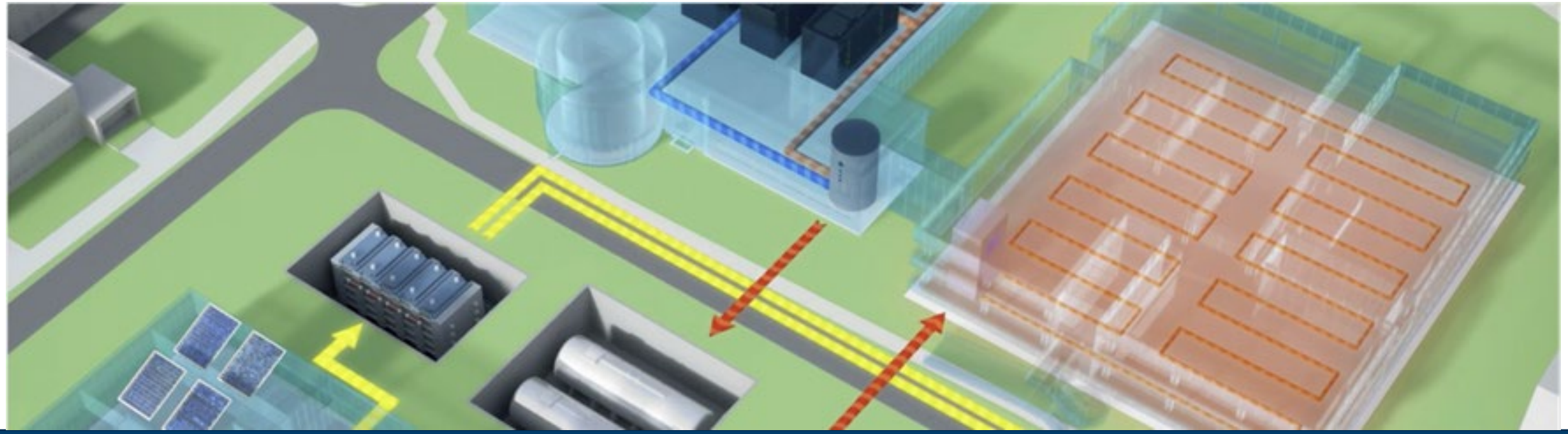


EFFICIENT HEAT SUPPLY FOR OFFICE BUILDINGS

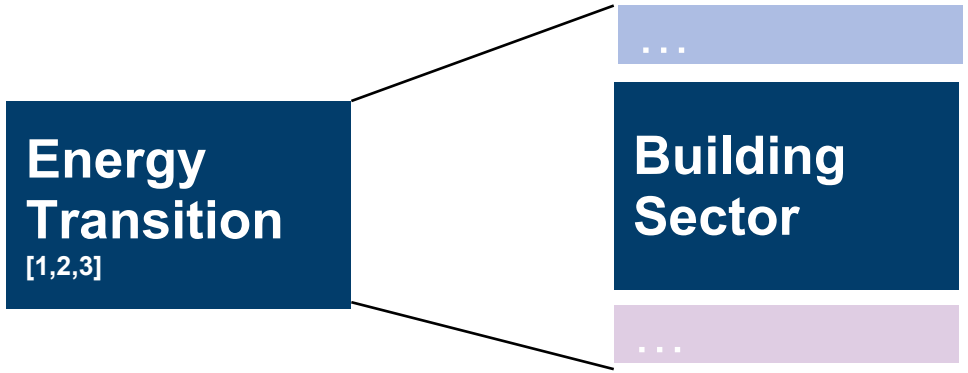
A research journey through different heat supply levels at the campus of Forschungszentrum Jülich

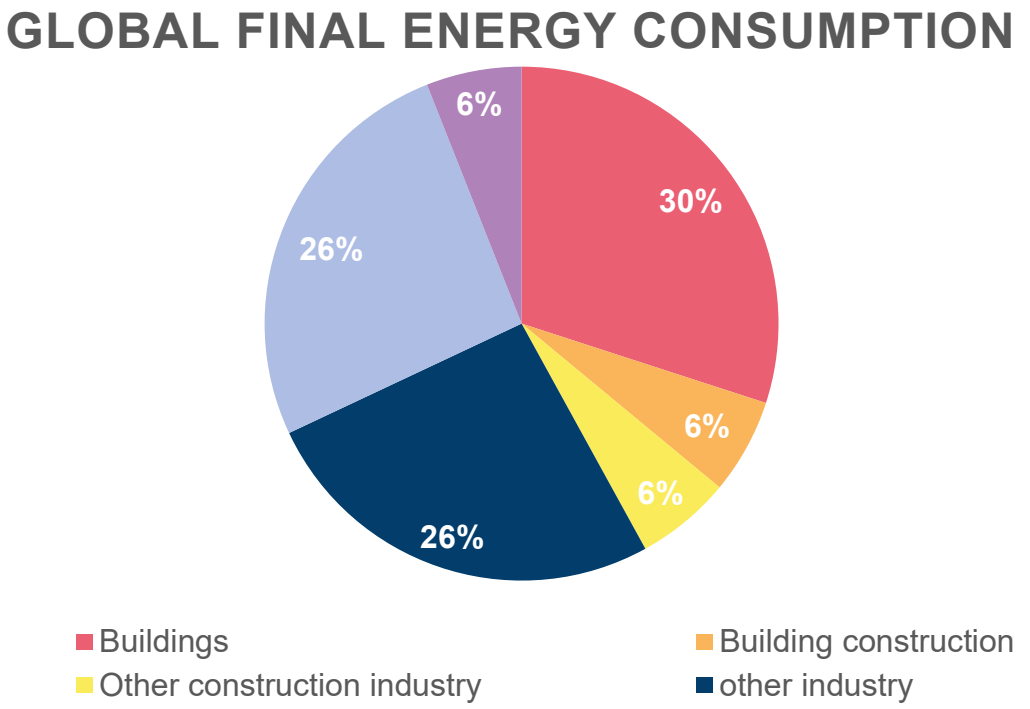
13/06/2023 | P. ALTHAUS (FZJ IEK-10) | HELMHOLTZ ENERGY CONFERENCE 2023 | KOBLENZ

Philipp Althaus, Dominik Hering, Sascha Johnen, Christian Küpper, Paul Lieberenz, Maximilian Mork, Jana Pick, Lea Riebesel, Florian Redder, Marek Schmülgen, Jan Stock, Eziama Ubachukwu, Lidia Westphal, Dirk Müller, André Xhonneux

MOTIVATION

General problem

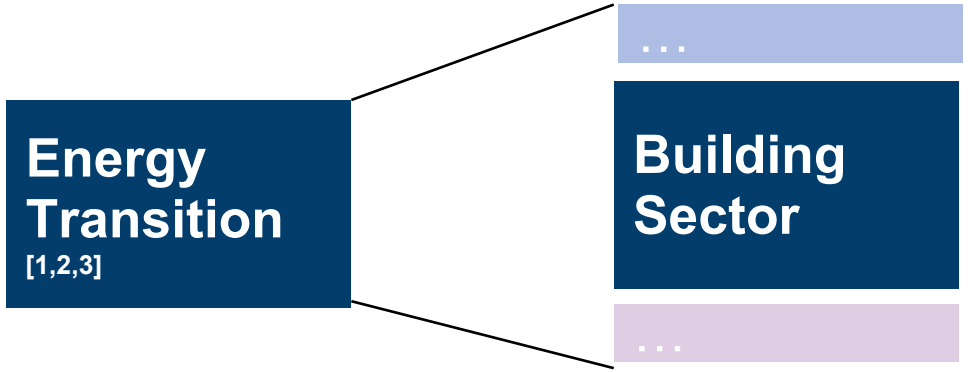


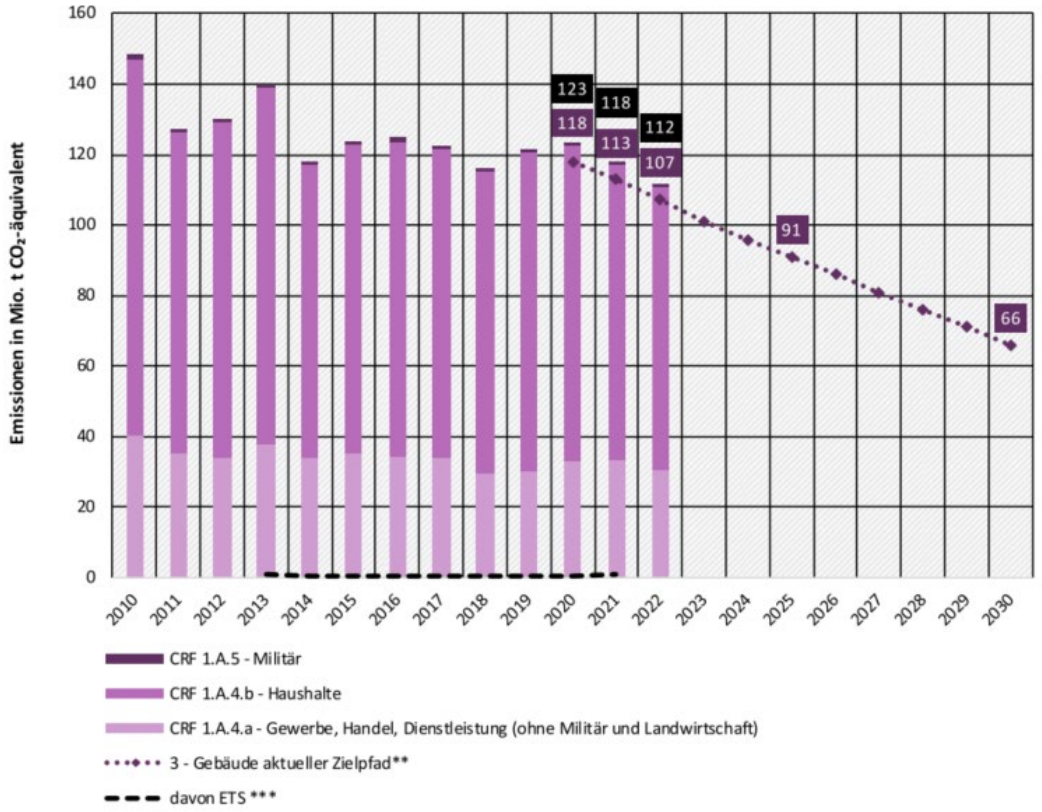


[1] IPCC. Global Warming of 1.5 C. Geneva, Switzerland, 2018. Available online: https://www.ipcc.ch/sr15/download/ (acc.: 27 February 2022).
[2] UNFCCC: Paris Agreement, 2015. Available online. https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf (acc. 30.05.2023).
[3] European Commission: The European Green Deal, 2019.
[4] taken with changes from: United Nations Environment Programme: 2021 global status report for buildings and construction, 2021

MOTIVATION

General problem



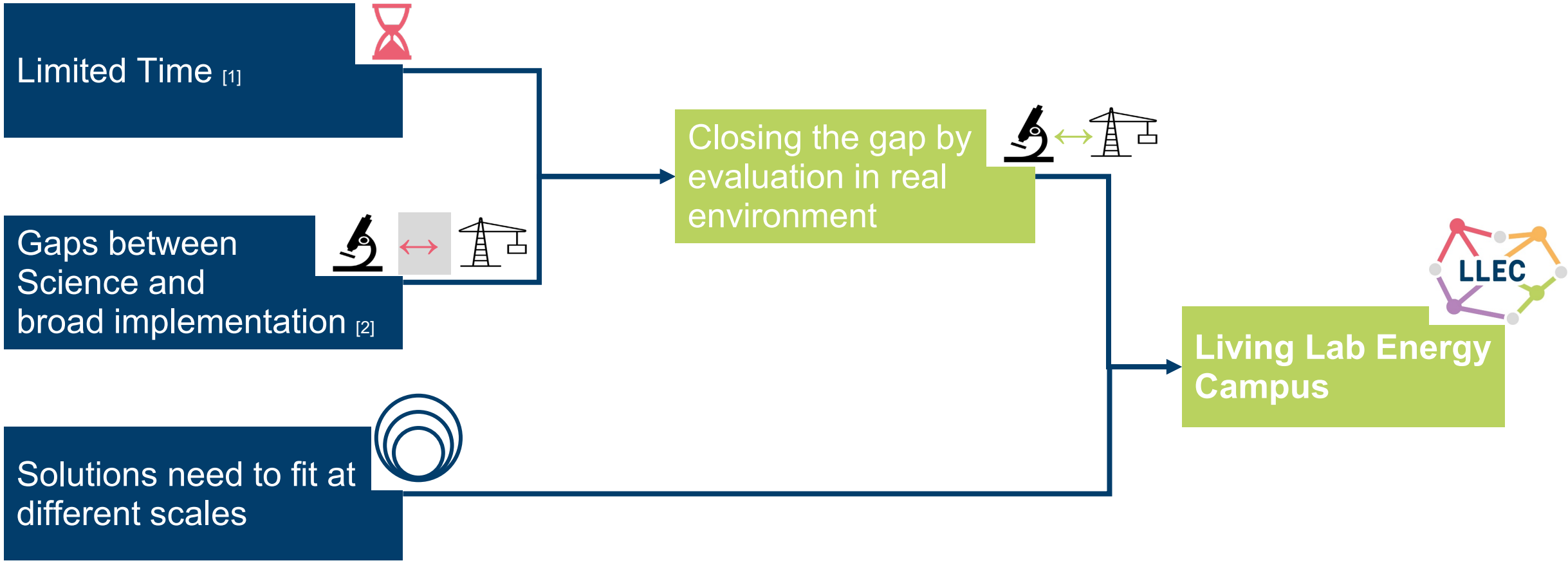


[4]

[1] IPCC. Global Warming of 1.5 C. Geneva, Switzerland, 2018. Available online: https://www.ipcc.ch/sr15/download/ (acc.: 27 February 2022).
[2] UNFCCC: Paris Agreement, 2015. Available online. https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf (acc. 30.05.2023).
[3] European Commission: The European Green Deal, 2019.
[4] taken with changes from: Günther, D., et al.: Berechnung der Treibhausgasemissionsdaten für das Jahr 2022 gemäß Bundesklimaschutzgesetz, 15.03.2023.
.

MOTIVATION

Living Lab Energy Campus (LLEC)



[1] IPCC. Global Warming of 1.5 C. Geneva, Switzerland, 2018. Available online:https://www.ipcc.ch/sr15/download/ (acc.: 27 February 2022).
[2] Drgoňa, J., et al.: All you need to know about model predictive control for buildings, 2020.

THE CAMPUS INFRASTRUCTURE

FZJ campus as a test-bed for real-world testing innovative monitoring and control approaches

- > 150 buildings with different uses
- > 6.500 employees

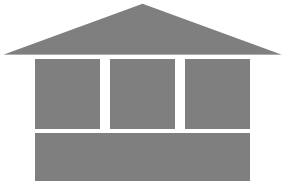
- District networks
  - Electricity
  - **Heat**
  - Cold
  - Gas

CONNECTED SCALES

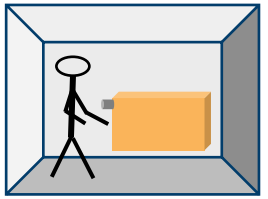
District heating

[1]

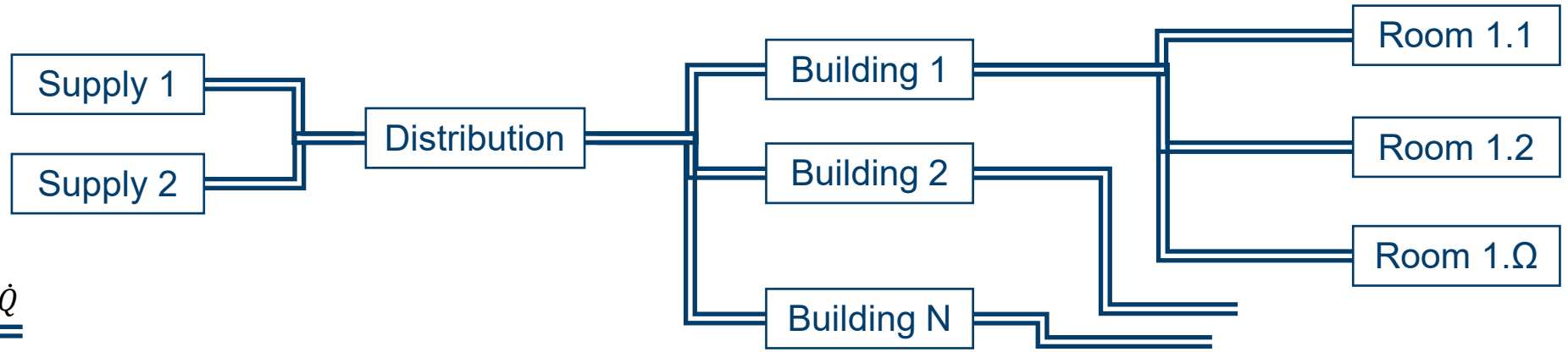
Building



Room



Scale

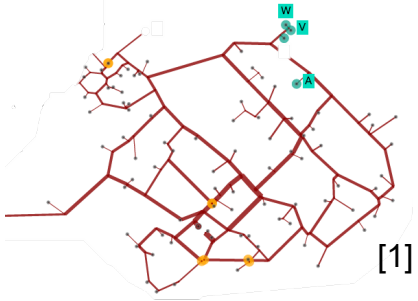


$\dot{m}, \Delta T, \dot{Q}$

[1] with changes from: Stock, Arjuna, Xhonneux, Müller; 2023: Modelling of Waste Heat Integration into an Existing District Heating Network Operating at Different Supply Temperatures

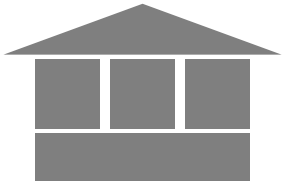
CONNECTED SCALES

District heating

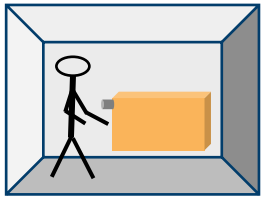


[1]

Building



Room



Scale

$\dot{Q}_{demand}$ $k_{comfort}$

$\dot{Q}_{loss} \searrow$ $CO_{2,eq} \searrow$

€ $\rightarrow \searrow$

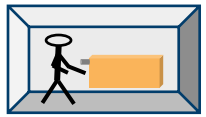
Waste heat integration ↗ | ... | Efficiency ↗

[1] with changes from: Stock, Arjuna, Xhonneux, Müller; 2023: Modelling of Waste Heat Integration into an Existing District Heating Network Operating at Different Supply Temperatures

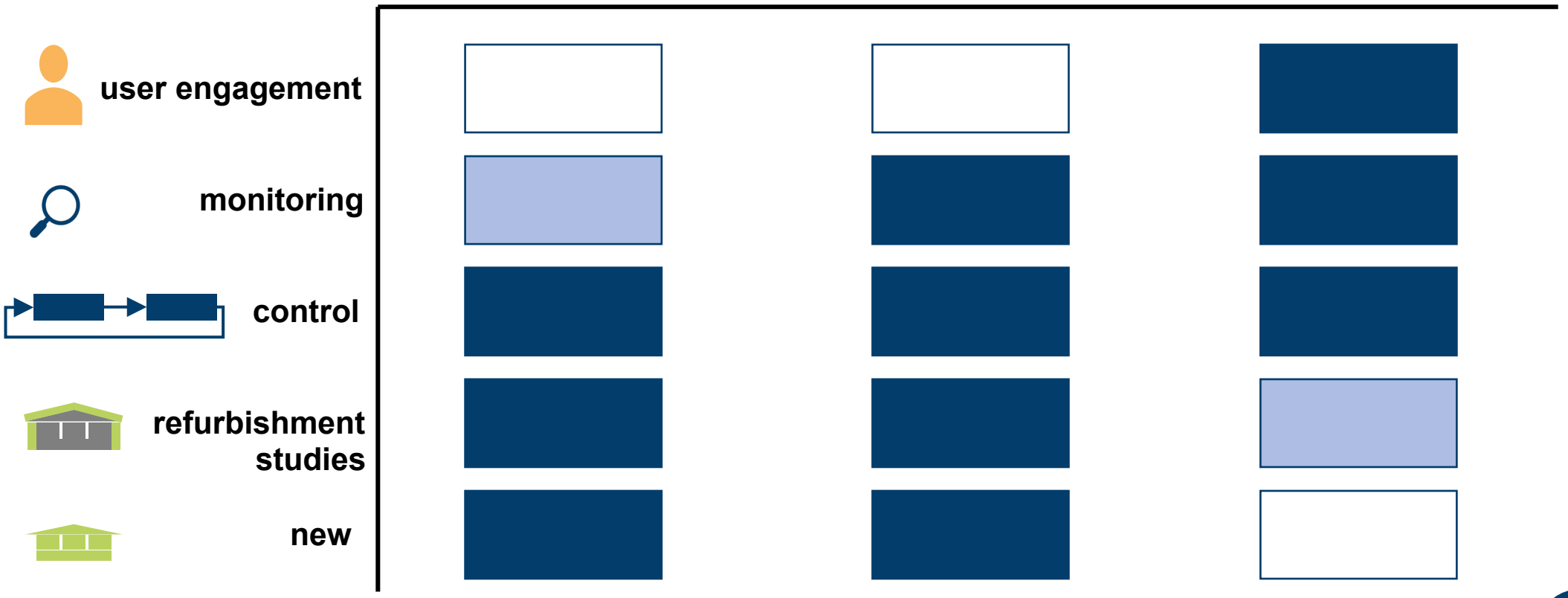
LLEC: AREAS OF RESEARCH IN HEATING SECTOR

District

Building



Room

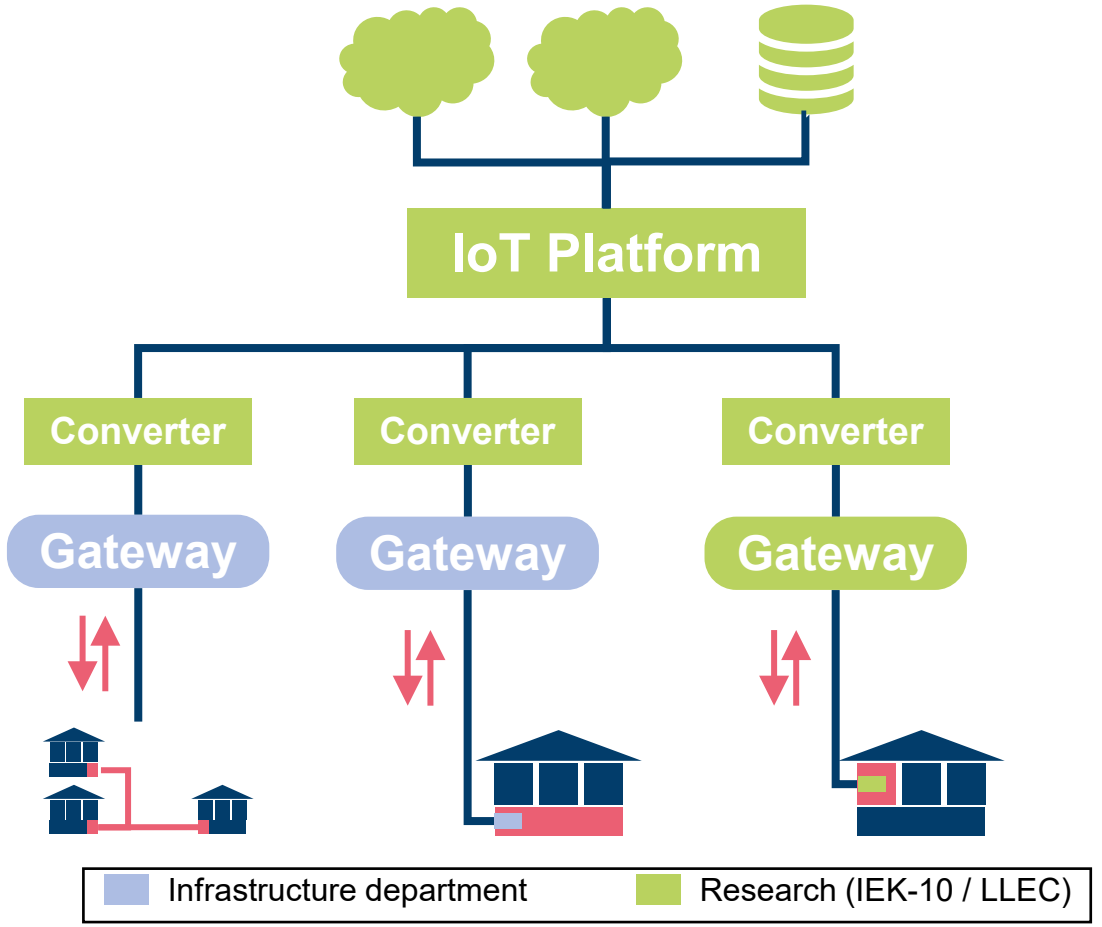


INFRASTRUCTURE

Information and Communication Technologies (ICT) as „connecting point“

- Challenge: heterogeneous data sources and data points

- ICT and IoT necessary to
  - Access field level bidirectionally
  - interconnect components
  - Unify raw data
  - Store data



DISTRICT LEVEL

Demonstration of low-temperature district heating with HPC waste heat usage [1]

Water-cooled high-performance computer (HPC)

➔ ~ 1.2 MW heat

➔ ~ 30 - 45 °C return temperature

➔ ~ 20 °C flow temperature

7 Existing buildings

➔ Design Temperatures 70/55 °C

New office building

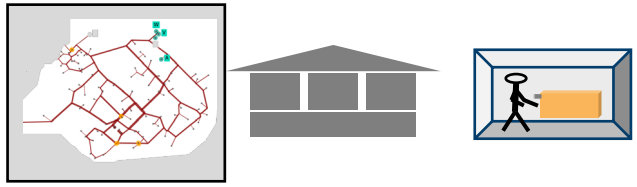
➔ Design Temperatures 40/30 °C

[2]

[1] taken with changes from: Hering; 14/12/2020: Integration of HPC Wasteheat into low temperature district heating

[2] taken with changes from: Althaus, Redder, Ubachukwu, Mork, Xhonneux, Müller, 2022: Enhancing Building Monitoring and Control for District Energy Systems: Technology Selection and Installation within the Living Lab Energy Campus; Appl. Sci. 2022, 12, 3305. https://doi.org/10.3390/app12073305

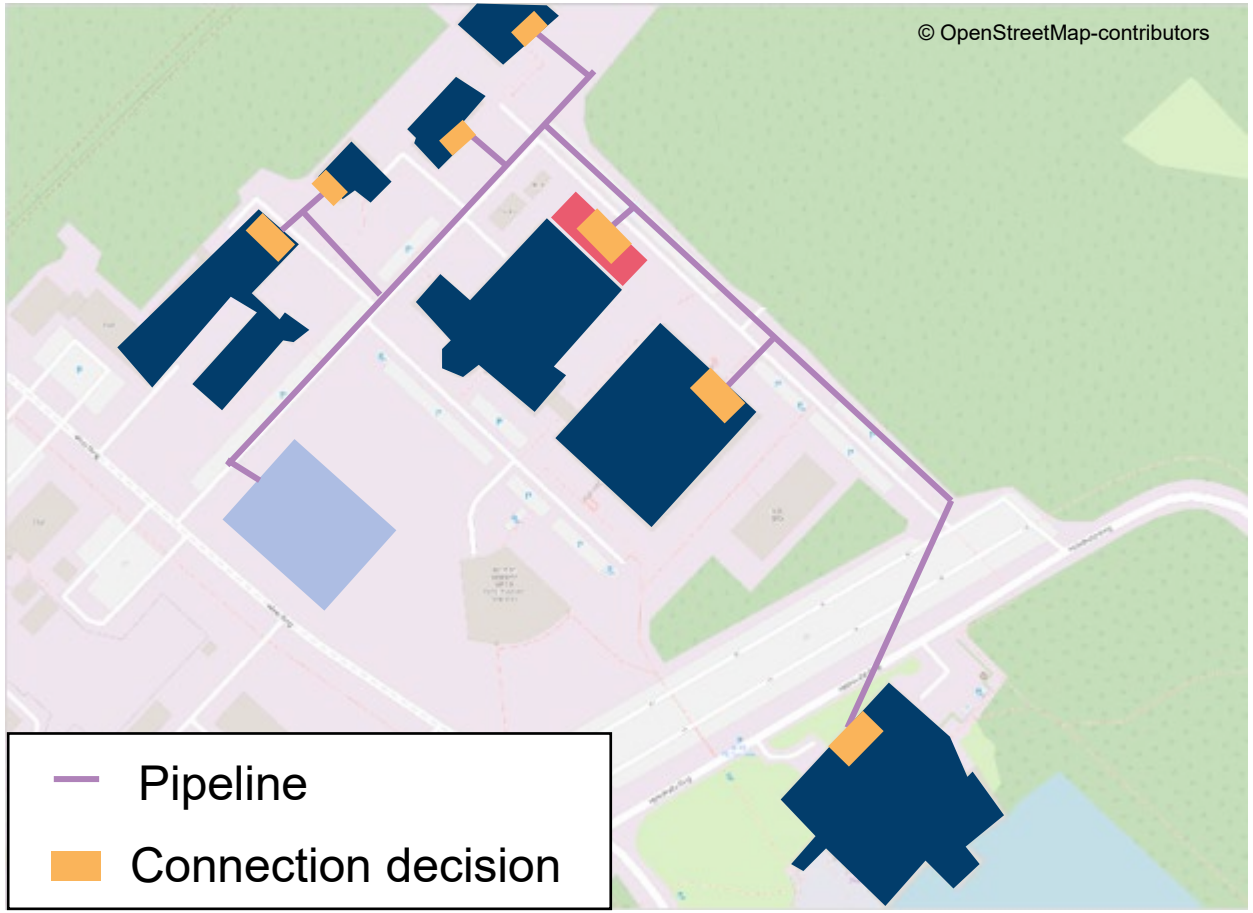
DISTRICT LEVEL



Superstructure problem and implementation [1]

- Design problem of a superstructure
  - demand of consumers
  - Restrictions at waste heat source
  - → **Mixed Integer Quadratically Constrained Programming** (MIQCP) for solving

- ⇒ **Building decentral heat pumps**
  - Lifting the supply temperature where needed



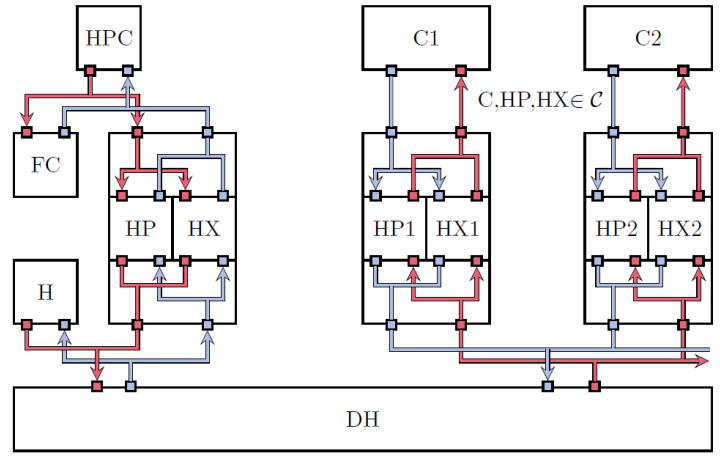
[2]

[1] Hering, Xhonneux, Müller: Design optimization of a heating network with multiple heat pumps using mixed integer quadratically constrained programming, 2021.
[2] taken with changes from: Althaus, Redder, Ubachukwu, Mork, Xhonneux, Müller, 2022: Enhancing Building Monitoring and Control for District Energy Systems: Technology Selection and Installation within the Living Lab Energy Campus; Appl. Sci. 2022, 12, 3305. https://doi.org/10.3390/app12073305

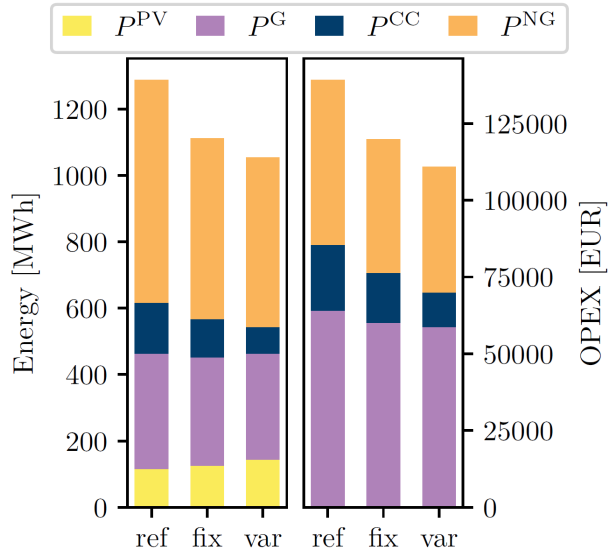
DISTRICT LEVEL

Superstructure problem, implementation and operational optimization

Initial question



Superstructure problem [2]



Result [1]

C_i: Consumer DH: Low temperature district network FC: Free cooler
HP: Heat pump HPC: High performance computer HX_i: Heat exchanger
H: Back-up heat supply

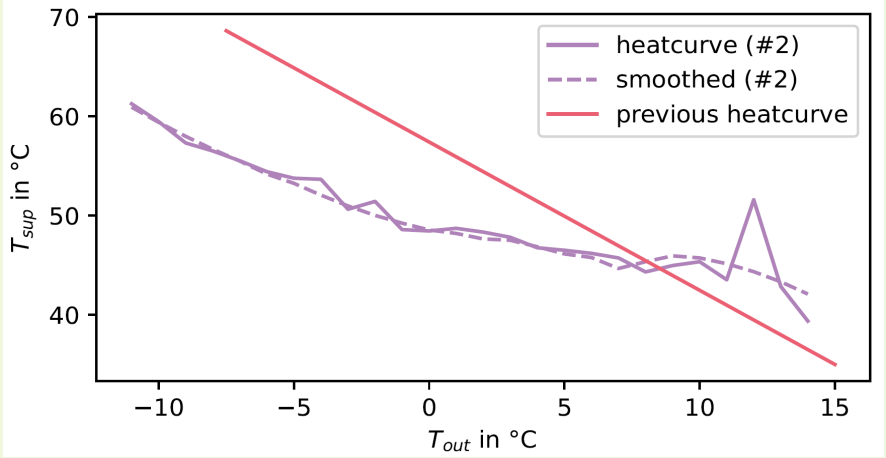
CC: Compression chillers G: Gas
NG: Natural gas PV: Photovoltaics

[1] taken from: Hering; 16/04/2021: Auslegungsoptimierung von Wärmepumpen in Wärmenetzen mit MIQCP
[2] taken from: Hering, Xhonneux, Müller: Design optimization of a heating network with multiple heat pumps using mixed integer quadratically constrained programming, 2021
[3] Hering, Faller, Xhonneux, and Müller. Operational optimization of a 4th generation district heating network with mixed integer quadratically constrained programming. Energy, 250:123766, 2022. ISSN 03605442. doi: 10.1016/j.energy.2022.123766.

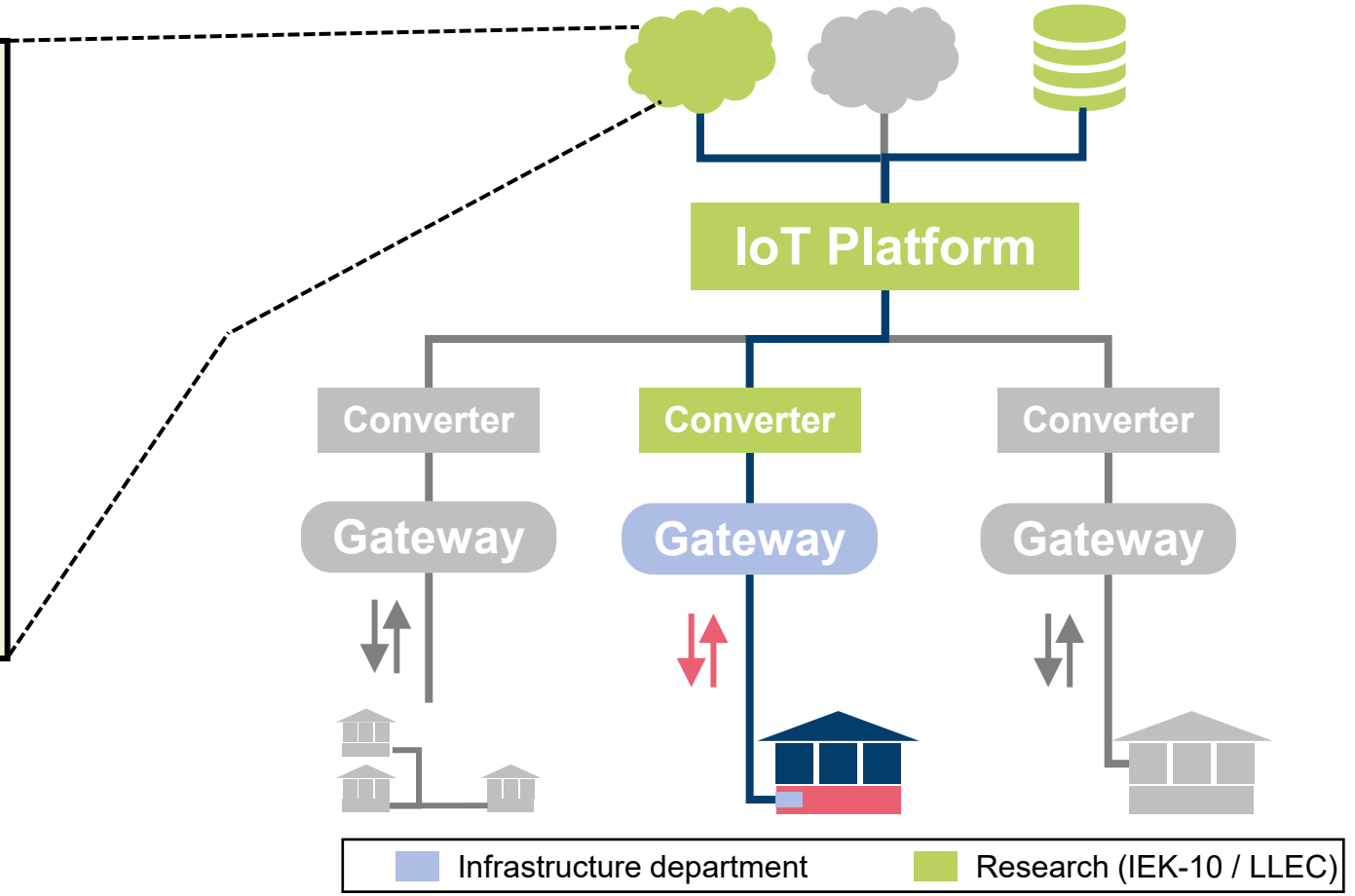
BUILDING LEVEL

Cloud-based supply temperature control | Test setup

Supply temperature setpoint
(implemented in cloud)



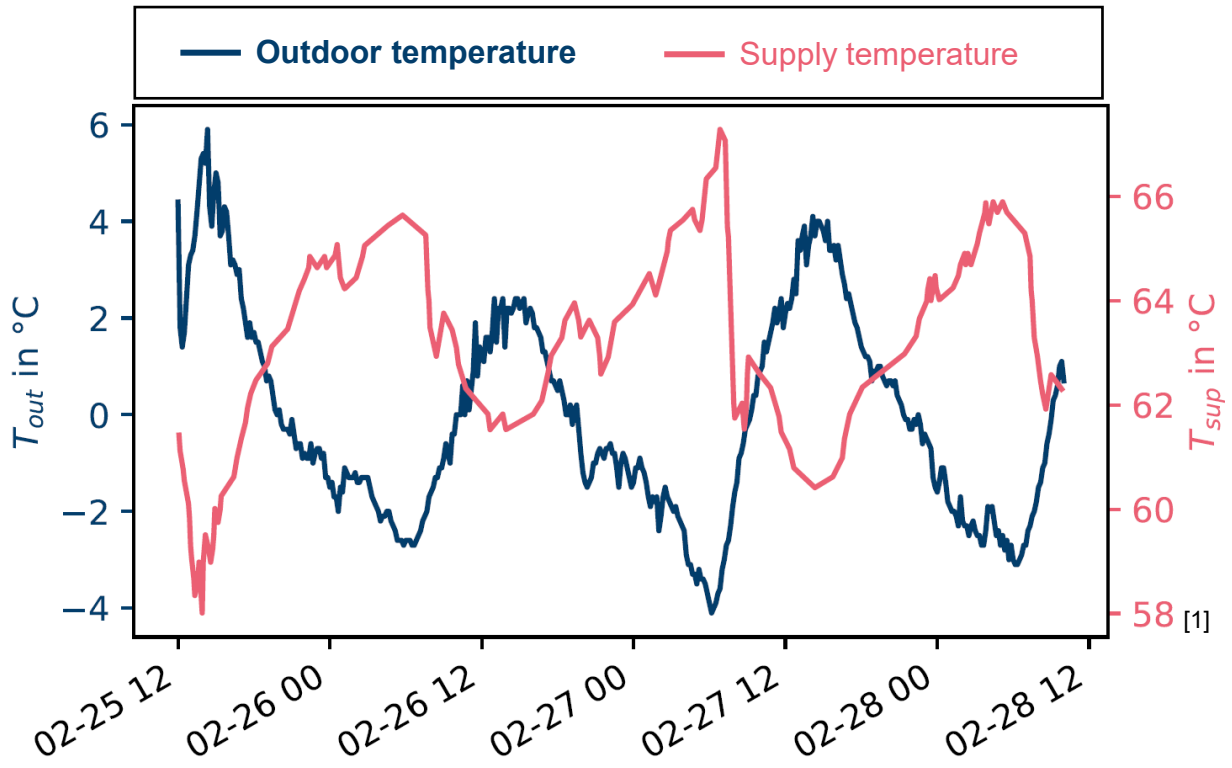
[1]



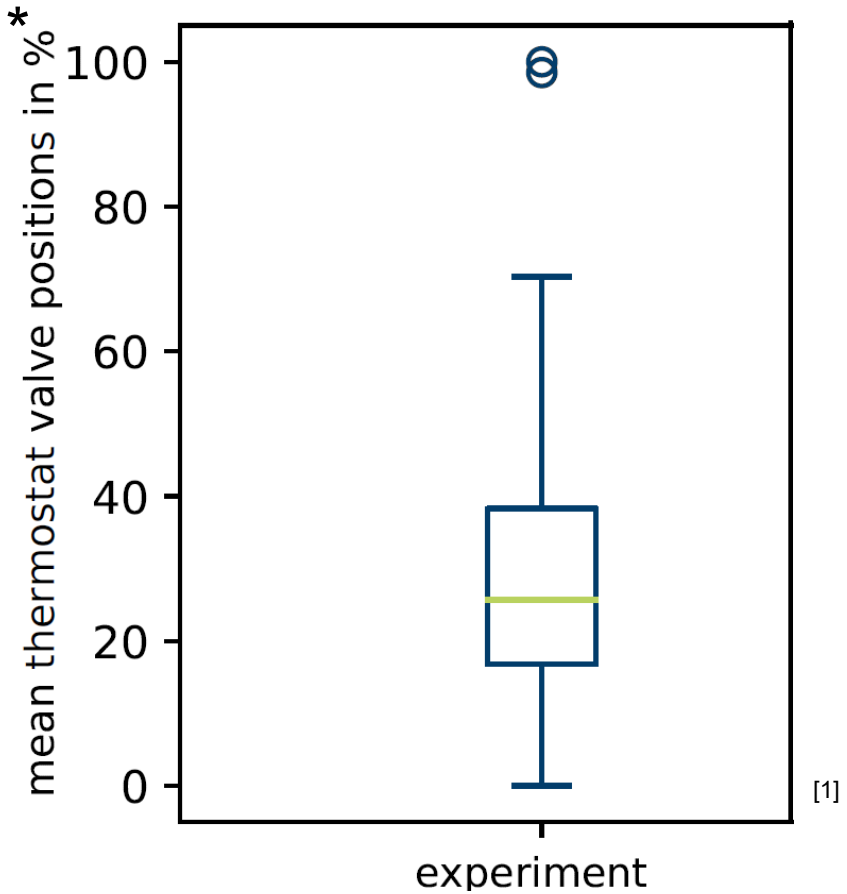
[1] taken with changes from: Stock, Althaus, Johnen, Xhonneux, Müller; 2023: (in review) Method development for lowering supply temperatures in existing buildings using minimal building information and demand measurement data

BUILDING LEVEL

Cloud-based supply temperature control | Exemplary results



[1]



[1]

* valve positions of radiator thermostat valves of all rooms in the building under test

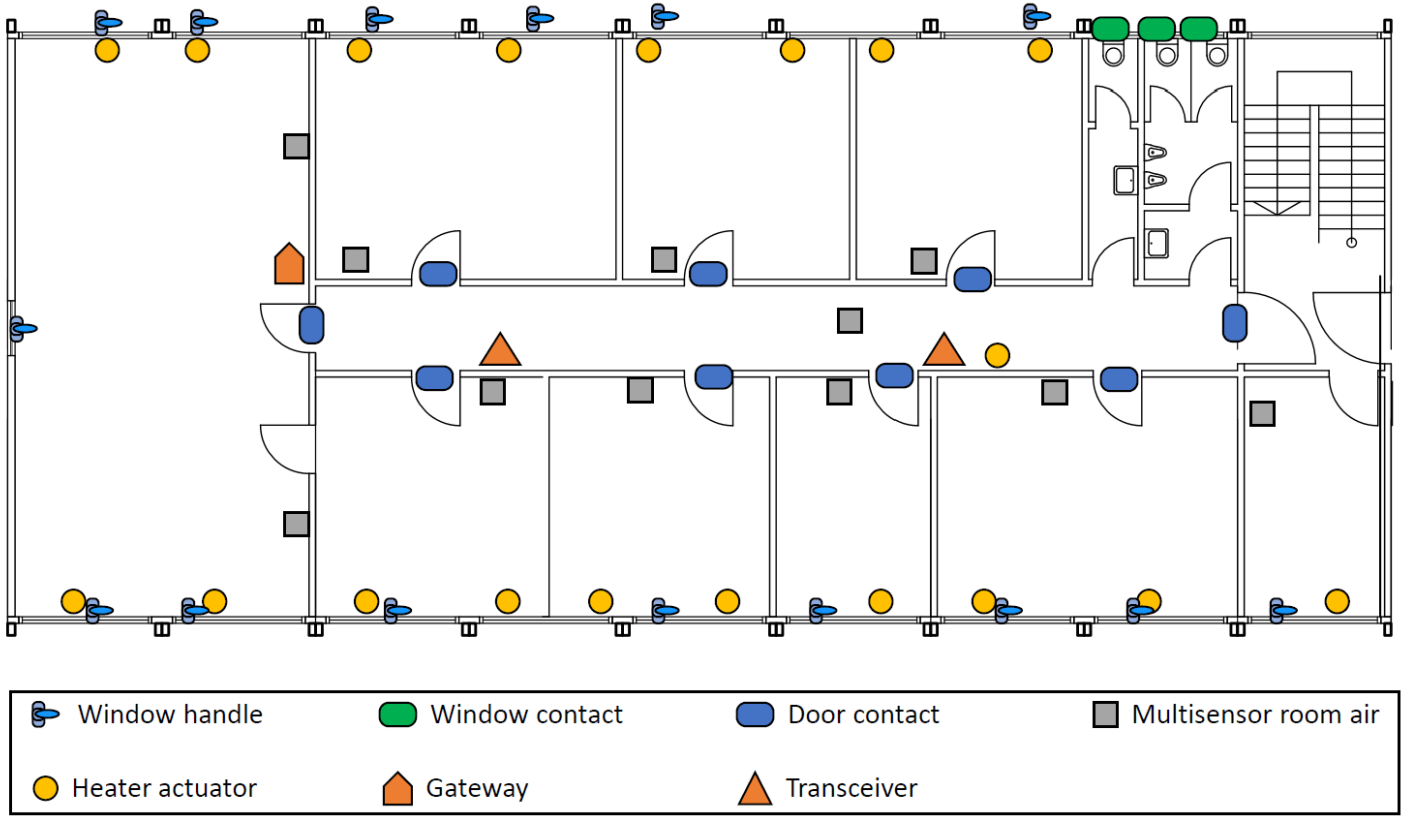
[1] taken with changes from: Stock, Althaus, Johnen, Xhonneux, Müller; 2023: (in review) Method development for lowering supply temperatures in existing buildings using minimal building information and demand measurement data

ROOM LEVEL

Components on field level

- In existing buildings, typically:
  - few measurements available
  - few control points available
- Retrofitting buildings with sensors/actuators
  - KNX (wired)
  - EnOcean / LoRaWAN (wireless)

  forming a test-bed for monitoring & control
- Currently > 4.000 EnOcean devices in 16 buildings at FZJ



Exemplary excerpt of building floor plan with EnOcean components [1]

[1] taken from: Althaus, Redder, Ubachukwu, Mork, Xhonneux, Müller, 2022: Enhancing Building Monitoring and Control for District Energy Systems: Technology Selection and Installation within the Living Lab Energy Campus; Appl. Sci. 2022, 12, 3305. https://doi.org/10.3390/app12073305

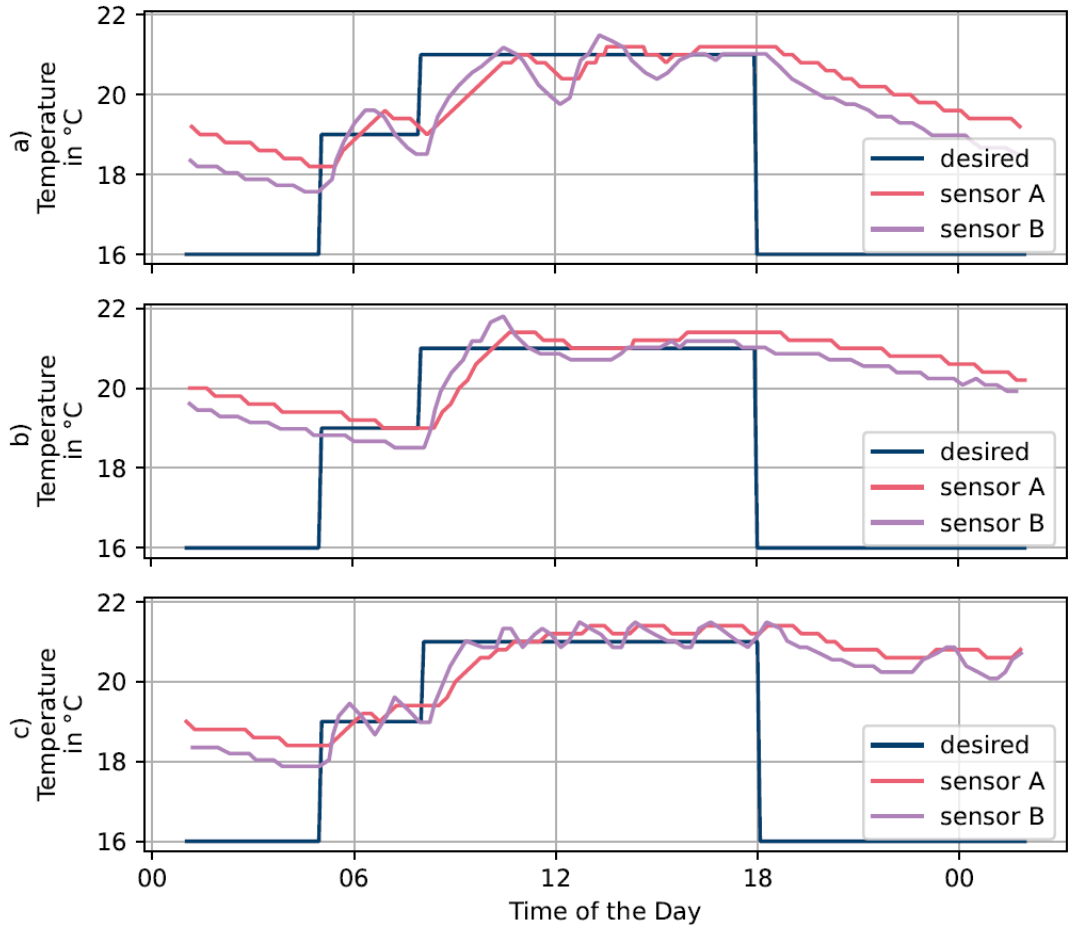
ROOM LEVEL

Control comparison | Different control algorithms and sensor signals used

a) **Local controller** of the thermostat

b) **Cloud controller**, proportional (k_p = 150), feedback: sensor A

c) **Cloud controller**, proportional (k_p = 150), feedback: sensor B



[1]

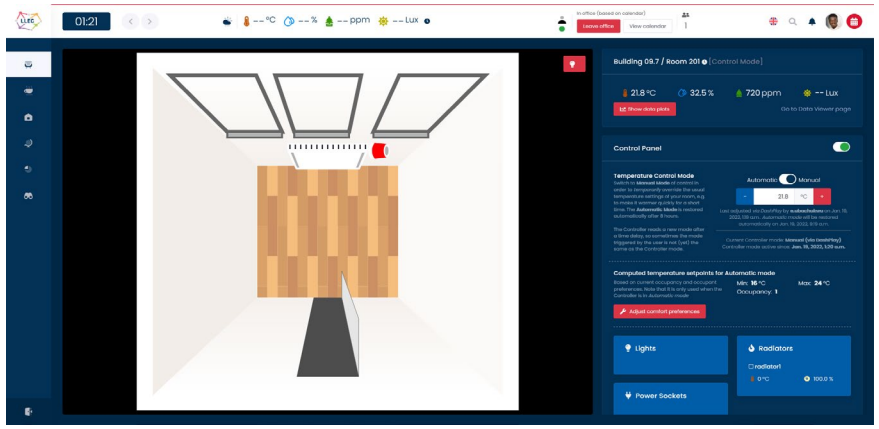
[1] taken from: Althaus, Redder, Ubachukwu, Mork, Xhonneux, Müller, 2022: Enhancing Building Monitoring and Control for District Energy Systems: Technology Selection and Installation within the Living Lab Energy Campus; Appl. Sci. 2022, 12, 3305. https://doi.org/10.3390/app12073305

ROOM LEVEL

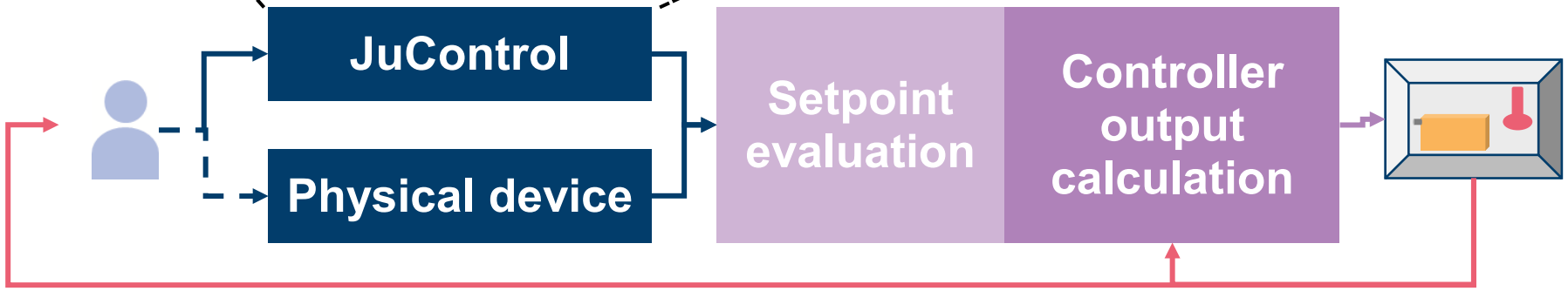
Control comparison | Incorporating user preferences and interactions

User Interactions via

- physical devices
- webbased user-interface *"JuControl"*
  - user-centric presence schedules and preferences
  - (e.g. for use in model predictive control)



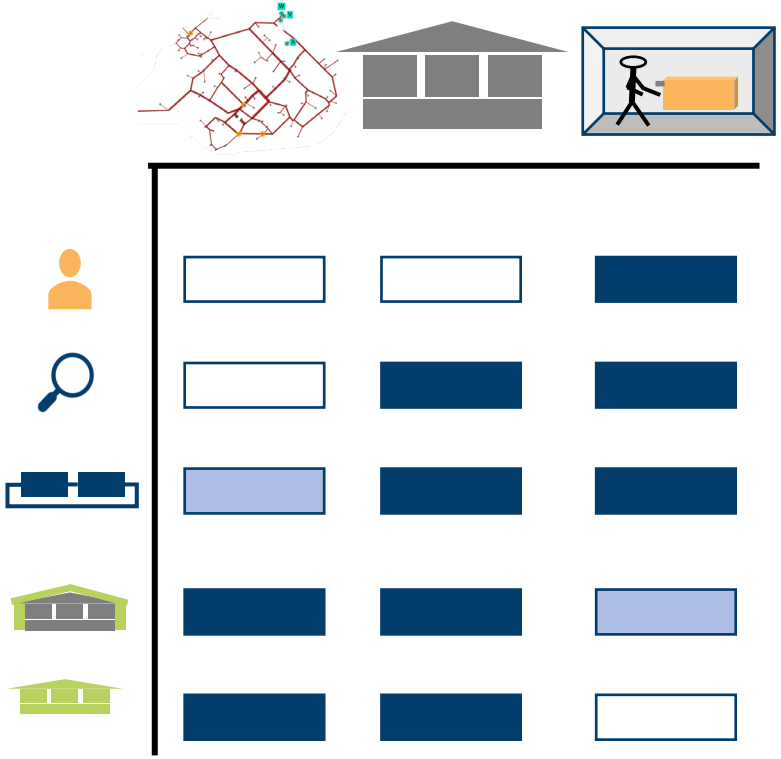
[1]

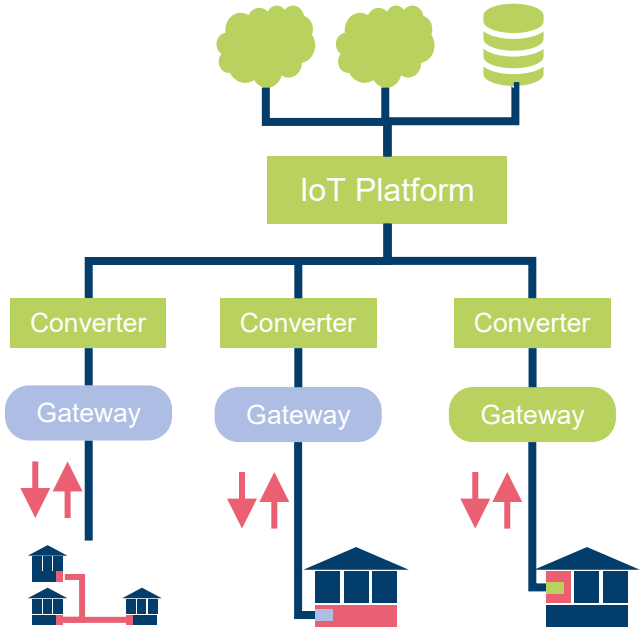


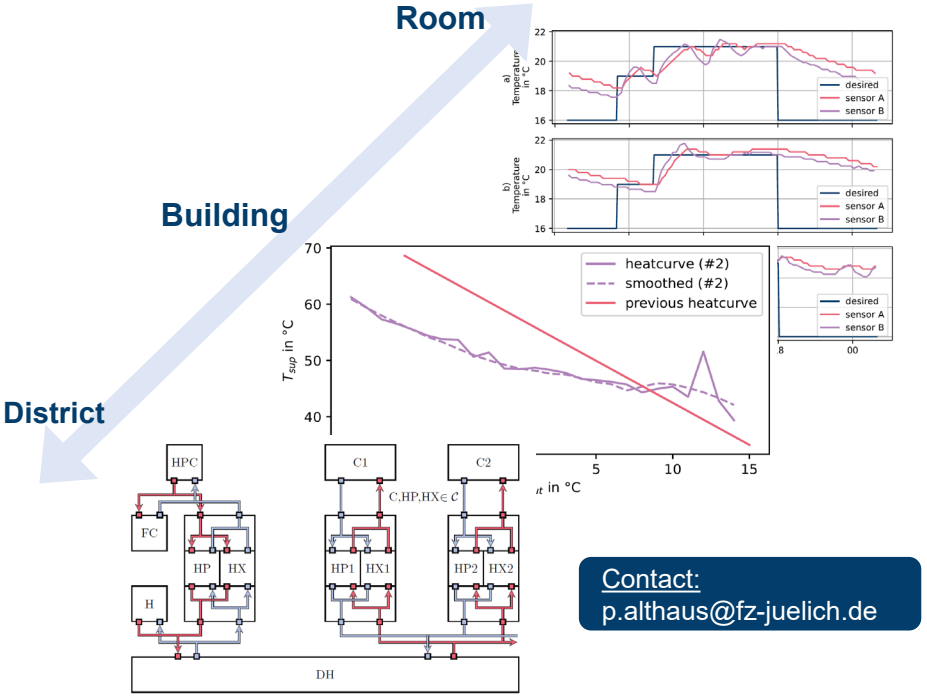
[1] screenshot taken from: Ubachukwu; 2022: JuControl

CONCLUSION

Research areas | **Infrastructure** | **Results**







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  - BMWK (German Federal Ministry of Economic Affairs and Climate Action), grant number 03ET1551A
  - Helmholtz PoF IV Energy Systems Design (ESD) programme

Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

- Collaborations
  - within IEK-10
  - with infrastructure departments at FZJ

Contact

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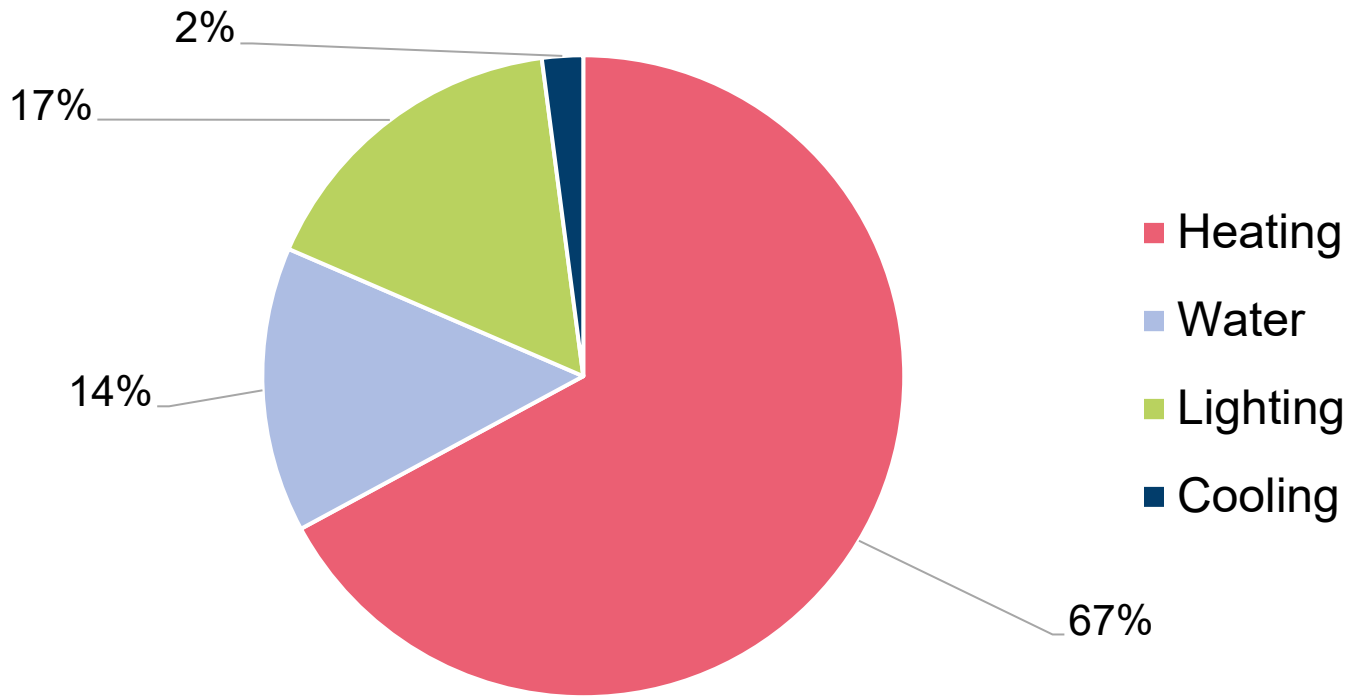
- André Xhonneux
a.xhonneux@fz-juelich.de

BACKUP

MOTIVATION

Energy consumption within buildings in Germany (2015)

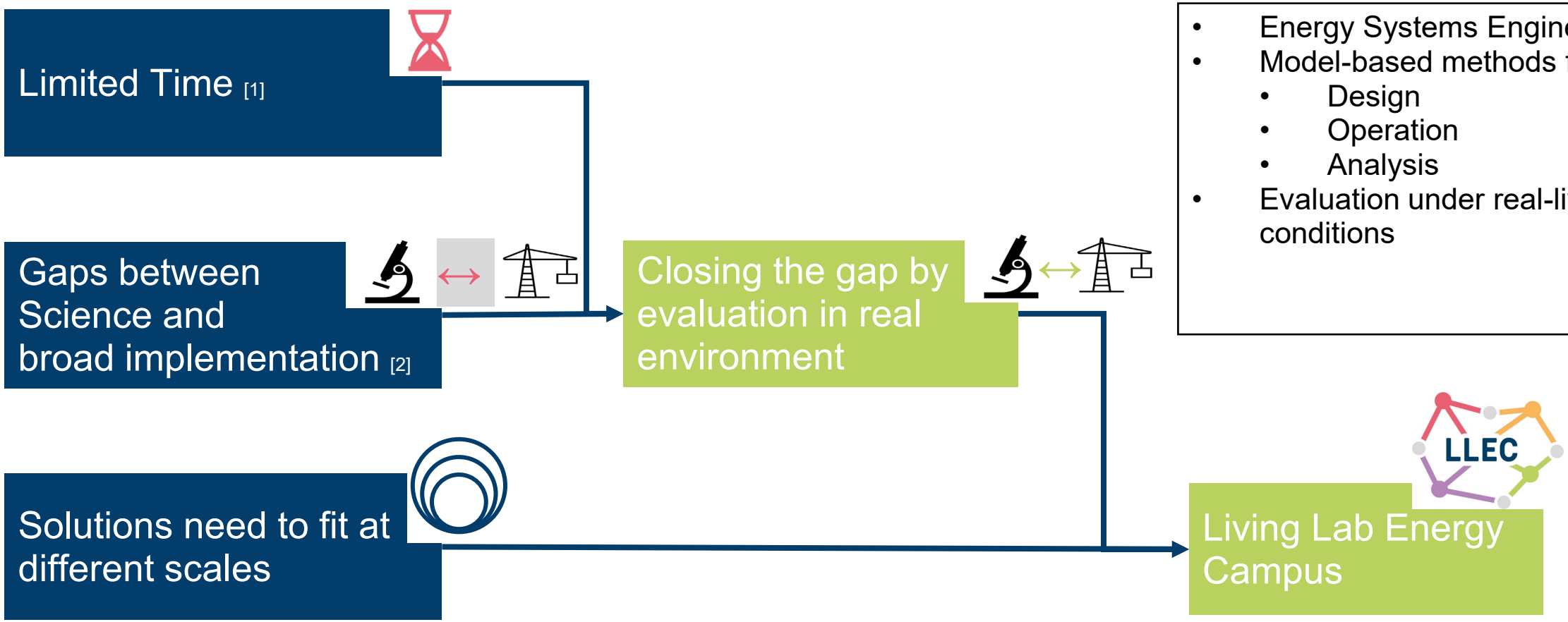


Primary Energy Consumption in Residential and Non-residential Buildings [1]

[1] with changes from: Deutsche Energie-Agentur (dena), *dena-Gebäudereport: Statistiken und Analysen zur Energieeffizienz im Gebäudebestand*, Deutschland, 2016

MOTIVATION

Living Lab Energy Campus

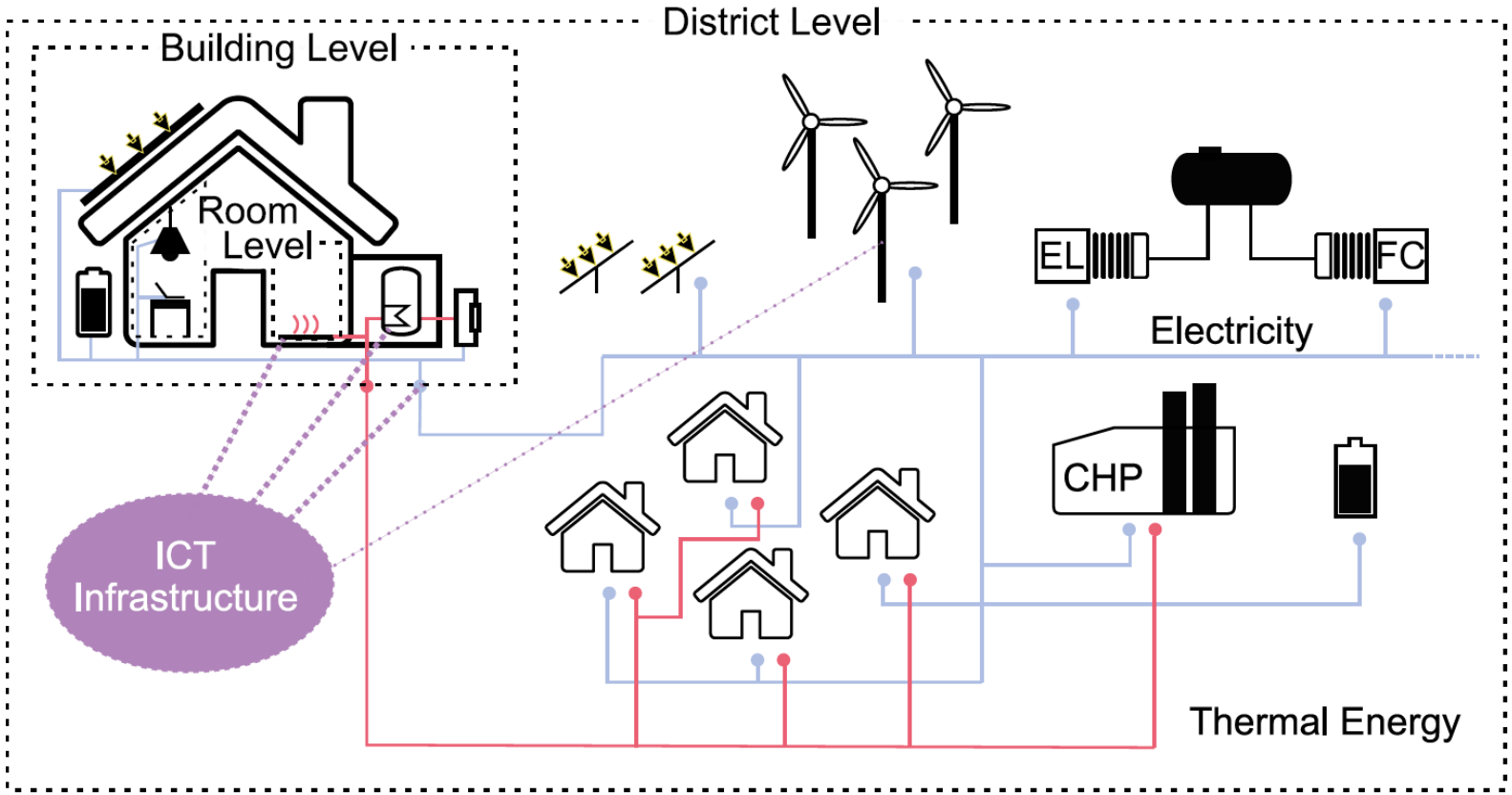


- Energy Systems Engineering
- Model-based methods for
  - Design
  - Operation
  - Analysis
- Evaluation under real-live conditions

[1] IPCC. Global Warming of 1.5 C. Geneva, Switzerland, 2018. Available online:https://www.ipcc.ch/sr15/download/ (acc.: 27 February 2022).
[2] Drgoňa, J., et al.: All you need to know about model predictive control for buildings, 2020.

ICT AS „CONNECTING POINT“

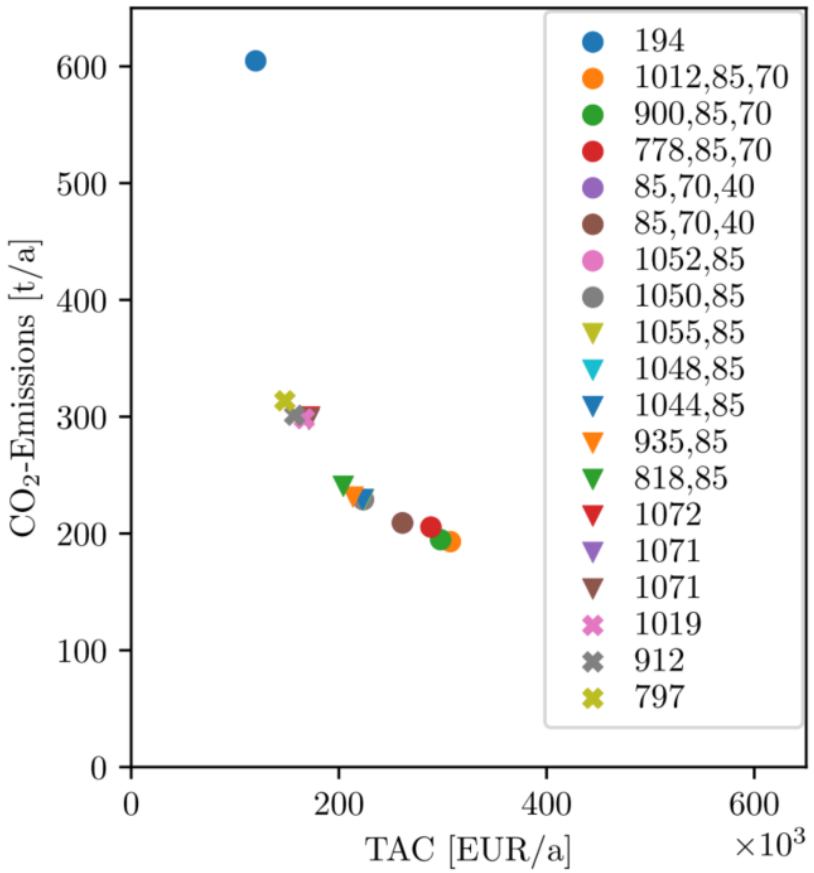
Connection to buildings + energy demonstrators



[2] taken from: Althaus, Redder, Ubachukwu, Mork, Xhonneux, Müller, 2022: Enhancing Building Monitoring and Control for District Energy Systems: Technology Selection and Installation within the Living Lab Energy Campus; Appl. Sci. 2022, 12, 3305. https://doi.org/10.3390/app12073305

DISTRICT LEVEL

Pareto front for design optimization [1]



Pareto front of results, where every marker represents a solution. The legend entry indicates the resulting design, where a preceding integer is $\dot{Q}^{\mathrm{HP}}_{\mathrm{design}}$, followed by the options 85, 70, 40, which represent the built decision for the corresponding HP.

[1] Hering, D., et al.: Design optimization of a heating network with multiple heat pumps using mixed integer quadratically constrained programming, 2021.

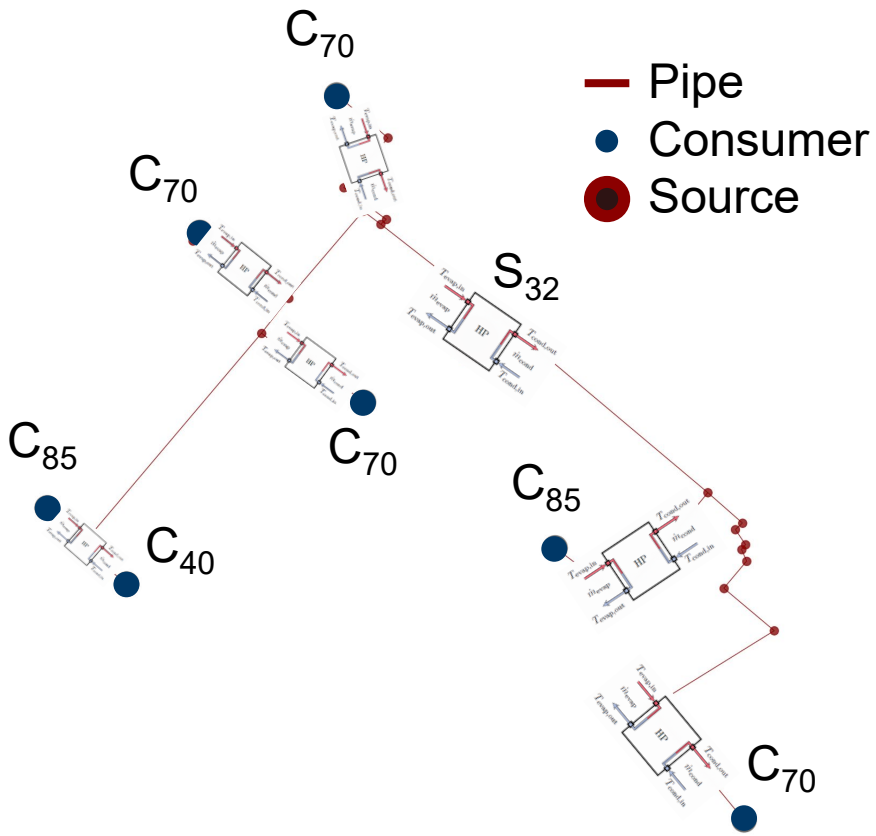
DISTRICT LEVEL

Installed heat pump capacities [1]

Building	Connected thermal power	Maximum feed temperature
A	630 kW	85°C
B	330 kW	85°C
C	144 kW	85°C
D	440 kW	85°C
E + F	100 kW	85°C
G	130 kW	85°C

[1] : Hering; 21/04/2021: Whitepaper: LLEC Niedertemperaturnetz mit Abwärmenutzung

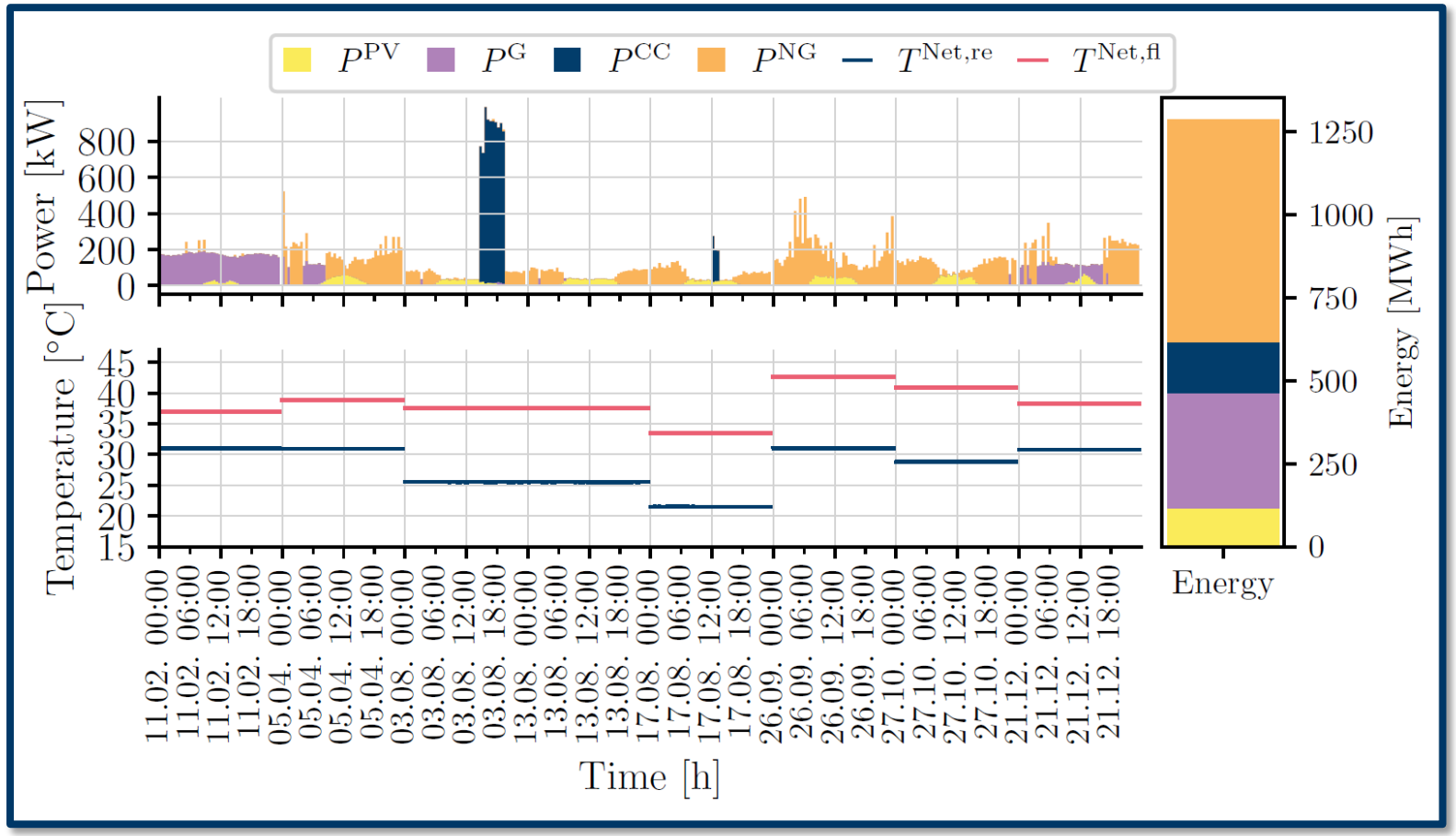
DISTRICT LEVEL



[2] taken from: Hering; 16/04/2021: Auslegungsoptimierung von Wärmepumpen in Wärmenetzen mit MIQCP

DISTRICT LEVEL

Operational Optimization for eight representative days



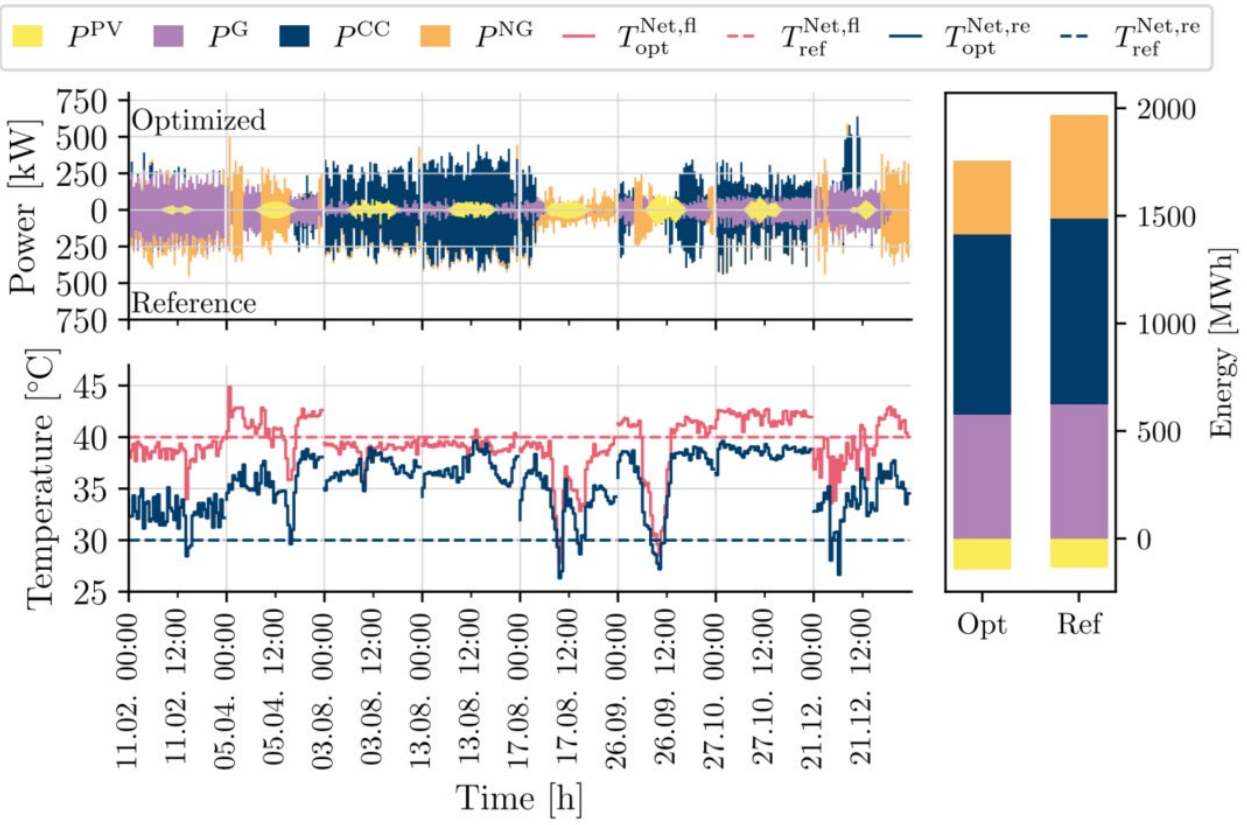
[2] taken from: Hering, Faller, Xhonneux, and Müller. Operational optimization of a 4th generation district heating network with mixed integer quadratically constrained programming. *Energy*, 250:123766, 2022. ISSN 03605442. doi: 10.1016/j.energy.2022.123766.

DISTRICT LEVEL

Operational Optimization for one year

- Savings of
  - 0.21 GWh/a (10.6%)
  - 19857€/a (8.16%)

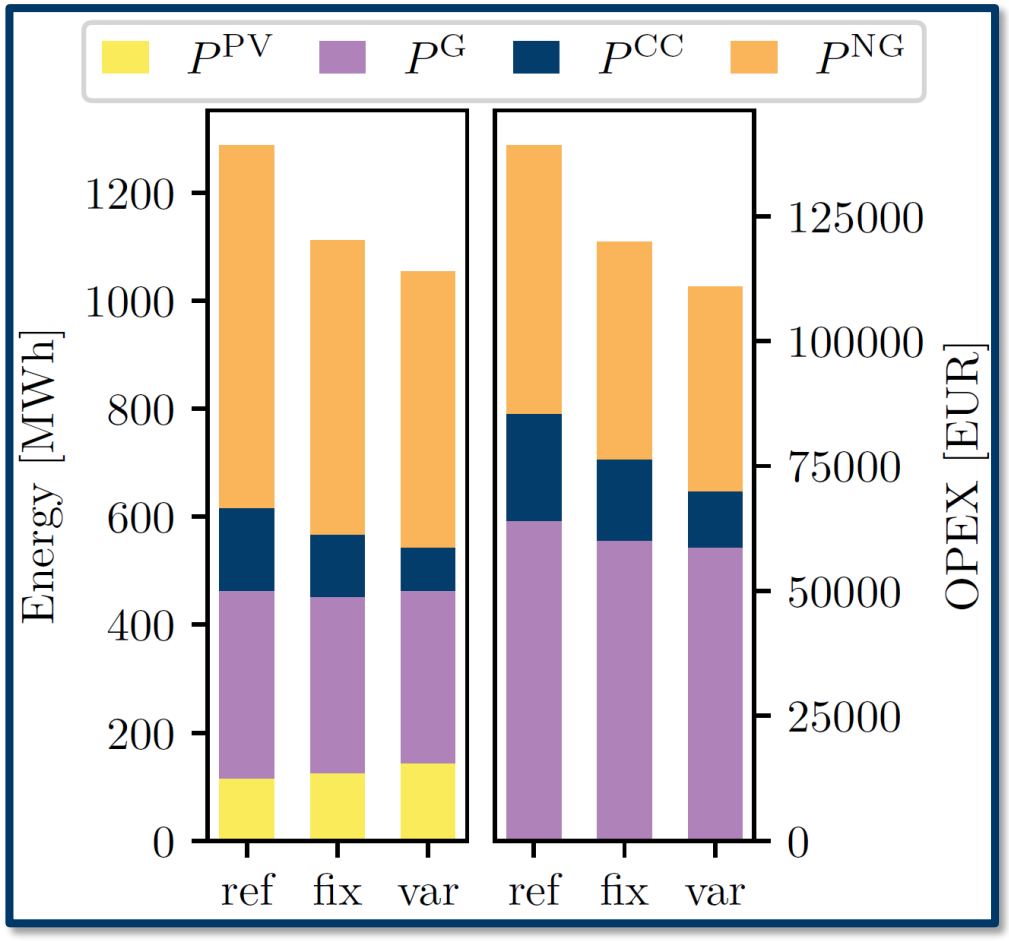
- Indexes
  - PV: photovoltaic
  - G: grid
  - CC: central cooling
  - NG: natural gas
  - Net: network
  - fl: feed
  - re: return
  - opt: optimized
  - ref: reference



[1] taken from: Hering, Faller, Xhonneux, and Müller. Operational optimization of a 4th generation district heating network with mixed integer quadratically constrained programming. *Energy*, 250:123766, 2022. ISSN 03605442. doi: 10.1016/j.energy.2022.123766.

DISTRICT LEVEL

District heating : network supply by operation optimization



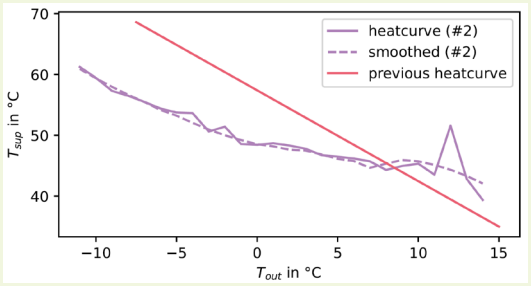
[2] taken from: Hering, Faller, Xhonneux, and Müller. Operational optimization of a 4th generation district heating network with mixed integer quadratically constrained programming. *Energy*, 250:123766, 2022. ISSN 03605442. doi: 10.1016/j.energy.2022.123766.

BUILDING LEVEL

Experiment setup: detailed view

LLEC

Cloud Control:
Supply temperature setpoint



[1]

Infrastructure department

OPC UA Server:
Gateway

Desigo:
Monitoring and approval

DDC:
Control-loop with access points

Field

Sensor:
Outdoor temp.

Sensor:
Feed temp.

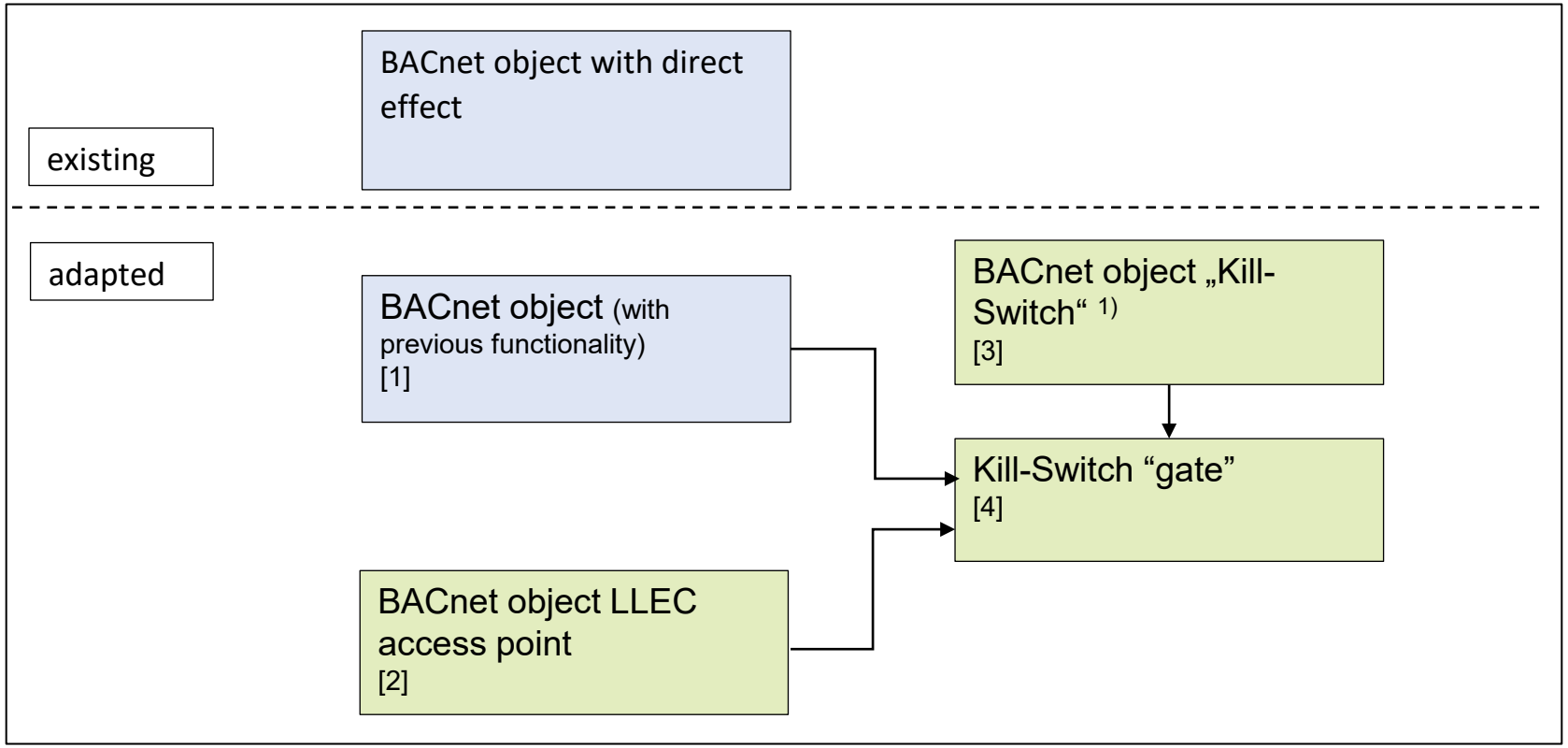
Actuator:
valve

[1] taken with changes from: Stock, Althaus, Johnen, Xhonneux, Müller; 2023: (in review) Method development for lowering supply temperatures in existing buildings using minimal building information and demand measurement data

BUILDING LEVEL

Basic idea about “Kill-Switch” for BACnet automation elements

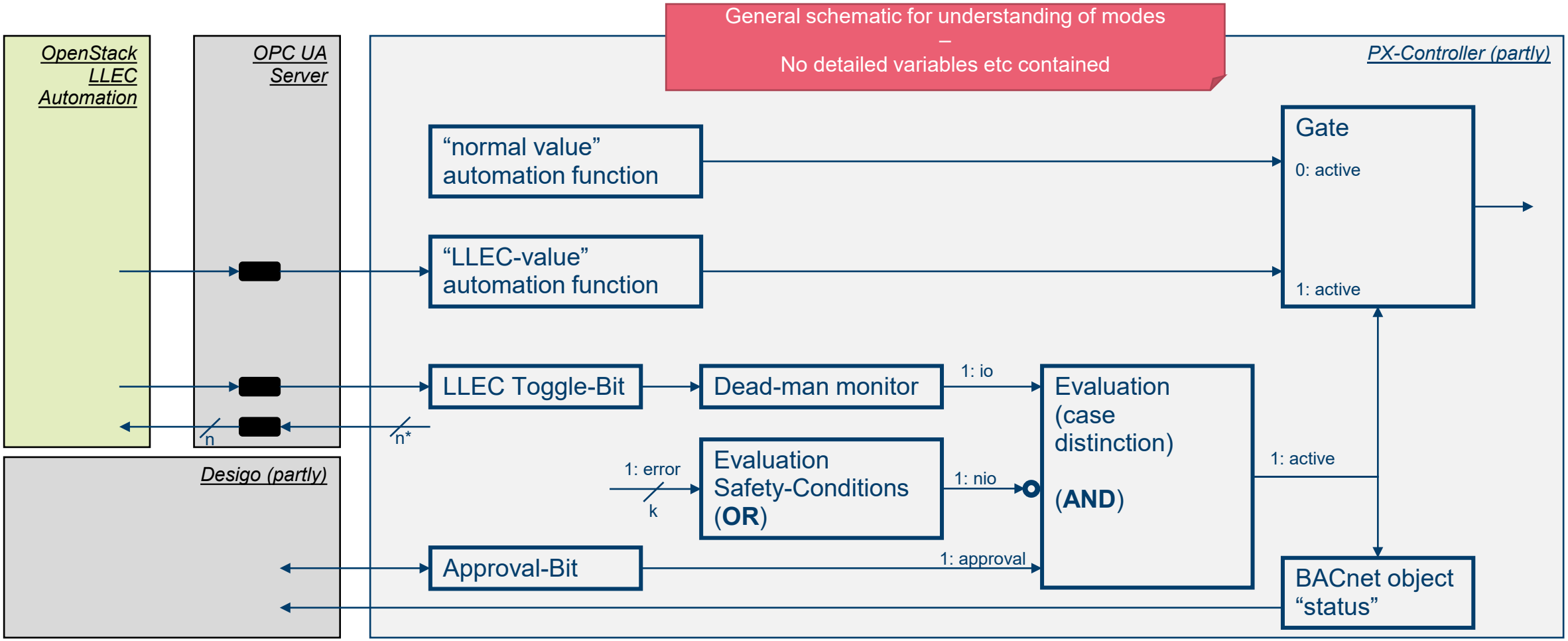
Basic idea



1) Kill-Switch as approval including monitoring

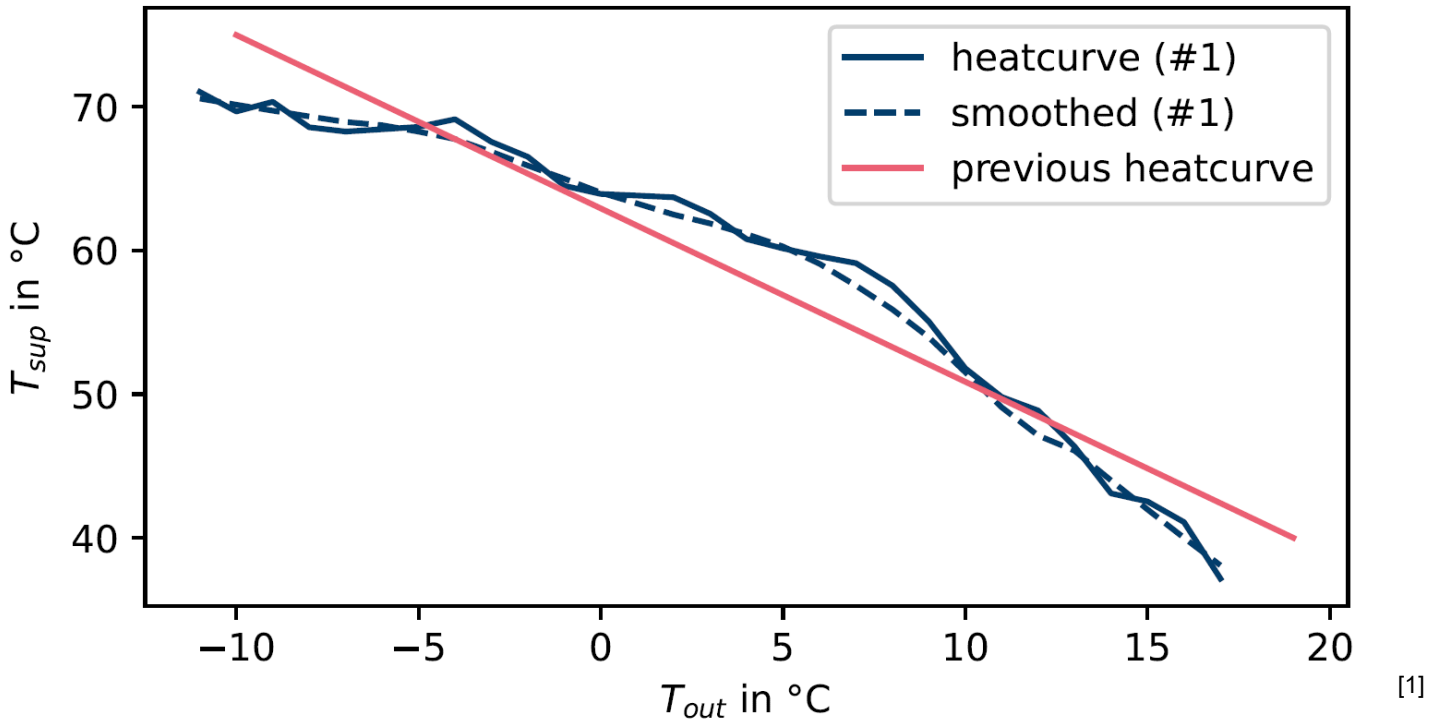
BUILDING LEVEL

Semi-detail view on automation (focus to BACnet controller part)



* Elemente auf PX (zB für Messgrößen & Stati) sind für LLEC ebenfalls sichtbar, grafisch nur angedeutet

HEATCURVE AS APPLIED TO REAL BUILDING



[1]

[1] taken with changes from: Stock, Althaus, Johnen, Xhonneux, Müller; 2023: (in review) Method development for lowering supply temperatures in existing buildings using minimal building information and demand measurement data

ROOM LEVEL: ENOCEAN DEVICES

Exemplary choice of devices

Window handle

- Window status: open/closed/tilted

Door contact / window contact

- Door status: open/closed
- Window status: open/closed/tilted (with two contacts)

Presence sensor

- precence
- illuminance

Sensor room air

- Temperature
- Humidity
- CO_2-concentration

Heating actuator

- Setting desired temperature or valve position from cloud
- Temperature measurement

CONCLUSION

Research areas | **Infrastructure** | **Results**