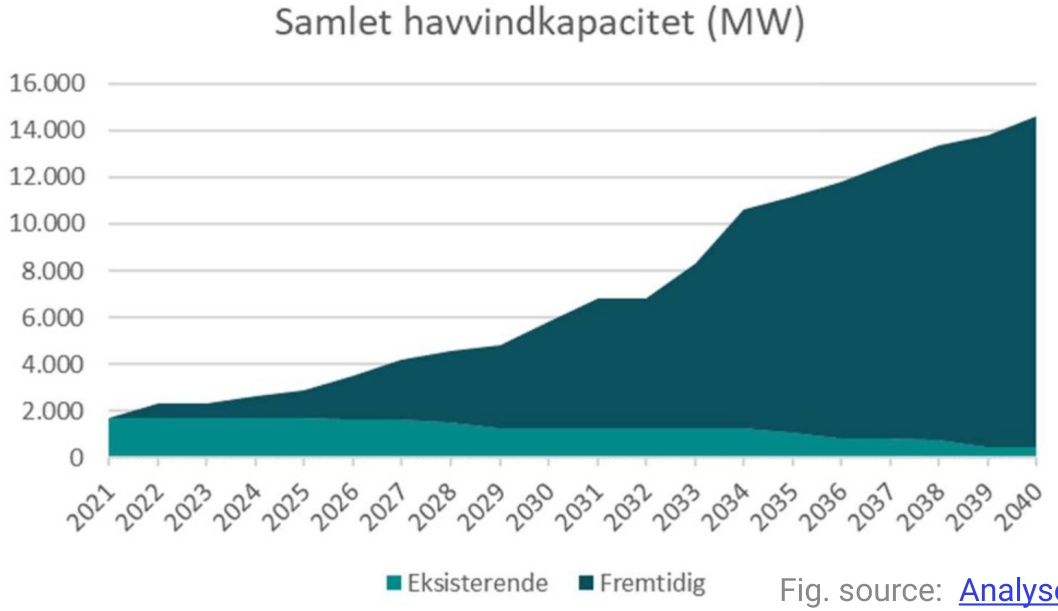




Drivers for grid transformation in DK

- Annual "known policy" analysis (DK Energy Agency, 2021): *Renewables outgrow demand*
- Electrification will stress distribution grids
- Dedicated, stationary electrical storage is not attractive at a large scale
- Conversion to other forms of energy (sector coupling) can help to solve several issues at once.





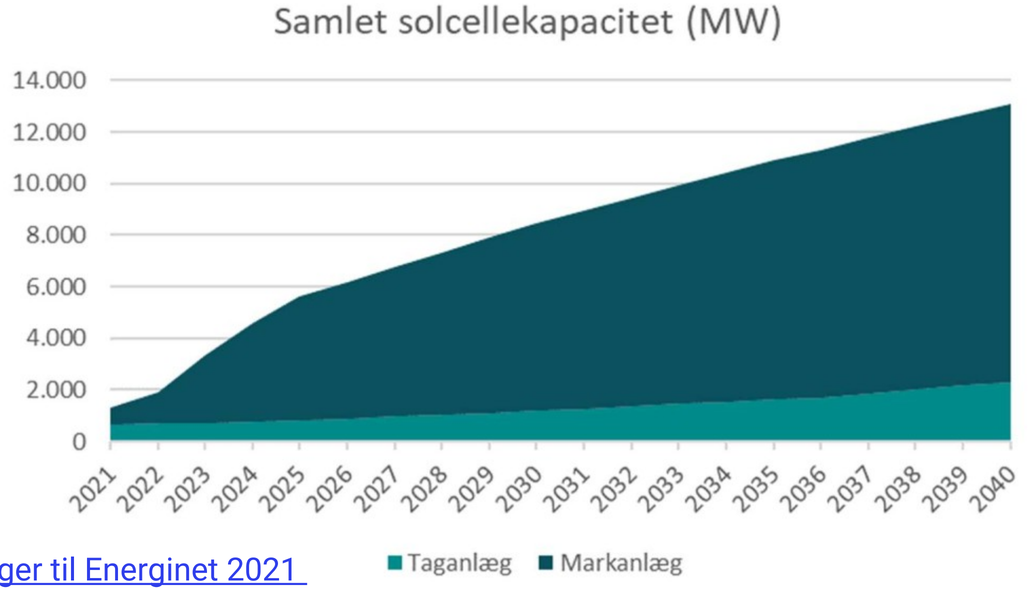
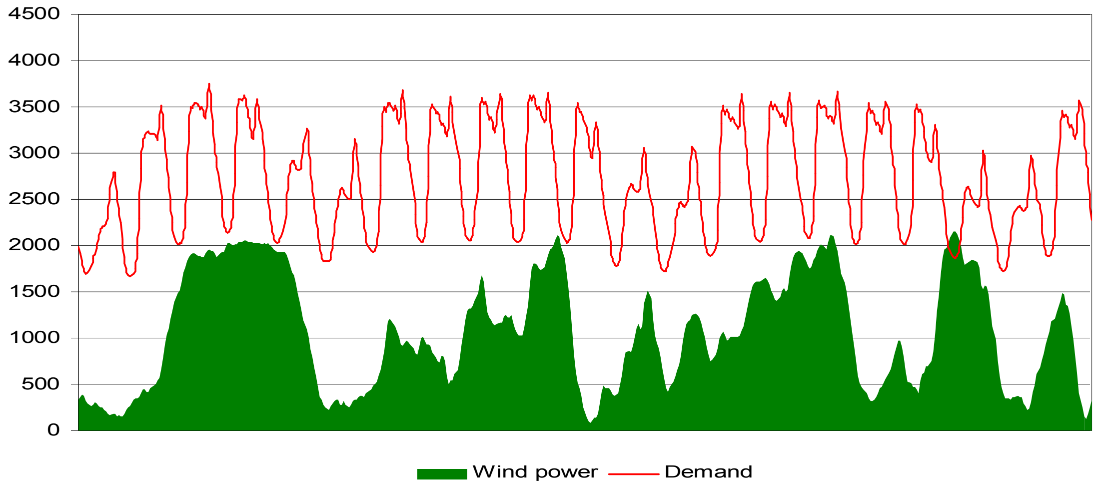


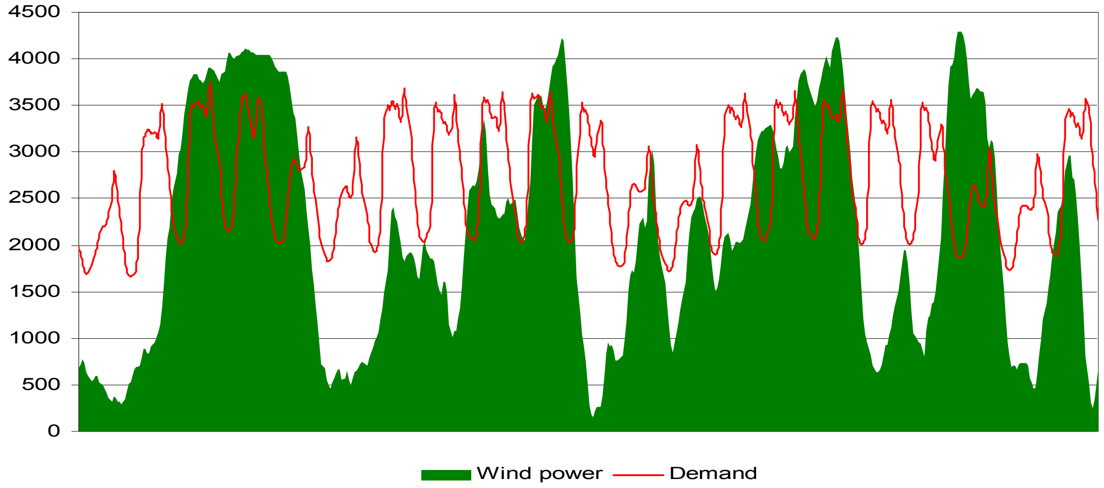
Fig. source: [Analyseforudsætninger til Energinet 2021]

Towards 100% renewables

- Already at 20% wind penetration in DK (~15 years ago), wind production exceeded total consumption on some occasions
- In an otherwise unchanged energy system with 80% wind and 20% PV, overflow would be massive.
- In a business-as-usual scenario, renewable production would have to be curtailed for thousands of hours per year.



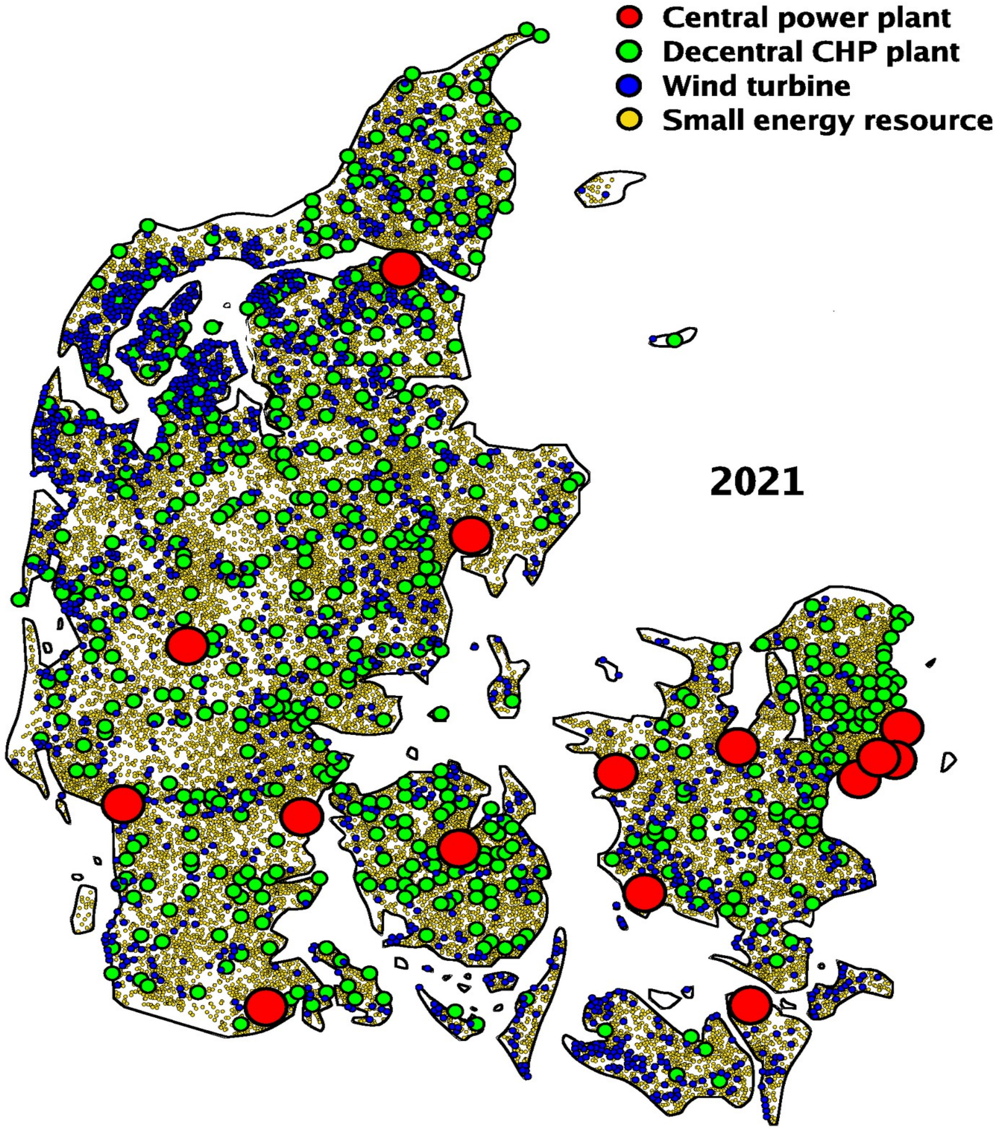
DK West, January 2008



DK West + 3GW

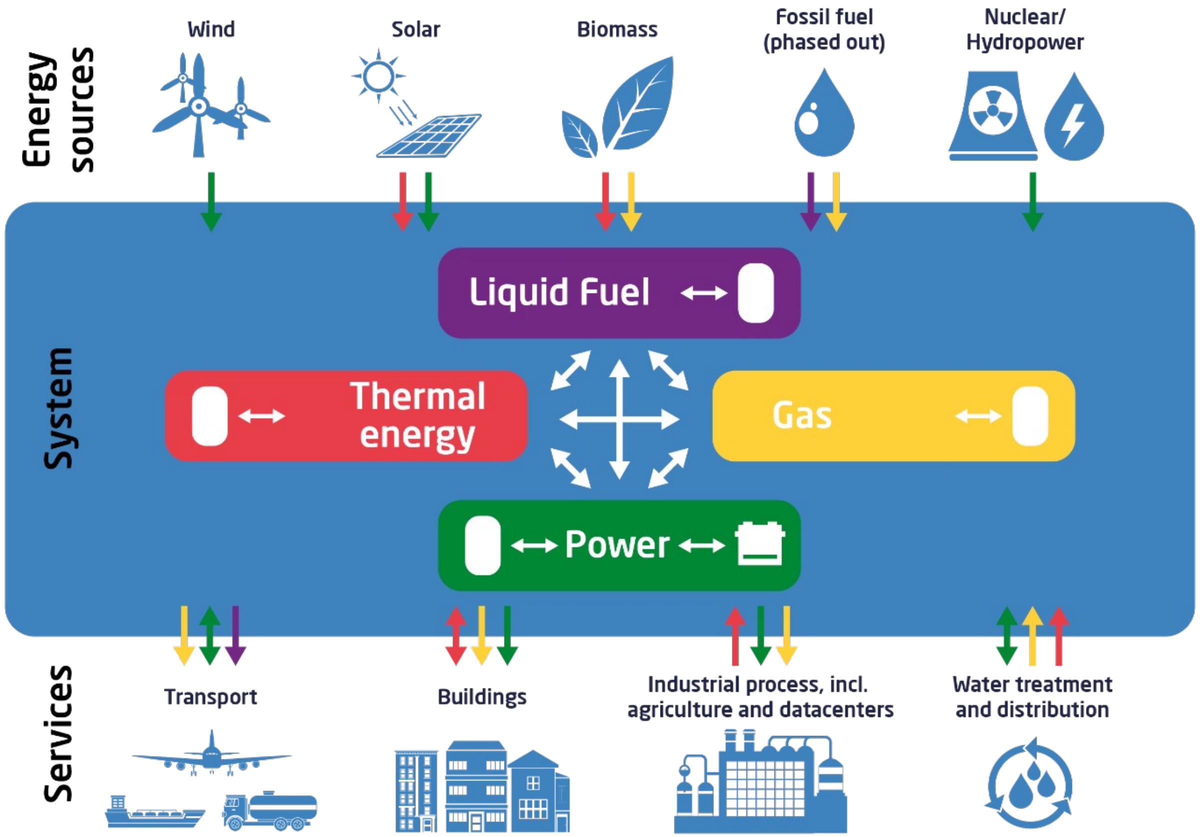
Contribution of small DER

- The impact of traditional providers of system services (power balancing, voltage regulation etc.) is decreasing
- In a grid with a high penetration of fluctuating sources, system services will have to be provided by all capable units
- System integration and control of small DER is necessary, particularly with respect to flexible demand.
  - Heating (air, water)
  - AC and refrigeration
  - Battery charging (EVs in particular)
  - Fans and pumps
  - Lighting (some applications, e.g. greenhouses)



Smart grids -> Smart energy systems

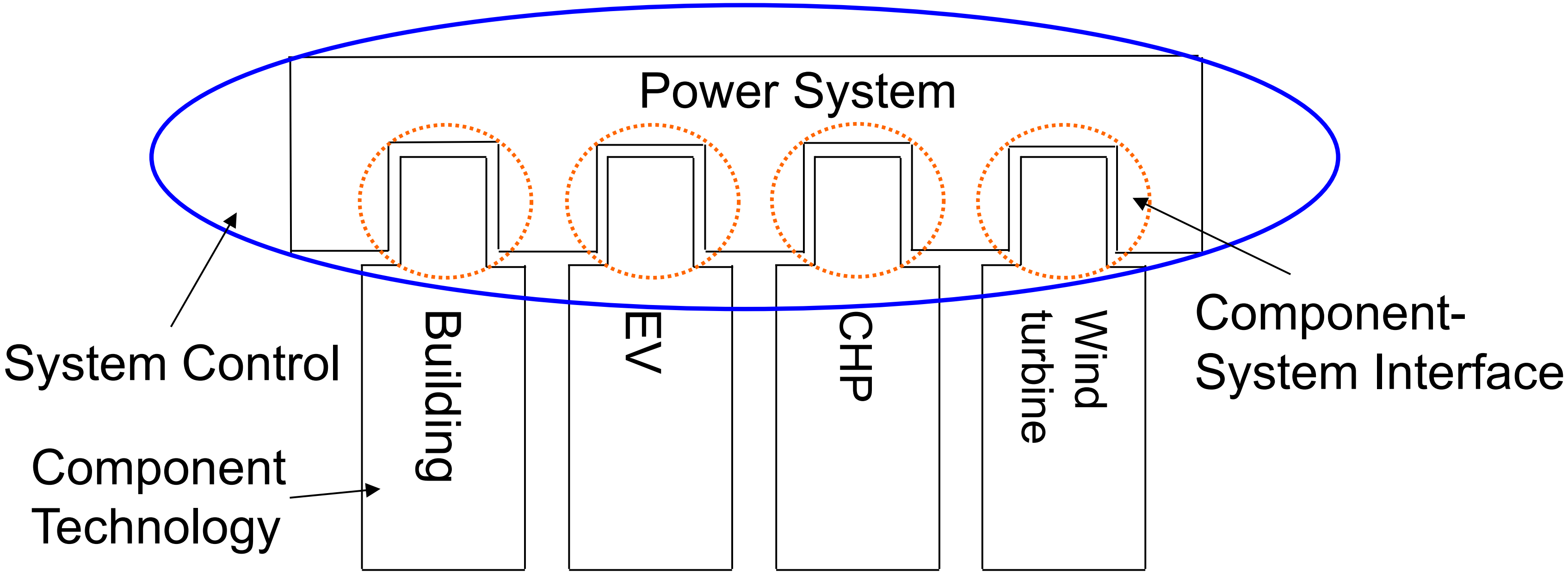
- A significant portion of electricity consumers have potential for some form of **intrinsic rather than dedicated storage**
  - The heat capacity of buildings, commercial as well as domestic
  - Goods in cold stores
  - Batteries in Electric Vehicles
  - Hot water in the district heating system
  - Power2Gas or similar technologies
  - …
- Leveraging this **flexibility potential** requires **coordinating control** between all units and the infrastructure networks.



SYSLAB: Early design sketch

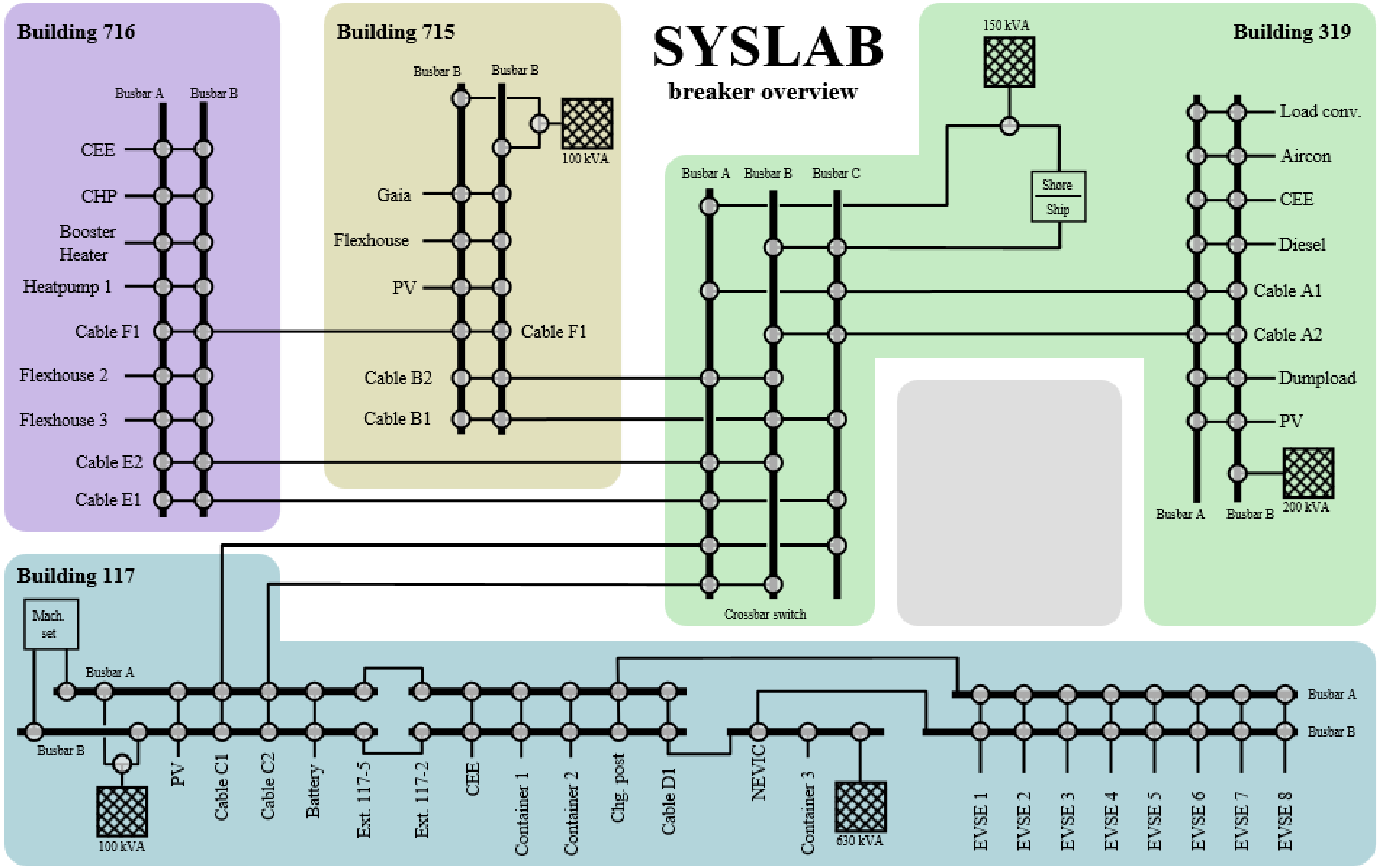
Test bed for system control concepts

- Distributed and decentralized control:
  Aggregation, VPP, micro grids, agents, local energy markets,...
- Implementation and utilisation of demand response
- Testing of communication protocols and data models



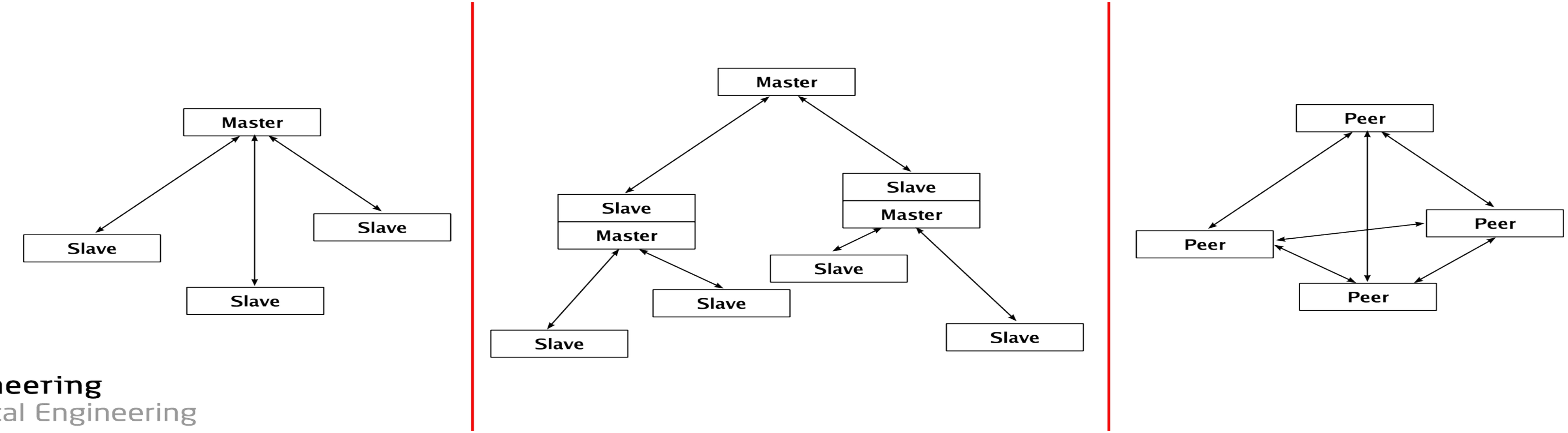
SYSLAB – Electrical system (before upgrade)

- 400V, 16-busbar grid
- 4.5 km of cables
- ~35 energy resources
  - Generation: Wind, PV, fossil
  - Consumption: Smart buildings, power-to-heat, EVs, heat pumps...
  - Storage: Vanadium battery, lithium batteries, supercap, vehicle-to-grid

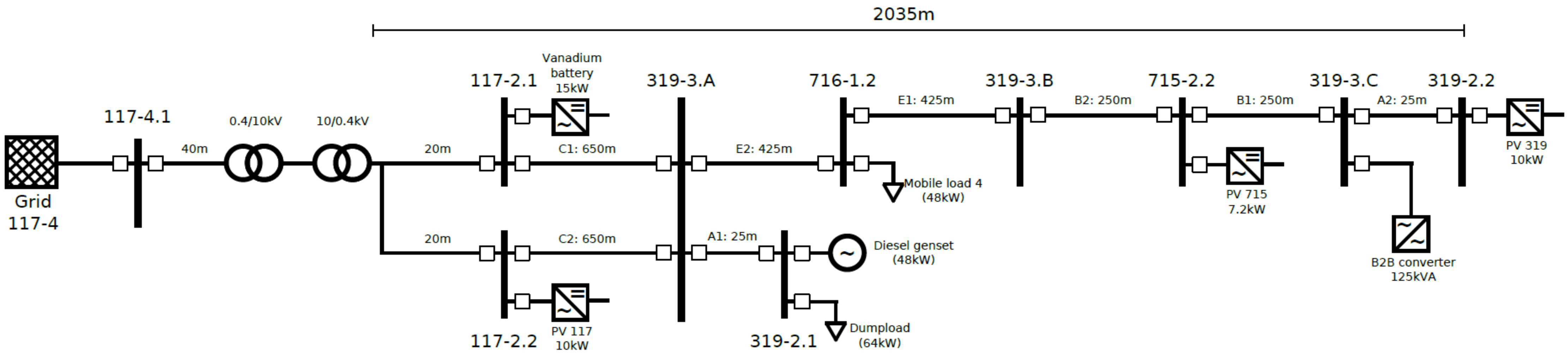


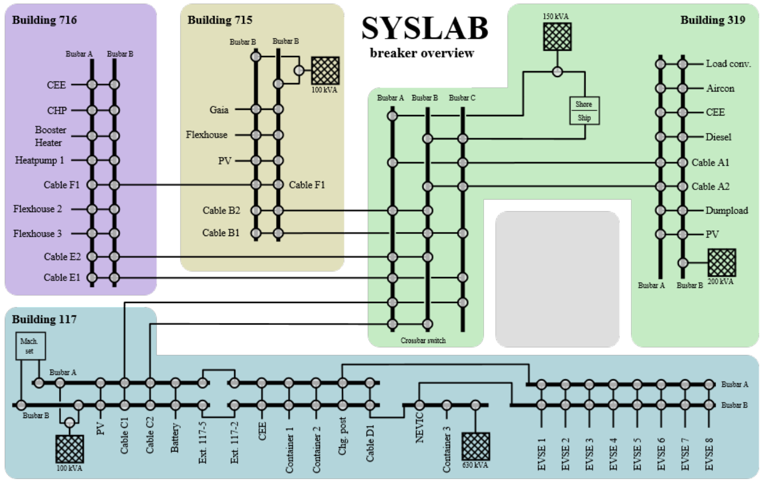
Lab testing of control architectures

- In order to work as a test bed for different smart grid concepts, the facility should not enforce a particular control architecture by design
- Every energy resource in SYSLAB has its own controller node, with no implicit assumption about the relationship between nodes.
- Interactions between entities are defined in software, not hardware
- Integration of off-site (remote) controllers should be similar to on-site controllers.



Example configurations (I)

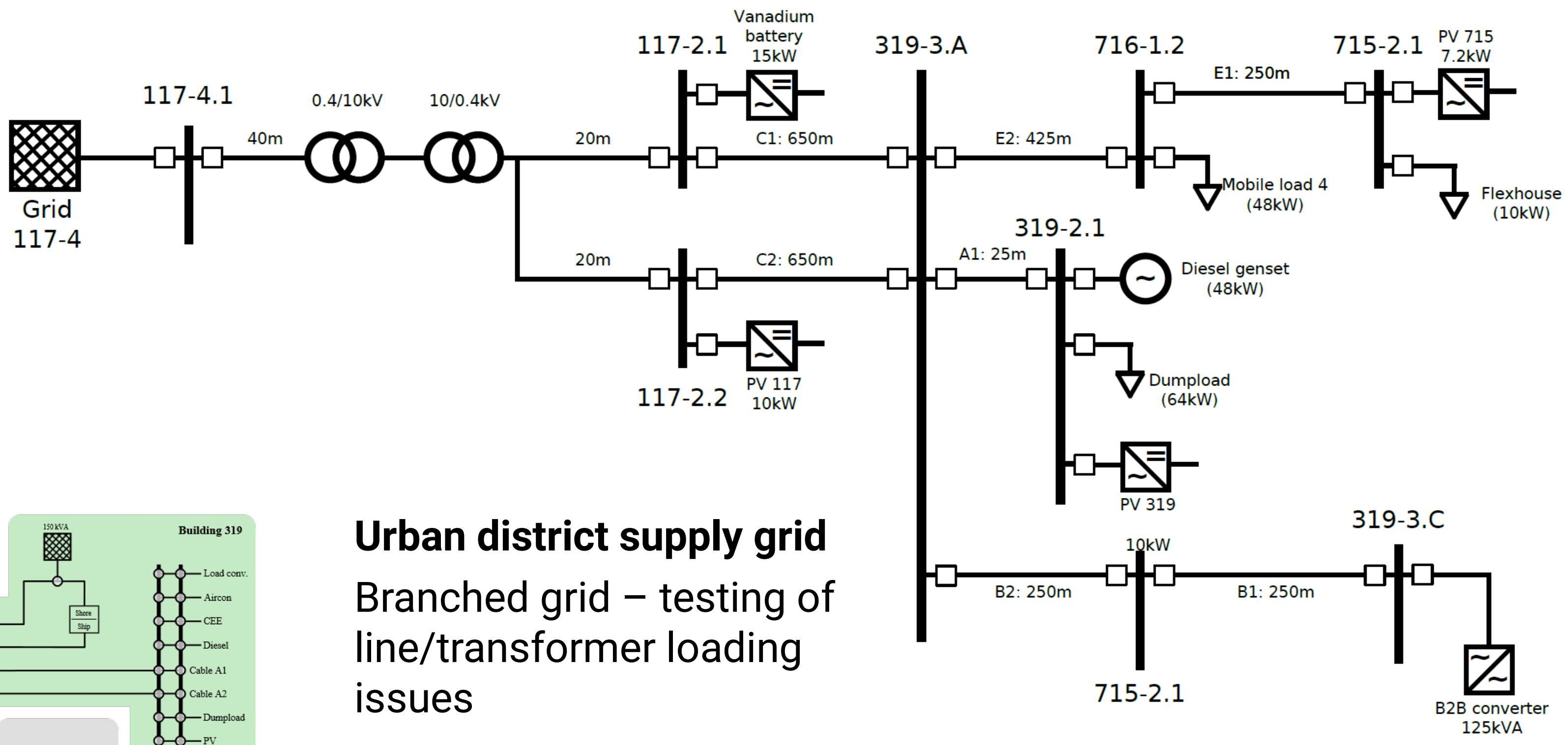




Rural district supply grid

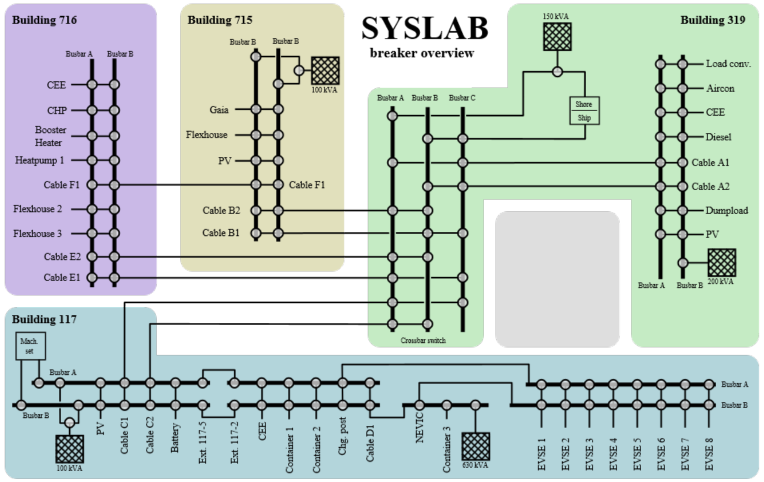
Long, weak feeders with PV – test of voltage regulation issues

Example configurations (II)



Urban district supply grid

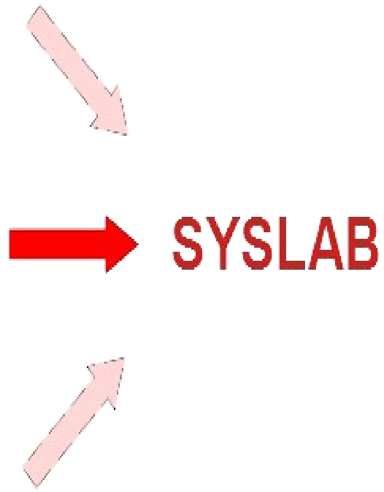
Branched grid – testing of line/transformer loading issues



What can SYSLAB be used for?

Development and testing of energy system components in isolation (Component testing lab)

Development and testing of integration and control solutions for components in a semi-realistic (emulated) energy system (System integration testing lab)



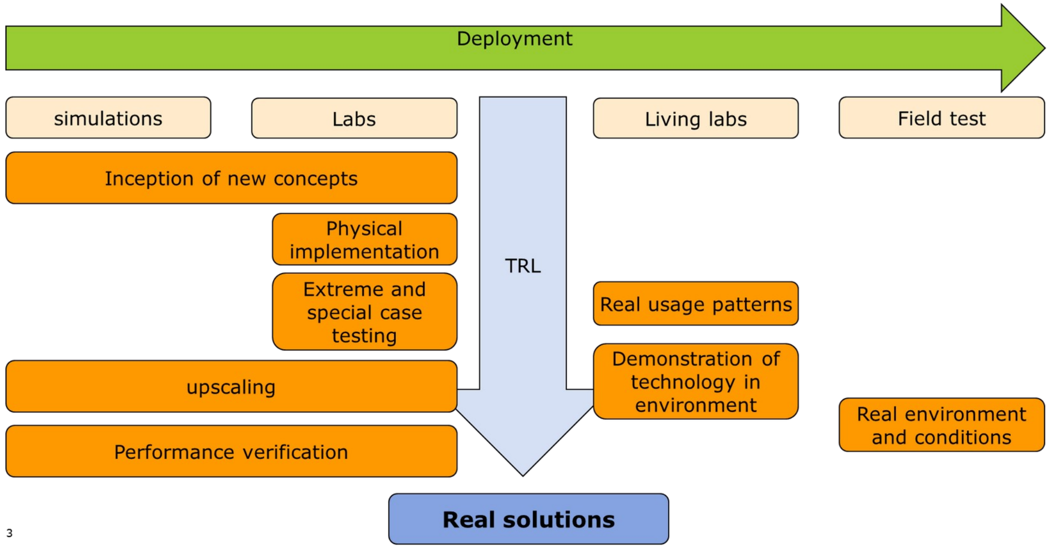
Testing under realistic but controlled field conditions (Living lab)

Full field test

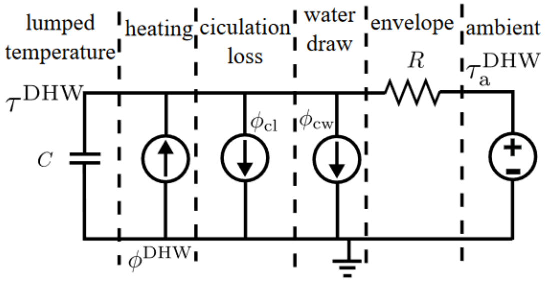
Toolchain from idea to rollout

Laboratory

Simulation and testing facilities



Simulation



Components

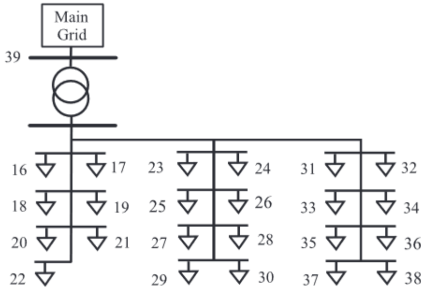
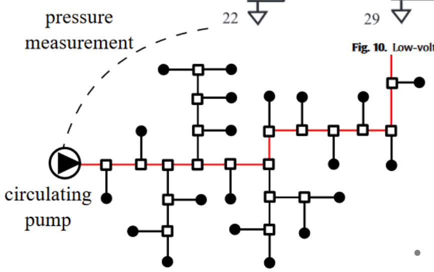


Fig. 10. Low-voltage network.



Grids / Infrastructure

Living labs

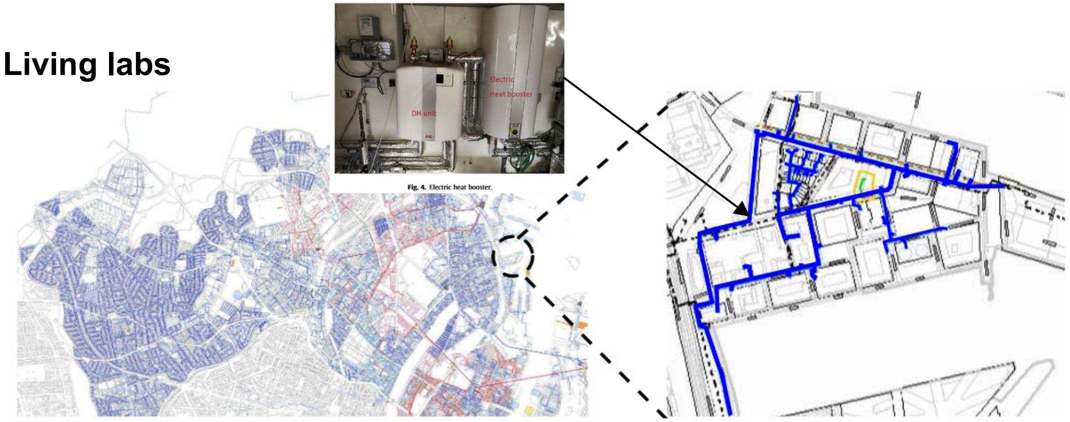
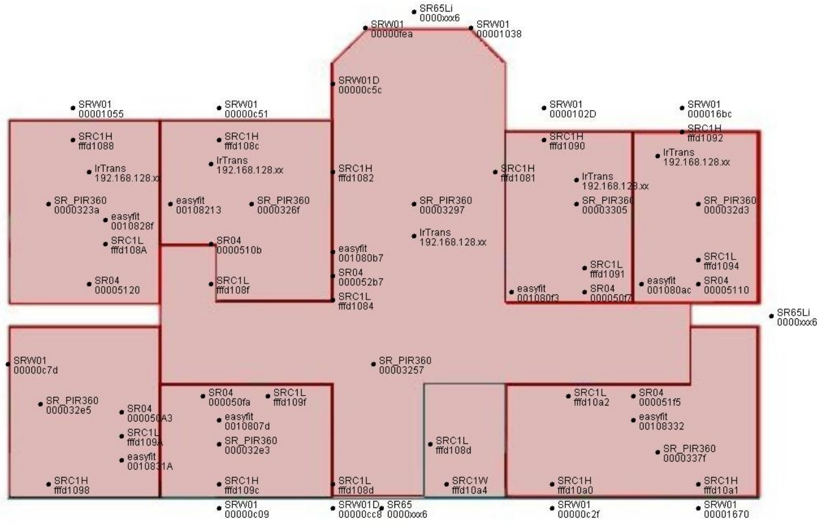


Figure 5: Nordhavn DH distribution network (right) as a part of a city-scale DHN (left)

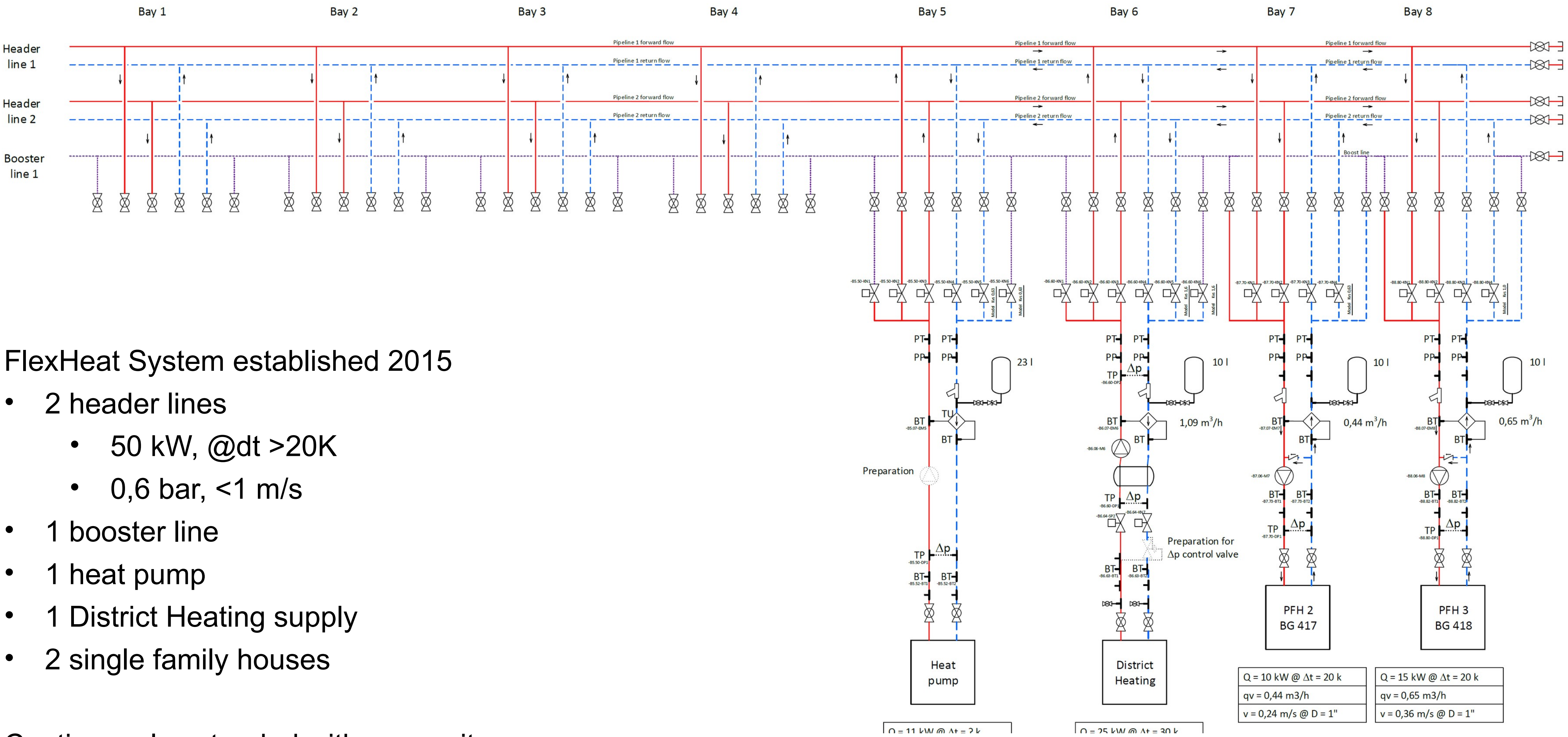
- Cai H, Ziras C, You S, et al. Demand side management in urban district heating networks[J]. Applied energy, 2018, 230: 506-518. link
- Cai, H., You, S., Wang, J., Bindner, H. W., & Klyapovskiy, S. (2018). Technical assessment of electric heat boosters in low-temperature district heating based on combined heat and power analysis. *Energy*, *150*, 938-49. https://doi.org/10.1016/j.energy.2018.02.084

Flexhouses I-III

- Former office building (electrical heating) and two single-family houses (water-borne heating)
- 50+ sensors per building (temperature, light, occupancy, meteorology etc.)
- Control of radiators, appliances, light
- Custom building controllers can be deployed
- Electrical/thermal and IT integration with SYSLAB



Energy System Integration Lab – SYSLAB
Present FlexHeat System



FlexHeat System established 2015

- 2 header lines
  - 50 kW, @dt >20K
  - 0,6 bar, <1 m/s
- 1 booster line
- 1 heat pump
- 1 District Heating supply
- 2 single family houses

Continuously extended with new units

Energy System Integration Lab - SYSLAB
Present FlexHeat System

Energy System Integration Lab - SYSLAB
Example of use

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Experimental evaluation of an integrated demand response program using electric heat boosters to provide multi-system services

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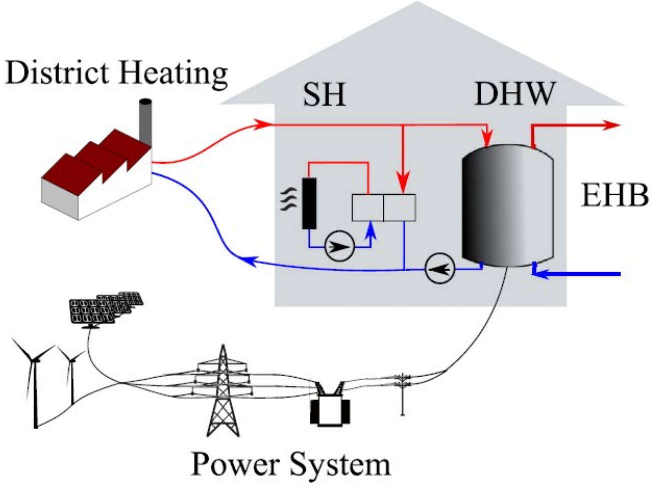
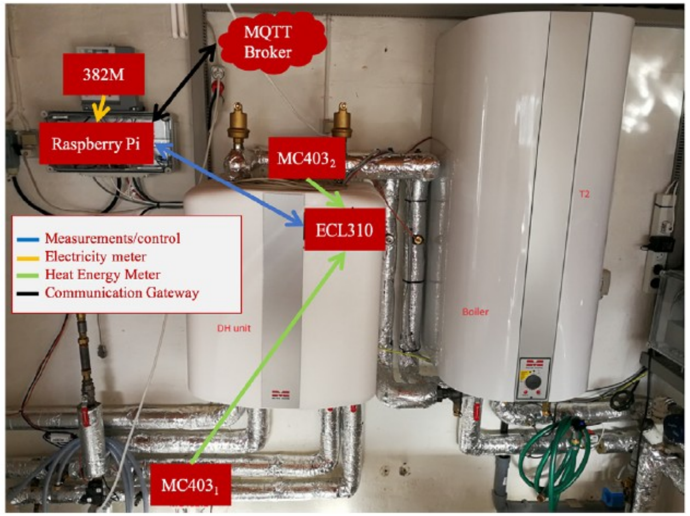
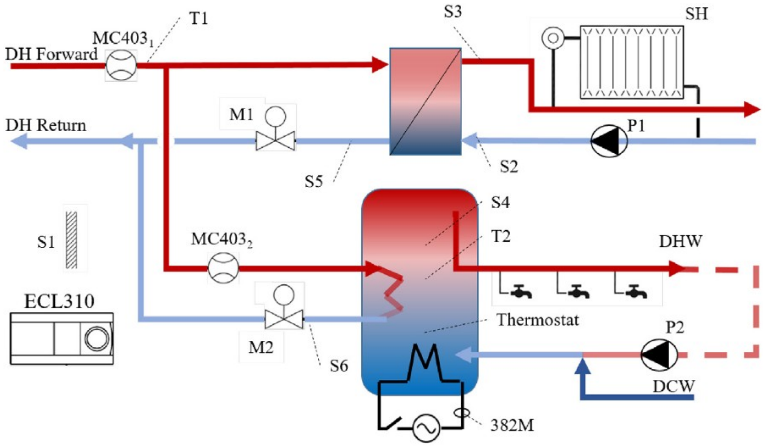
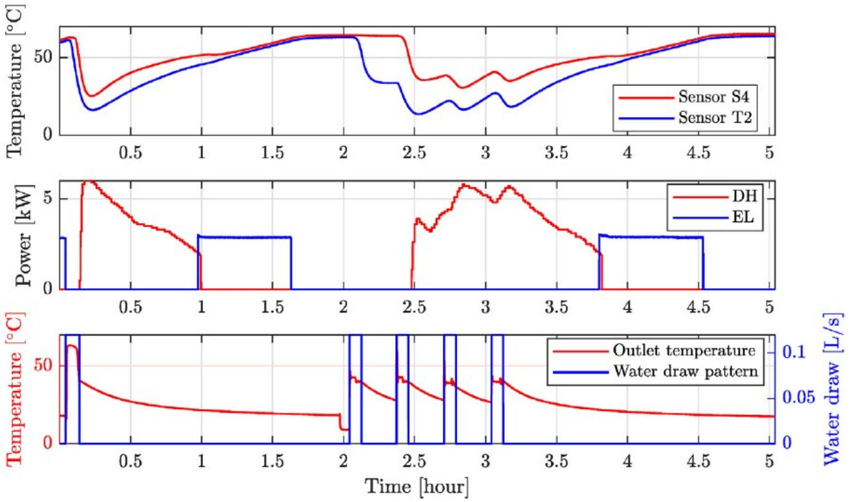




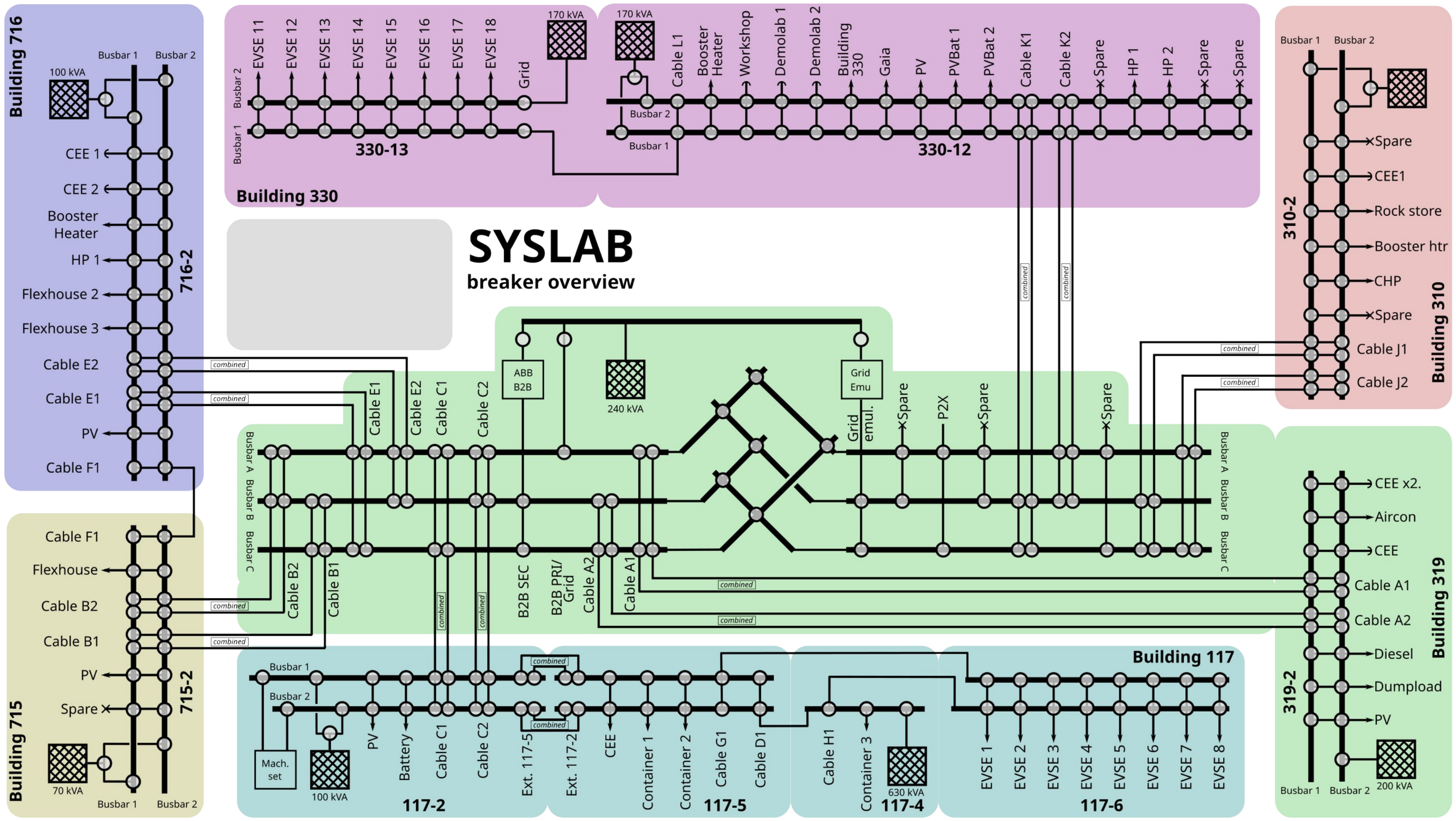




Energy System Integration Lab – UNILAB extension of SYSLAB (2022/2023)

SYSLAB – Electrical extension (→end Q2/2023)

- Backbone capacity upgrade (100/200kVA lines, 400kVA crossbar)
- Extension from 4 to 6 sites
- Additional components (PV, storage, office building, EVSEs, P2H units)
- Integration with district heating network



SYSLAB – Heat extension (→end Q4/2023)

- New multi-site district heating network
- Interconnections at 4 (+1) of the 6 electrical sites
- Additional heat components (P2H units, CHP, gas boiler, heat pumps, heat storage, solar thermal generation)
- Integration with electrical network