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Fraunhofer IEE

EBC Energy in Buildings and Communities Programme

IEA EBC Annex 84 – Subtask D

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Case Study Profiles

Demand-Side-Management (DSM) in buildings in thermal networks

Reader Guidebook

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A total of 29 case studies from various research projects have been collected as part of Subtask D of IEA EBC Annex 84, “Demand Management of Buildings in Thermal Networks”

This presentation provides a standardized and categorized summary of each case study, offering valuable insights into different approaches, technologies, and strategies for optimizing demand management in thermal networks.

Slides 2–7 explain the information presented.

Slides 8–10 offer the tables of contents and an overview of all published case studies.

List of Abbreviations

DSM	Demand Side Management
DR	Demand Response
DH	District Heating
HEMS	Home Energy Management System
SH	Space Heating
DHW	Domestic Hot Water
MPC	Model Predictive Control
GHG	Greenhouse Gas

Explanation of Case Study Categories I

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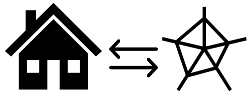
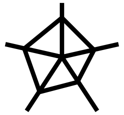
Status of research project: Idea → In Preparation → In Progress → Completed

Status of DSM implementation: In Preparation → In Progress → Completed → No Implementation

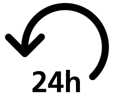
System boundary:

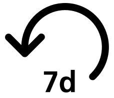


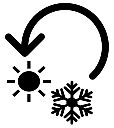


The DSM method considers either 1) building only, 2) building and thermal grid or 3) thermal grid only.

Time scale:







The DSM method is activated for/within a 1) daily timescale, 2) weekly timescale or 3) seasonal timescale.

Explanation of Case Study Categories II

Subject	Highlight information about the case study
Overview	General Information about the project and problem
Objective	Objective of the case study / project
Scope	Details on the scope and setting of the case study
System boundary, Time scale	Details regarding the system boundary and timeframe for the case study. The study can exclusively focus on the building itself, the thermal grid, or both in conjunction. The timeframe for the implemented DSM measure can be daily, weekly or seasonal.
Building	Type and use of buildings participating in the DSM
Network	Generation and supply temperature of DH grid
Heat Source of DH-Network	Heat source of DH network
Storage	Storage used for implementing DSM

Explanation of Case Study Categories III

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DSM	1) Describes the type and purpose of DSM: active or passive DSM for permanently increasing efficiency or actively shifting or shedding load or use of on-site generation 2) Describes the involvement of the customer in activating the DSM method: limited, indirect or direct involvement of customer
Intended Benefits	Why is the DSM measure implemented?
Who is benefitting?	Who benefits from implementing DSM?
Results	Details on the specific results after the DSM measure was implemented
Collaboration Detail	Detailed information on the collaboration in the implementation and activation of DSM measure (if available)
Technology Detail	Detailed information on used sensors, controls, IT infrastructure and more (if available)
Control Detail	Detailed information on the control, input and outputs of the DSM measure (if available)

Control and Purpose of Demand-Side-Management

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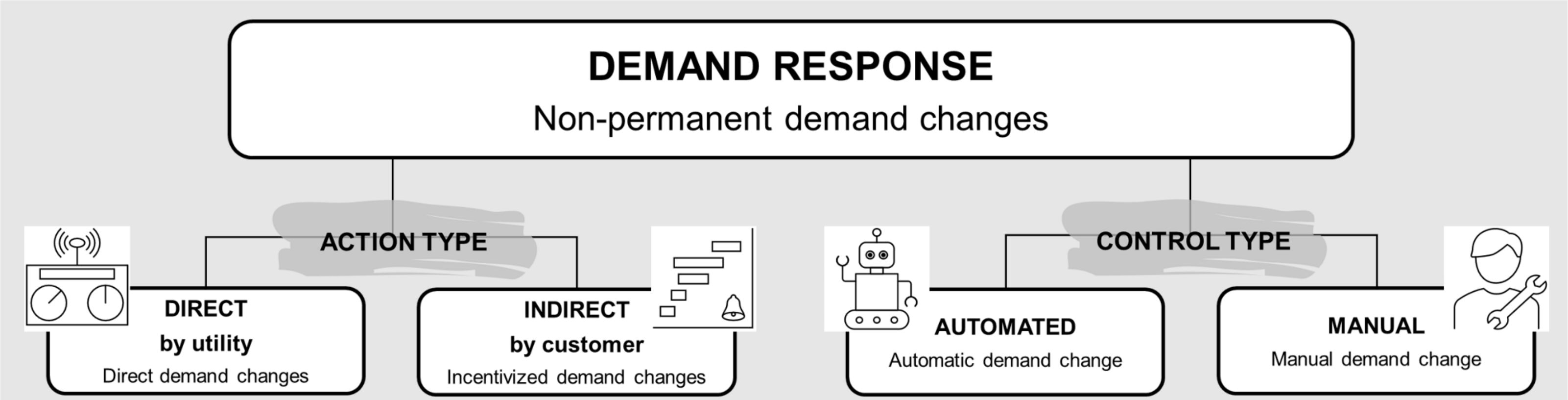
Terminology applied in IEA EBC Annex 84



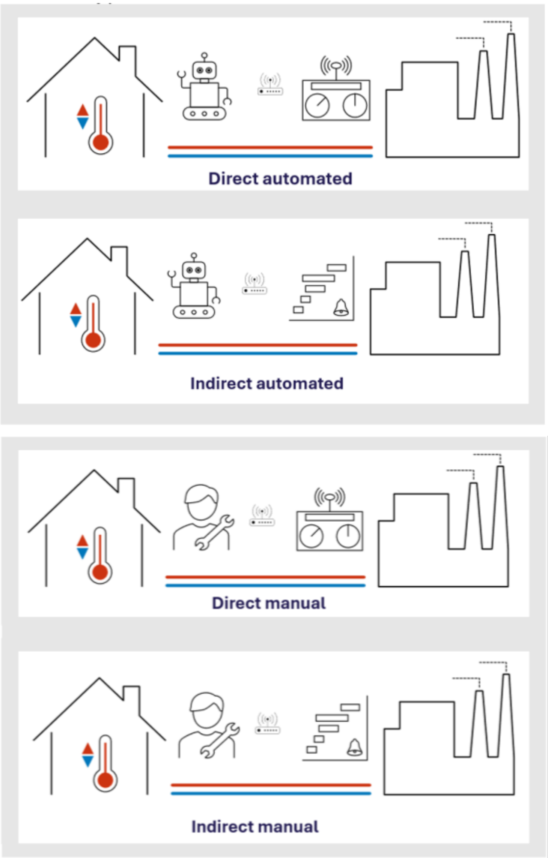
Direct DR: the change in the demand profile is directly activated in–the building by **the DHC grid operator** according to the agreement conditions made between the end-user and DHC utility. The DR event does not require constant customer engagement and reactions. The DR event/output has a low uncertainty and a high reliability.

Indirect DR: the change in the demand profile is expected to be the response to the variations in the broadcasted signal (e.g. energy price, environmental footprint, shot-down periods, flexibility market bid). **The end-user** is the actuator of the DR event. The DR event/output has a high uncertainty and a low reliability.

Automated: the change of the demand profiles is made by automated and remote adjustment of the settings of heat installation components. To execute the DR event, there **MUST** be interoperability components present. The DR event/output has a low uncertainty and a high reliability.

Manual: the change of the demand profiles is made by manual adjustment of the settings of heat installation components. To execute the DR event, there **CAN** be interoperability components present. The DR event/output has a high uncertainty and a low reliability.

Illustration of the four type of DR according to Annex 84



Case Study Overview I

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	Title	Research Project	Implementation	Affiliation
1	Peak shaving in Turin District Heating	completed	completed	Politecnico di Torino
2	Data-driven automated DSM technology	completed	completed	AEE INTEC
3	100% renewable District Heating Leibnitz	completed	completed	AEE INTEC
4	Flexible energy system integration	completed	completed	AIT
5	Smart energy in homes	completed	completed	Aalborg University
6	Substitution of conventional controllers	in progress	completed	TU Dresden
7	DSM in Danish single-family house	in progress	completed	Aarhus University
8	Geo-solar low-temperature DH network	completed	no implementation	Fraunhofer IEE
9	Digitizing DH supply infrastructure	completed	completed	Fraunhofer IEE
10	DH networks within hybrid energy systems	in progress	in preparation	Fraunhofer IEE
11	Renewable energy integration in DH grid	in progress	in preparation	Fraunhofer IEE
12	Flexible and innovative DH grid operation	completed	completed	Fraunhofer ISE

Case Study Overview II

EBC
Energy in Buildings and Communities Programme

	Title	Research Project	Implementation	Affiliation
13	Acceptance of fluctuating indoor temperatures	completed	completed	Aarhus University
14	Remote control of radiator thermostats	completed	completed	Aalborg University
15	Temperature optimisation for LTDH	completed	completed	VITO / Energy Ville
16	Energy and cost savings in office building	completed	completed	DTU
17	DSM in smart homes: living-lab experiments	completed	completed	DTU
18	Energy flexibility of low-energy buildings	completed	completed	DTU
19	Buildings as thermal energy storage in DH grids	completed	completed	Chalmers University
20	Thermal conditions and flexibility potential	completed	completed	Aalborg University
21	Occupant fade-out from demand response	completed	completed	Aalborg University
22	Application of the STORM controller in Rottne	completed	completed	VITO
23	Optimal dispatch of heat in DH grid	in progress	in preparation	Idiap Research Institute
24	Load shifting in buildings connected to DH	completed	completed	UC London

Case Study Overview III

EBC
Energy in Buildings and Communities Programme

	Title	Research Project	Implementation	Affiliation
25	Perceptions of indoor climate during DR	completed	completed	Chalmers University
26	DR in Student Apartment Buildings	completed	completed	VTT Finland
27	Thermostats overrides during DR events	completed	completed	DTU
28	DR events in a university building	completed	completed	Aalto University
29	Smart grid flexibility in single-family houses	completed	completed	Aalborg University

Peak shaving in Turin District Heating

2014-2017; Turin, Italy

Project: completed | Implementation: completed | System boundary: thermal grid | Time scale: 24h daily

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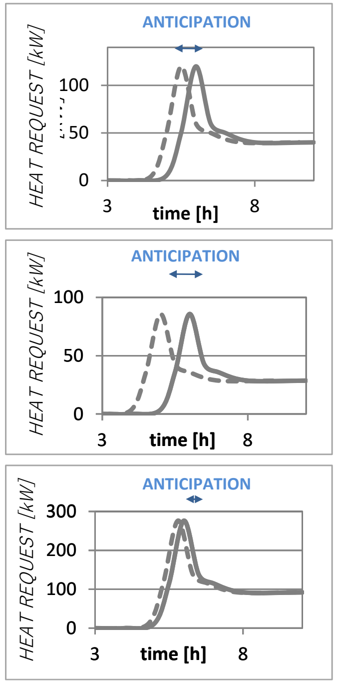
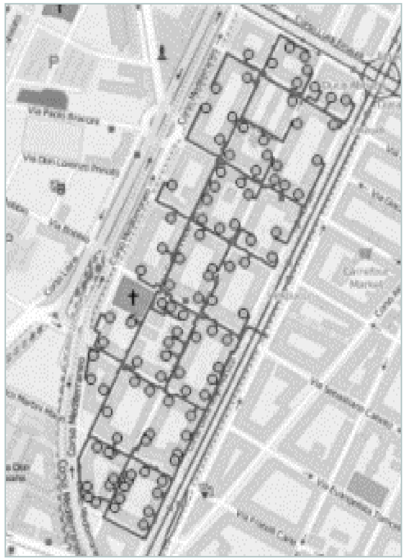
Subject

The project analyzed a fraction of buildings connected to Turin DH to find the optimal anticipation time to achieve minimum peak demand.

BUILDING LEVEL

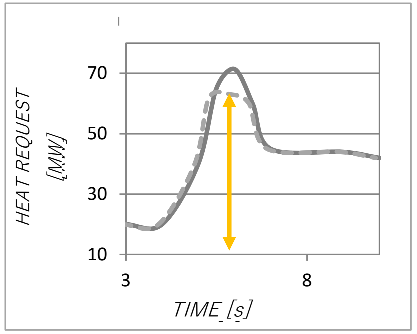


NETWORK LEVEL



NETWORK THERMO-FLUIDYNAMIC

THERMAL PLANT LEVEL



FIND THE BEST SET OF ANTICIPATIONS IN ORDER TO MINIMIZE THE PEAK REQUEST

Ref.: Guelpa and Verda, 2021, URLc

Peak shaving in Turin District Heating

2014-2017; Turin, Italy

Project:	Implementation:	System boundary:	Time scale:
completed	completed	thermal grid	24h daily

Energy in Buildings and Communities Programme

Subject	The project analyzed a fraction of buildings connected to Turin DH to find the optimal anticipation time to achieve minimum peak demand.
Overview	Turin DH heating grid, one of the largest DH grid in Italy, one of the 182 distribution networks adopted for the test, heat system switched off during night and switched on during the morning.
Objective	Eliminate or reduce the morning peak due to switch-off of the heating systems during the night
Scope	Load shifting in one of 182 distribution networks, considering only a couple of connected buildings
System boundary, Time scale	Thermal grid, daily
Building	Existing/renovated buildings with mixed use
Network	SH only, 2nd Generation (T > 100°C)
Heat Source of DH-Network	Heat Generation in two cogeneration plants and various heat-only boilers

Peak shaving in Turin District Heating

2014-2017; Turin, Italy

Project:	Implementation:	System boundary:	Time scale:
completed	completed	thermal grid	24h daily

EBC Energy in Buildings and Communities Programme

Storage	centralized & decentralized thermal storage, water-based short-term buffer, building mass
DSM	Active, direct and automatic DSM for load shed, peak shaving, Grid operator anticipates peak by substation control with no involvement of customer, DR for max. 20 min
Intended Benefits	peak shaving, avoid morning peak to avoid use of heat only boiler
Who is benefitting?	DH grid operator and customer indirectly
Results	Peak reduction of about 5% (8 to 7.6 MW), when a fraction of buildings lower than 30% is considered for a maximum anticipation of 20 min. Simulation shows: when all the buildings are considered and the allowed anticipation is up to 60 min, the peak can be completely shaved (adopting anticipations larger than 40 min only in 15% of buildings).
Collaboration Detail	No collaboration between DH operator and customers.
Technology Detail	Measurements in the buildings: mass flow rate at the primary side of the heat exchanger, temperature at the inlet section of the primary side, temperature at the outlet section of the primary side, temperature at the inlet section of the secondary side, temperature at the outlet section of the secondary side, the outdoor air temperature.
Control Detail	The best anticipation time was found by using a genetic algorithm optimizer.

Peak shaving in Turin District Heating

2014-2017; Turin, Italy

Project: completed | Implementation: completed | System boundary: thermal grid | Time scale: 24h daily

Best Practices / Lessons Learned:

- Simple measures can already yield significant benefits
- Limited impact on room temperature by 20 min shutdown period
- Results support implementation of demand response in DH network

Peak shaving in Turin District Heating

Further information and references

Project: completed | Implementation: completed | System boundary: thermal grid | Time scale: 24h daily

- Guelpa, E., Marincioni, L., Deputato, S., Capone, M., Amelio, S., Pochettino, E., & Verda, V. (2019). Demand side management in district heating networks: A real application. *Energy*, *182*, 433-442.

Data-driven automated DSM technology

2019-2022; Austria

Project: completed

Implementation: completed

System boundary: building + thermal grid

Time scale: 24h daily

Energy in Buildings and Communities Programme

Subject

The aim of the project is to reduce peak loads through the development of an automated, data-driven DSM technology for small district heating networks.

Ref.: Adobe Stock, killykoon, 599991754, URL

Data-driven automated DSM technology

2019-2022; Austria

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building + thermal grid	24h daily

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Subject	The aim of the project is to reduce peak loads through the development of an automated, data-driven DSM technology for small district heating networks.
Overview	Typical Austrian medium-sized DH network with a few hundred connected customers, located in a rural area with continental climate. Peak loads and peak boiler operation in winter, Customer are divided into flexible and fixed customers.
Objective	Develop data-driven thermal load model to forecast fixed customers and optimize flexible customers to avoid peak loads and peak boiler operation.
Scope	Medium sized DH network with a few hundred connected customer
System boundary, Time scale	Building + thermal grid, daily
Building	Existing/renovated buildings with mixed use
Network	SH + DHW, 3rd Generation (70 $< T <$ 100°C)
Heat Source of DH-Network	biomass boilers, peak oil boilers

Data-driven automated DSM technology

2019-2022; Austria

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building + thermal grid	24h daily

Energy in Buildings and Communities Programme

Storage	Decentralized thermal storage, building + heating system mass
DSM	Active, direct and automatic DSM for load shift; Grid operator uses flexibility by substation and building heating curve control; Explicit, direct involvement of customer: controls limits of room temperature
Intended Benefits	Reduce/avoid peak boiler operation, Increase renewable share, Cost savings, Grid integration of new customer
Who is benefitting?	DH grid operator and customer indirectly
Results	The developed DSM solution is applicable to typical small to medium-sized heating networks and considers the typical network infrastructure and adjusts to common boundary conditions such as common control strategies. It works data-only, requires no hardware or sensor retrofit of any kind, almost no parameterization, and involves no additional investments for the end customers. Hence, it is comparably easy and cheap to deploy and suitable for a "fast transition" to renewables approach.

Data-driven automated DSM technology

2019-2022; Austria

Project: completed

Implementation: completed

System boundary: building + thermal grid

Time scale: 24h daily

EBC Energy in Buildings and Communities Programme

Collaboration Detail	Bidirectional data exchange between the network customers and a central hub.
Technology Detail	Various sensors measures supply and return temperatures, set points, volume flow, power and energy, valve positions, pressure, ambient temperature etc.
Control Detail	The developed DSM software solution (implement as a git-based shared project) learns the buildings heating curve and individual customer settings. The output of the optimization algorithm are ambient temperature offsets, calculated at 15-min rate for 36 hours. A temperature offset is added to the actual ambient temperature, leading to a change in the building's supply temperature.

Data-driven automated DSM technology

2019-2022; Austria

Project: completed

Implementation: completed

System boundary: building + thermal grid

Time scale: 24h daily

Energy in Buildings and Communities Programme

Best Practices / Lessons Learned:

- Facilitation of re-using existing infrastructure by implementation of DSM solution
- Simple and cost-effective Implementation of entirely data-based DSM solution
  - No requirements for hardware, sensor equipment and no additional investments
  - Suitable for rapid transition to renewable energies
- Possibility for replication on a large scale as a purely digital solution, though economically not feasible for larger networks
- Inaccuracies for complex buildings (use of highly simplified building models)
- Engagement of customer not necessary, implementation without any complaints
- Consideration and adaptation to typical network infrastructures and common boundary conditions by the DSM solution
- Classification of customer with (flexible) and without (fix) load flexibility

Data-driven automated DSM technology

References and further information

Project: completed | Implementation: completed | System boundary: building + thermal grid | Time scale: daily

- Presentation: http://aee-intec.at/download/DataDrivenLM_Final_Presentation_2022-07.pdf
- General project information: https://projekte.ffg.at/projekt/3205634
- Project website: URL.
- Final project report "DataDrivenLM": URL.

100% renewable District Heating

2018-2022; Leibnitz, Austria

Project: completed

Implementation: completed

System boundary: thermal grid

Time scale: 24h daily

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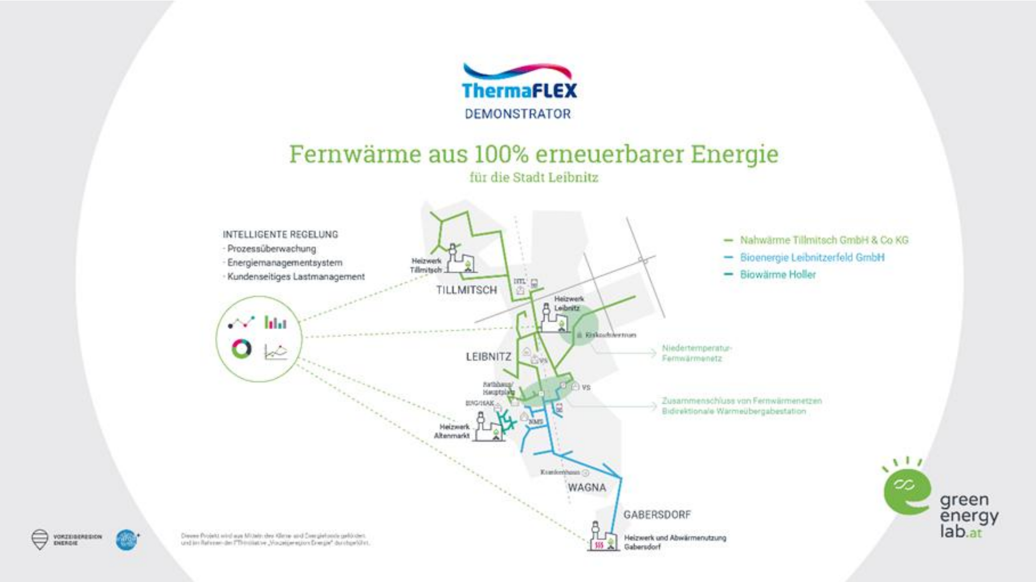
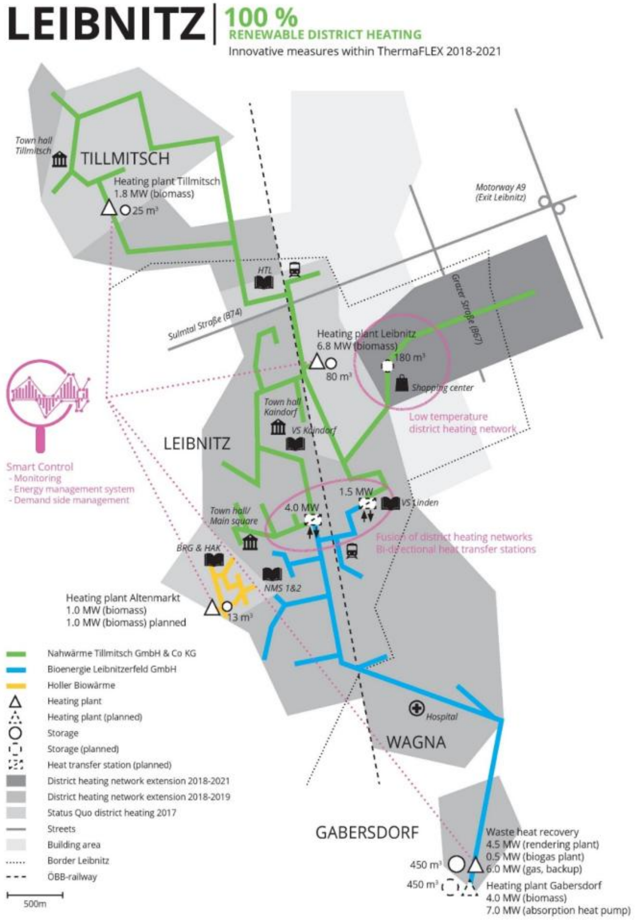
Subject Substation model control to increase the flexibility and EMS to optimize the supply of the district heating network of Leibnitz





Ref.: Kelz et al, 2023, URL

100% renewable District Heating

2018-2022; Leibnitz, Austria

Project: completed | Implementation: completed | System boundary: thermal grid | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Subject	**Substation model control to increase the flexibility and EMS to optimize the supply of the district heating network of Leibnitz**
Overview	The DH supply of the city of Leibnitz and surrounding communities will be massively expanded over the next few years. It is planned to use nearly 100% renewable energy from biomass and waste heat. Further it is planned to merge two DH networks with a bidirectional heat transfer station, to implement smart control with an overall energy management system for both networks including DSM and low temperature district heat supply of a new quarter.
Objective	Facilitate the use of only renewable energy, examine DSM method which uses a model to calculate limits on the supply capacity for each substation
Scope	DH grid of Leibnitz
System boundary, Time scale	Thermal grid, daily
Building	Existing/renovated buildings with residential use. Building types includes apartment, terraced and semi-detached.
Network	SH + DHW, 3rd Generation ($70 < T < 100$°C)
Heat Source of DH-Network	Energy generation by wood chip boilers, natural gas boiler, waste heat (rendering plant, biogas CHP)

100% renewable District Heating

2018-2022; Leibnitz, Austria

Project:	Implementation:	System boundary:	Time scale:
completed	completed	thermal grid	24h daily

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Storage	centralized & decentralized thermal storage, water-based short-term buffer, building mass
DSM	Active, direct and automatic DSM for load shed and load shift; Limited, indirect involvement of customer; DR active for variable time depending on DHW demand, day or night operation and the ambient temp.; DR active for max. half a day, supply limit resets back to 100% between 12pm-4am, 12am-1pm
Intended Benefits	Improve overall operation of network with multiple feed-in points, avoid large load peaks in the morning, maximize waste heat utilization, increase renewable share.
Who is benefitting?	DH grid operator
Results	First results of the simulation show a promising reduction of CO2 emissions by 35% and a fuel cost reduction of 7% due to better utilization of the production capacities. EMS and DSM act mostly independently of each other of the overall DH system.

100% renewable District Heating

2018-2022; Leibnitz, Austria

Project:	Implementation:	System boundary:	Time scale:
completed	completed	thermal grid	24h daily

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Collaboration Detail	Not indicated
Technology Detail	No hardware described
Control Detail	DSM method investigated in the project: controlling of the primary flow to enforce a limit for the supply capacity. Substation model (regression model with historic data) is updated every hour, safety measures are evaluated every 5min; two control approaches for interconnected DH networks: EMS provides optimal control plans for the generator side, DMS influences the consumers within the DH network; additionally, if DHW activity is detected, the load limit can be increased temporarily; most importantly, If the secondary flow temperature falls below the setpoint value for a certain time, the load limit is incrementally increased by 10% until the setpoint temperature is reached again;

100% renewable District Heating

2018-2022; Leibnitz, Austria

Project: completed | Implementation: completed | System boundary: thermal grid | Time scale: 24h daily

Energy in Buildings and Communities Programme

Best Practices / Lessons Learned:

- Differentiation between two-day classes in the demand forecast: working day and non-working day
- An important improvement seems possible if the trigger of the DSM is coordinated by the EMS (DH supply) or by linking it to the management of the thermal energy storage. (DSM can be used as a tool to use the virtual storage capacity (building mass) of consumers)
- The test operation of the DSM showed the ability to reduce load peaks, but the demand profile could not be flattened for each consumer with active DSM. (presumably due to oversized consumer substations leading to very low relative DSM limits, resulting in negative effects on the safety mechanisms.)
- The simulation study indicates that, while the gas boiler operation was reduced during real operation, direct control of the EMS over the boilers and a longer prediction horizon would improve the performance.

100% renewable District Heating

References and further information

Project: completed | Implementation: completed | System boundary: thermal grid | Time scale: 24h daily

- Valentin Kaisermayer, Jakob Binder, Daniel Muschick, Günther Beck, Wolfgang Rosegger, Martin Horn, Markus Gölles, Joachim Kelz, Ingo Leusbrock. Smart control of interconnected district heating networks on the example of "100% Renewable District Heating Leibnitz". Smart Energy, Volume 6, 2022. (https://doi.org/10.1016/j.segy.2022.100069)
- Intelligente Regelungen zum optimierten Betrieb von Wärmenetzen. Nachhaltige Technologien 2022-02, Page 9-11. (https://www.aee-intec.at/zeitung/nachhaltige_technologien-2-2022/8/)
- Final project report "ThermaFLEX": Link
- https://greenenergylab.at/projects/100-renewable-district-heating-leibnitz/

Flexible energy system integration

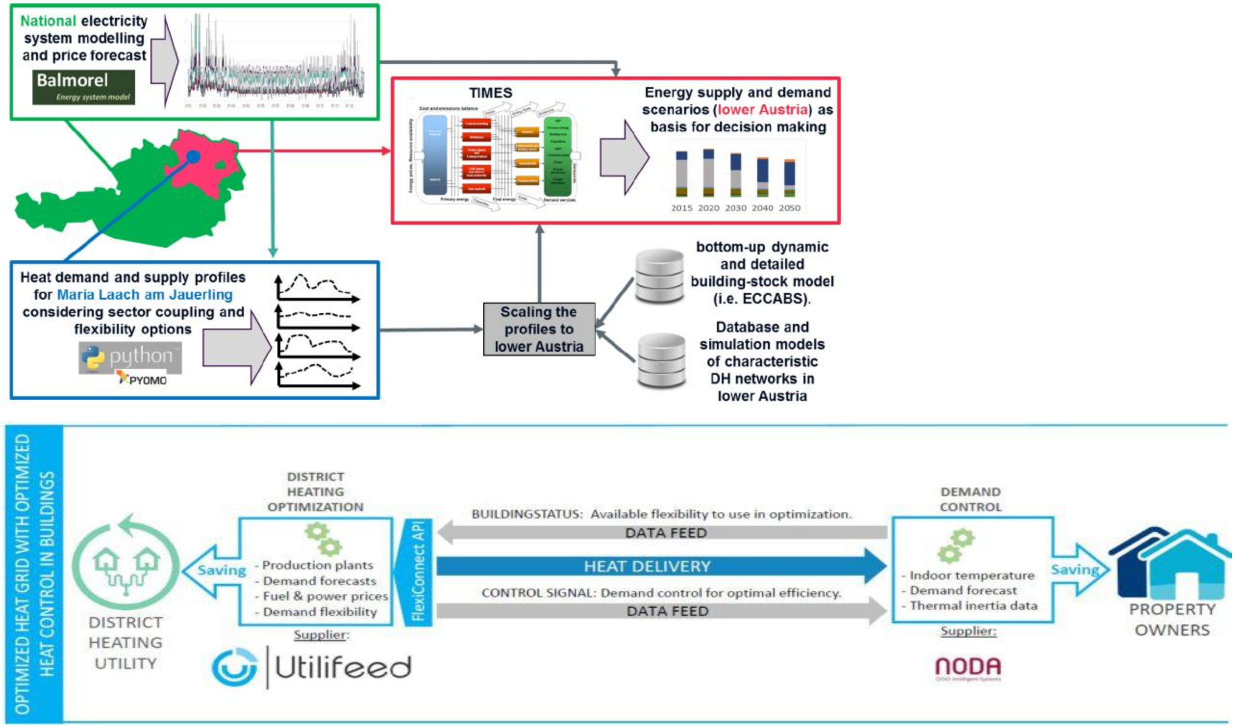
2019-2022; Maria Laach, Austria

Project: completed
Implementation: completed
System boundary: building + thermal grid
Time scale: 24h daily

Energy in Buildings and Communities Programme

Subject

Demand forecast and optimized dispatch to increase and utilize building flexibility in the district heating grid of Maria Laach



Ref.: Schmidt et al., 2022, URL

Flexible energy system integration

2019-2022; Maria Laach, Austria

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building + thermal grid	24h daily

EBC Energy in Buildings and Communities Programme

Subject	Demand forecast and optimized dispatch to increase and utilize building flexibility in the district heating grid of Maria Laach
Overview	The overall goal of Flexi-Sync aims to optimize the flexibility in the district energy sector, a sector with untapped potential to balance the energy system. This case study tested the flexibility through the building thermal inertia controlled by remotely making alternative settings of the substation controllers. The optimization software is used to create an operating plan for the building that considers the weather and building flexibility.
Objective	The district heating grid of Maria Laach, represented by the project partner Agrar Plus, is a rural district heating grid. Optimize the flexibility of district energy sector (DH network)
Scope	DH system (1.5 km) supplies to 30 consumers, but the test considered only 5 building which are responsible for around half of the energy demand (total yearly demand around 1650 MWh/a)
System boundary, Time scale	Building + thermal grid, daily
Building	Existing/renovated buildings with mixed use. Building types includes apartment, terraced and semi-detached.
Network	SH + DHW, 3rd Generation (70 < T < 100°C)
Heat Source of DH-Network	Biomass (wood chip), Bioenergy, renewable heat

Flexible energy system integration

2019-2022; Maria Laach, Austria

Project: completed | Implementation: completed | System boundary: building + thermal grid | Time scale: 24h daily

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Storage	centralized & decentralized thermal storage, water-based short-term buffer, building mass
DSM	Active, direct and automatic DSM for load shed; Limited, indirect involvement of customer;
Intended Benefits	Optimization of grid operation, avoid peak boiler operation instead use CHP, allow grid integrations of new customers without grid extension, cost savings (without major changes in comfort)
Who is benefitting?	DH grid operator and customer indirectly
Results	The increase of flexibility in actual operation can be realized. There haven't been increased complaints from tenants about thermal comfort in the tested building. Practical tests show, that the output dispatch plants of the optimization are viable. In case of Maria Laach, with the optimisation, the peak load could be reduced (shifted) by about 80 kW, or about 6% of the contracted load compared to regular operation. Live tests were made for one spring month and saved about 6 MWh, or 7% of the energy demand in this month.

Flexible energy system integration

2019-2022; Maria Laach, Austria

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building + thermal grid	24h daily

Energy in Buildings and Communities Programme

Collaboration Detail	Actors involved: DH Network Operator Maria Laach, Optimization and Control companies (Utilifeed, Noda). The costumers are informed in an early stage of the project but were not involved in the testing phase. Two business cases viable: 1) including new components with additional flexibility (CHP or HP), 2) electricity market participation on day-ahead and/or on the *automatic Frequency Restoration Reserve* (secondary reserve); both business models use building flexibility; barriers: cost for flexibility integration, licencing and operation of DSM technology possibly to high for small rural grids, optimization runs were laborious and needed a person taking care of the selection of the right parameter regularly
Technology Detail	Several substations at consumers are installed with buffer storage tanks, which are planned to be used as a common storage tank for the whole plant. New substation controllers were installed, SCADA software was updated and a new software interface between the existing Schneid SCADA system (data management system) and NODA was installed.
Control Detail	Alternative remote adjustment of the substation controllers based on weather and demand forecast, demand forecast comes from machine learning model and historical demand of every single substation in the grid, Utilifeed's optimization software was used (April 2022) to then solve for the optimal dispatch

Flexible energy system integration

2019-2022; Maria Laach, Austria

Project: completed | Implementation: completed | System boundary: building + thermal grid | Time scale: 24h daily

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Best Practices / Lessons Learned:

- In the future, with a CHP plant in Maria Laach, excess electricity could also be used for load compensation and stabilizing the power grid
- Tests include five different types of buildings
- Test has been performed in the actual day-to-day operation of the district heating system
- Finding a low-cost solution is necessary (too high cost of the implementation for small rural grids)

A case study within the project Flexi

References and further information

Project: completed | Implementation: completed | System boundary: building + thermal grid | Time scale: 24h daily

- Conference Presentation: S. Demet, Flexible and synchronized local energy systems-concept development and demonstration – A case study of a rural district heating network in Austria: https://www.tugraz.at/fileadmin/user_upload/tugrazExternal/738639ca-39a0-4129-b0f0-38b384c12b57/files/pr/Session_E5/551_PR_Schmid.pdf
- Conference Presentation: C. Fuchs, Electricity Market Participation of Flexible District Heating Networks in Austria – A case study of a rural district heating network in Austria: https://www.tugraz.at/fileadmin/user_upload/tugrazExternal/738639ca-39a0-4129-b0f0-38b384c12b57/files/pr/Session_A5/155_PR_Fuchs.pdf
- Webinar: Flexi-Sync Webinar #7: Cost-optimal flexibility and flexibility price models: https://www.ivl.se/projektwebbar/flexi-sync/webinars/220510-webinar-7.html
- Webinar: Flexi-Sync Webinar #6: Demo of district energy flexibility optimization tool: https://www.ivl.se/evenemang/2022-02-08-flexi-sync-webinar-6-demo-of-district-energy-flexibility-optimization-tool.html
- Webinar: Flexi-Sync Webinar #5 Austrian rural district heating at the power market: https://www.ivl.se/evenemang/2021-10-20-flexi-sync-webinar-5-austrian-rural-district-heating-at-the-power-market.html
- Webinar: Flexi-Sync webinar 2: Austrian and Swedish demos: https://www.ivl.se/projektwebbar/flexi-sync/webinars/2020-05-26--flexi-sync-webinar-2.html
- T. C. Ernström, ‘How to optimise district energy flexibility’, Celsius Initiative: https://celsiuscity.eu/how-to-optimise-district-energy-flexibility
- Deliverables: https://www.ivl.se/projektwebbar/flexi-sync/publications.html
- Homepage: https://www.ivl.se/projektwebbar/flexi-sync.html

Smart energy in homes

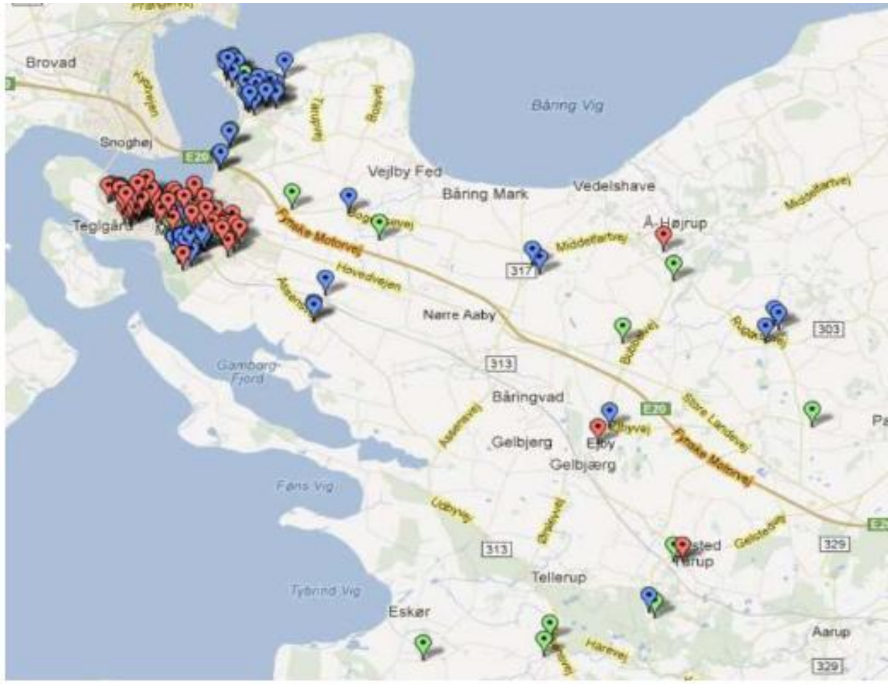
Implemented in 2014/2015; Middelfart, Denmark

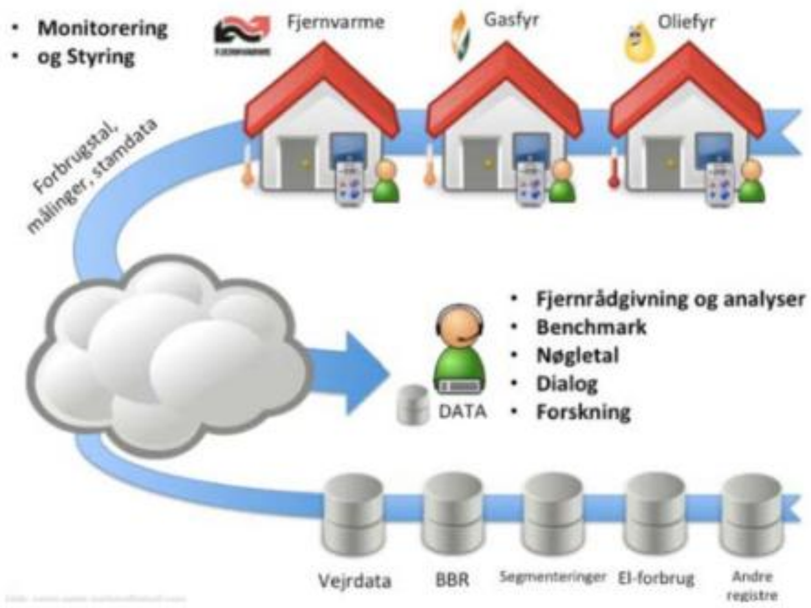
Project:	Implementation:	System boundary:	Time scale:
completed	completed	buidling	24h daily

EBC
Energy in Buildings and Communities Programme

Subject

Utilizing smart home thermostats and energy consumption monitoring in an online portal to save energy driven by the same end-users





Ref.: Nielsen, 2013, URL

Smart energy in homes

Implemented in 2014/2015; Middelfart, Denmark

Project:	Implementation:	System boundary:	Time scale:
completed	completed	buidling	24h daily

EBC
Energy in Buildings and Communities Programme

Subject	Utilizing smart home thermostats and energy consumption monitoring in an online portal to save energy driven by the same end-users
Overview	In this case study (part of the project "Smart Energy I Hjemmet") occupants can voluntarily activate set-back action, i.e. reduce the set-point temperature by changing the position of the thermostat OR by the centrally-controlled system in the representative zone.
Objective	Improve the energy saving potential for households by investigating the occupants' involvement in the DR activities
Scope	Monitoring took place over a period of 1.5 years and included 72 households
System boundary, Time scale	Building, daily
Building	Existing/renovated buildings with mixed use. Building types includes terraced and semi-detached.
Network	SH + DHW, 3rd Generation (70 < T < 100°C)
Heat Source of DH-Network	Should be investigated as part of the project

Smart energy in homes

Implemented in 2014/2015; Middelfart, Denmark

Project:	Implementation:	System boundary:	Time scale:
completed	completed	buidling	24h daily

Storage	decentralized thermal storage, water-based short-term buffer, building mass
DSM	Active and indirect DSM with automatic and manual control for permanently decreasing energy demand and use setback strategies; Explicit, direct involvement of customer: DR active for variable period (user preference)
Intended Benefits	Night set-back, energy savings
Who is benefitting?	Customer
Results	Annual energy reduction of all costumers and DH customer amounts to 6.5% and 2.6%, respectively
Collaboration Detail	Highly end user driven, common agreement in multi-family house, occupants were driving factor, customers could contact a consultancy company to improve their energy savings
Technology Detail	Remote controlled thermostats
Control Detail	individual and centrally control of smart thermostats

Smart energy in homes

Implemented in 2014/2015; Middelfart, Denmark

Project: completed
Implementation: completed
System boundary: buidling
Time scale: 24h daily

Energy in Buildings and Communities Programme

Best Practices / Lessons Learned:

- Considering the building and their residents as individuals is important
- Testing on buildings with different characteristics (detached, town, row house etc.)
- Engaging the residents into the process to improve heating control and demand response

Smart energy in homes

References and further information

Project:	Implementation:	System boundary:	Time scale:
completed	completed	buidling	24h daily

Energy in Buildings and Communities Programme

- Project report "Smart Energi i Hjemmet": URL.
- Nielsen, 2013, https://de.slideshare.net/slideshow/smart-energyhome-a-project-that-lives-by-data/18006257#3

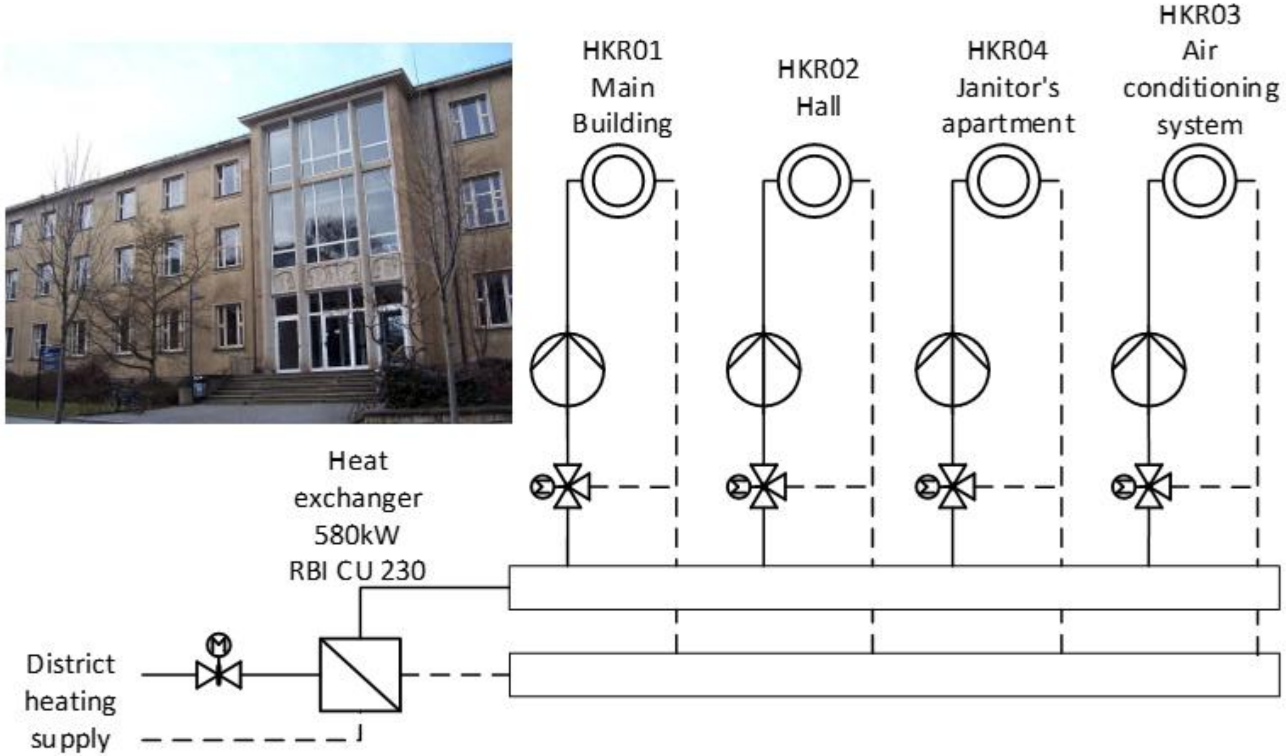
Substitution of conventional controllers

2022-2024; Dresden, Germany

Project: in Progress | Implementation: completed | System boundary: buidling | Time scale: 24h daily

EBC Energy in Buildings and Communities Programme

Subject Potential of modern radiator thermostats to reduce heat consumption at low investment costs



Ref.: © TU Dresden, Project Camper-Move, URL

Substitution of conventional controllers

2022-2024; Dresden, Germany

Project: in Progress | Implementation: completed | System boundary: buidling | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Subject	**Potential of modern radiator thermostats to reduce heat consumption at low investment costs**
Overview	Case study within the project "CAMPER-MOVE". The radiators in the office building are equipped with electronic controllers accompanied by monitoring. In addition to the energy consumption of the building, the thermal comfort of users is also evaluated.
Objective	During the analysis, particular attention was paid to the motivation of users to adopt energy-saving behavior. Load shifting is realized by preheating the thermal mass before the start of working hours on selected days; examine the potential of introduction of modern PI(D) radiator controls can significantly reduce space heating consumption
Scope	One office building (campus building)
System boundary, Time scale	Building + thermal grid, daily, weekly and seasonal
Building	Existing/new building with non-residential use, Office, labs, lecture rooms
Network	SH + DHW, 2nd Generation (T > 100°C)
Heat Source of DH Network	Renewable heat, fossil-based heat (natural gas and biomass)

Substitution of conventional controllers

2022-2024; Dresden, Germany

Project: in Progress | Implementation: completed | System boundary: buidling | Time scale: 24h daily

EBC Energy in Buildings and Communities Programme

Storage	Centralized and decentralized storage, water-based short-term buffer, water-based seasonal
DSM	Active, direct and automatic DSM with for permanent efficiency, load shed at particular hours throughout the work-day and load shift in form of preheating the thermal mass before working hours on selected days; night/weekend setback routine (possibility for superior intervention); user can intervene and adjust the setpoint on the thermostatic control valve
Intended benefits	Cost savings, reduction of GHG emission
Who is benefitting?	Customer and DH grid operator indirectly
Results	The energy saving potential resulting from the use of modern radiator controllers and load shed was quantified as part of various scientific studies: energy saving of about 10-15% can be assumed for the entire building. If the initial state is correspondingly poor, energy saving can be larger. Load shift reduces the peak loads in the campus area, therefore reduces higher peak costs.
Collaboration Detail	night/weekend setback routine (and possibility for superior intervention): (set point specification for indoor temperature).
Technology Detail	Radiators are equipped with electronic controllers and accompanied by monitoring, homematic IP thermostat with wireless connection to the internet via access points in the building
Control Detail	User can adjust the setpoint on the thermostatic control valve, electronic radiator controller.

Substitution of conventional controllers

2022-2024; Dresden, Germany

Project: in Progress | Implementation: completed | System boundary: buidling | Time scale: 24h daily

Energy in Buildings and Communities Programme

Best Practices / Lessons Learned:

- Through load shift the load peaks in campus area can be reduced and higher peak cost could be avoided

Substitution of conventional controllers

References and further information

Project: in Progress | Implementation: completed | System boundary: buidling | Time scale: 24h daily

Energy in Buildings and Communities Programme

- Homepage: https://tu-dresden.de/ing/maschinenwesen/iet/gewv/forschung/forschungsprojekte/projekt-camper

DSM in Danish single-family house

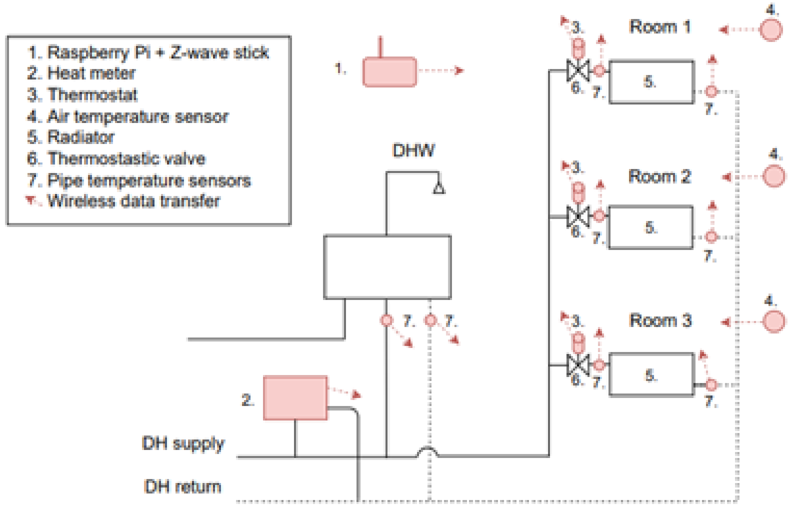
2020-2023; Aarhus, Denmark

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

Energy in Buildings and Communities Programme

Subject

The indoor air temperature was modulated according to a schedule mimicking the typical behavior of a real E-MPC, results were then analyzed regarding the load shifting potential.



Ref.: Amato et al., 2023, URL

DSM in Danish single-family house

2020-2023; Aarhus, Denmark

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Subject	The indoor air temperature was modulated according to a schedule mimicking the typical behavior of a real E-MPC, results were then analyzed regarding the load shifting potential.
Overview	Three rooms of one single-family house were examined and equipped. The radiators were set in such a way that they simulated the behavior of a real economic-model-predictive-control (E-MPC) during the heating season 2020/21.
Objective	Increasing and optimization of the load shifting potential under the use of an E-MPC.
Scope	One Single-Family house from 1968
System boundary, Time scale	Building, daily
Building	Existing/renovated building with residential use
Network	SH and DHW, 4th Generation (T = 55 – 75 °C)
Heat Source of DH-Network	Renewable heat, waste heat, fossil-based heat

DSM in Danish single-family house

2020-2023; Aarhus, Denmark

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building	24h daily

Energy in Buildings and Communities Programme

Storage	Building mass
DSM	Active, direct and automatic DSM for peak shaving by 2h (from 6-8 am); explicit, direct involvement of occupants
Intended Benefits	Peak shaving (morning peak)
Who is benefitting?	Customer and DH grid operator indirectly
Results	Shifting the heat load of a house by E-MPC of hydronic space heating systems with a few radiators to achieve a demand response is not recommended; Boost periods lead to high return temperature from the radiators which can be obtained by customization of the radiator heating set-point
Collaboration Detail	Dialogue with the residents to choose the active and passive zones.
Technology Detail	Equipment consist about remote-controlled thermostats and air temperature sensors used for experiments; thermostats from Aeotec model number ZWA021; Integration of the thermostats in a Z-wave network; enabling control of the temperature set-points or valve opening signals remotely using MATLAB or the AppDaemon environment.
Control Detail	E-MPC behavior; smart thermostats; supply temperature is manipulated

DSM in Danish single-family house

2020-2023; Aarhus, Denmark

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building	24h daily

Best Practices / Lessons learned:

- Load shift had hardly any effect on heat consumption of the house (due to parallel connection of radiators)
- Overheating of rooms can be a problem, due to a high supply temperature
- Boost periods cause high return temperature from the radiators
- Load shifting by E-MPC with only a few radiators cannot be recommended
- Good practice to select active/passive rooms for DR according to expected load shifting potential and occupants' comfort

DSM in Danish single-family house

References and further information

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building	24h daily

Energy in Buildings and Communities Programme

- Amato V., Hedegaard R.E., Knudsen M.D., Petersen S. Room-level load shifting of space heating in a single-family house – a field experiment (2022). In review at Energy and Buildings

- Project website “PreHeat”: URL.

Geo-solar low-temperature DH network

2015-2018; Kassel, Germany

Project: completed

Implementation: no implementation

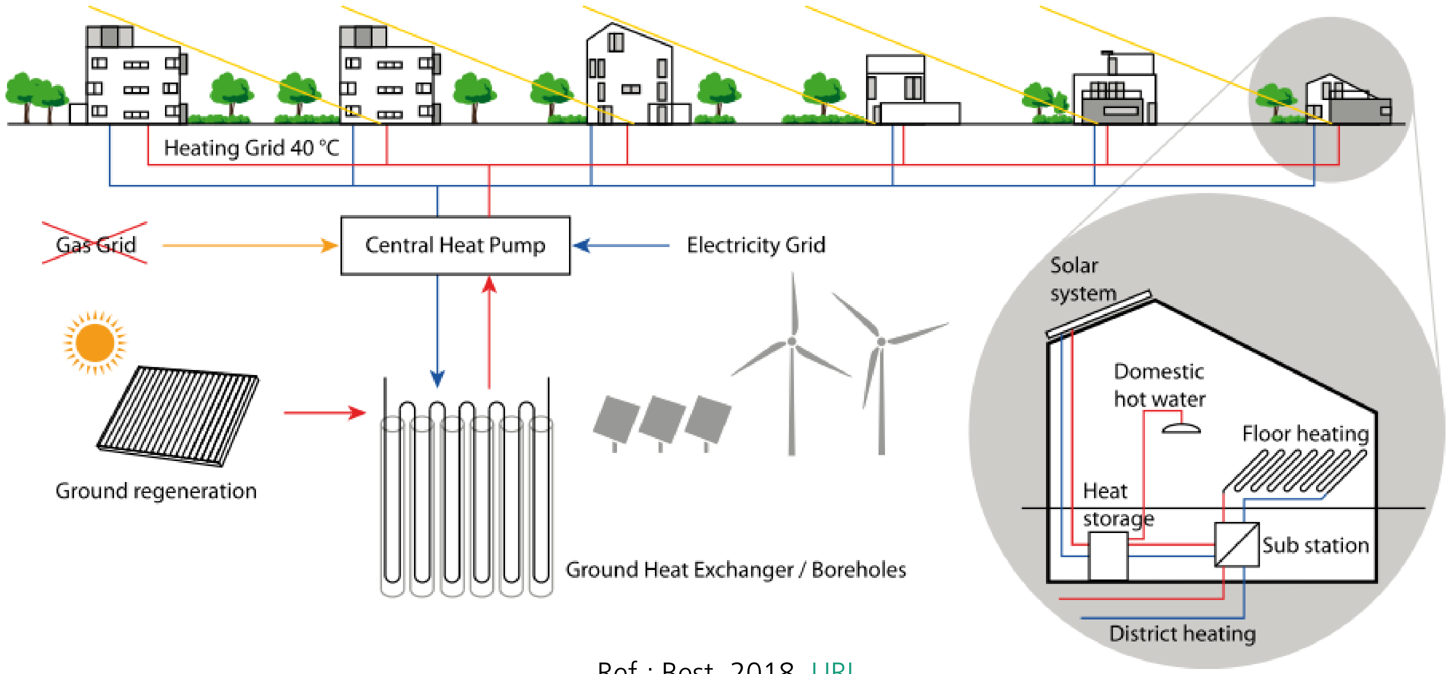
System boundary: building + thermal grid

Time scale: 24h daily

Energy in Buildings and Communities Programme

Subject

Effect of load management and optimized use of central heat pump in low-temperature district heating on energy and economic savings potential



Ref.: Best, 2018, URL

Geo-solar low-temperature DH network

2015-2018; Kassel, Germany

Project: completed | Implementation: no implementation | System boundary: building + thermal grid | Time scale: 24h daily

Energy in Buildings and Communities Programme

Subject	**Effect of load management and optimized use of central heat pump in low-temperature district heating on energy and economic savings potential**
Overview	A local district heating network is to be implemented for the new building area, as a connection to the existing district heating network is not possible for geographical reasons.
Objective	Energy sources should be renewable. Develop a predictive control system to balance the morning peak load by preheating the thermal energy storage (distribution grid) with the central heat pump during the night. Manage these power peaks by minimally using the electrical peak load boiler, as this is economically (much lower efficiency, expensive) and environmentally ($CO2$ emissions from electricity) disadvantageous.
Scope	New district with buildings each with energy demand of <50 kWh/m²a, 1-2 storey detached and semi-detached houses, two-storey terraced houses and large three-storey apartment buildings, heating capacity: 927 kW
System boundary, Time scale	Building + thermal grid, daily
Building	New building with residential use. Building type includes apartment, terraced and semi-detached.
Network	SH + DHW, 5^{th} Generation (T < 40°C)
Heat Source of DH Network	Renewable heat, heat pump which supplies geothermal heat regenerating through solar thermal heat

Geo-solar low-temperature DH network

2015-2018; Kassel, Germany

Project: completed

Implementation: no implementation

System boundary: building + thermal grid

Time scale: 24h daily

Energy in Buildings and Communities Programme

Storage	Centralized and decentralized thermal storage, water-based short-term buffer, water-based seasonal
DSM	Active, direct and automatic DSM for load shift with implicit, indirect involvement of the customer; DR active during the night (preheating thermal energy storage)
Intended Benefits	Shift morning peak to night to use heat pump instead of direct electric heating
Who is benefitting?	DH grid operator and customer indirectly
Results	The integration of low-temperature heat sources led to an improvement in the environmental balance. The overall efficiency can be increased by shifting the electricity demand from the peak load boiler to the central heat pump (reduction of the boiler share from 22% to 10%); reduction of operating costs lies between 4 and 11 percent depending on the difference between high and low prices of the HP tariff (from 0 to 10 ct/kWh)
Collaboration Detail	It is assumed that HP tariffs are available, considering low and high price windows depending on the time of day
Technology Detail	Distributed solar thermal systems in every building with an electrical back-up.
Control Detail	Predictive control is developed, Intelligent control strategy with load management to optimize the low-temperature district heating system in winter operation to balance the peak load that occurs.

Geo-solar low-temperature DH network

2015-2018; Kassel, Germany

Project: completed

Implementation: no implementation

System boundary: building + thermal grid

Time scale: 24h daily

Best Practices / Lessons Learned:

- By using the distribution network as a thermal energy storage system, more flexible operation of the district heating system could be realized
- By balancing out the peak loads, expensive operating times could be reduced and thus operating costs saved

Geo-solar low-temperature DH network

References and further information

Project: completed | Implementation: no implementation | System boundary: building + thermal grid | Time scale: 24h daily

EBC Energy in Buildings and Communities Programme

- I. Best, J. Orozaliev, K. Vajen, M. Schurig, D. Schmidt, O. Reul, T. Ebert: Geosolare Wärmeversorgung für die Neubausiedlung „Zum Feldlager" in Kassel, 26. Symposium Thermische Solarenergie 20.-22. April 2016, Bad Staffelstein.
- J. Orozaliev, I. Best, K. Vajen, D. Schmidt, M. Schurig, A.M. Kallert, O. Reul, J. Bennewitz, and P. Gerhold: Development of an Innovative Heat Supply Concept for a New Housing Area – A Case Study of IEA EBC Annex 64, CLIMA 2016 - proceedings of the 12th REHVA World Congress.
- O. Reul; H. Räuschel; D. Schmidt; J. Orozaliev; P. Gerhold; J. Bennewitz: Coupling of borehole heat exchangers with solarthermal systems. Proceedings of the 19th International Conference on Soil Mechanics and Geotechnical Engineering, Seoul 2017.
- O. Reul; H. Räuschel; D. Schmidt; J. Orozaliev; P. Gerhold; J. Bennewitz: Kopplung und Optimierung von Erdwärmesonden-Speichern mit solarthermischen Systemen. Fachsektionstage Geotechnik 2017/09 – 7. Symposium Umweltgeotechnik Abstract eingereicht – mündl. Vortrag.
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- Best I., Orozaliev J., Vajen K.: Low-temperature versus ultra-low-temperature solar district heating for low heat demand density housing developments in Germany, 3rd International Conference on Smart Energy Systems and 4th Generation District Heating, Copenhagen, Proc., DK, 12.09.-13.09.2017

Digitizing DH supply infrastructure

2019-2023; Hannover, Germany

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building + thermal grid	24h daily

EBC
Energy in Buildings and Communities Programme

Subject

Investigating the possibilities and potential of the digitalization in the Hannover DH grid

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Digitizing DH supply infrastructure

2019-2023; Hannover, Germany

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building + thermal grid	24h daily

Energy in Buildings and Communities Programme

Subject	Investigating the possibilities and potential of the digitalization in the Hannover DH grid
Overview	The research project "SmartHeat" investigates the potentials and possibilities of digitizing transfer stations in the field of district heating, with a focus on existing heat supply structures: digital accessibility of plants, available communication technologies, requirements of a digital system (suitable control, regulation procedures, data exchange methods). This case study was part of the project which should identify peak loads of individual properties and validate historical data through a thermal simulations.
Objective	Simulative quantification of potential flexibility potentials in buildings connected to Hannover DH grid as well as practical implementation (short-term tests)
Scope	20 buildings
System boundary, Time scale	Building + thermal grid, daily
Building	Existing/renovated and new building with mixed use. Building type includes apartment and terraced building.
Network	SH + DHW, 2nd Generation (T > 100°C)
Heat source of DH network	Renewable heat and waste heat

Digitizing DH supply infrastructure

2019-2023; Hannover, Germany

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building + thermal grid	24h daily

EBC
Energy in Buildings and Communities Programme

Storage	Decentralized thermal storage, water-based short-term buffer, building mass
DSM	Active, direct and automatic DSM for load shift with implicit involvement of the customer; three different simulative DR scheme were tested: 1) stepwise increase of reduced room set temperature (night setback), three steps over three hours, setpoint is reached at the same time, heating starts earlier to avoid peak; 2) priority control for charging the DHW storage, space heating is switched off during charging, normal charging process takes less than 15 min; 3) Charging of the DHW storage during night;
Intended Benefits	Load smoothing, variable heating tariffs
Who is benefitting?	DH grid operator and customer
Results	Simulation shows reduction of peak demand hours per year, by DSM scheme: 1) between 5 and 35% depending on the building, 2) between 42 and 88% depending on the building, 3) between 0 and 15% depending on the building; practical tests were too short-term and exemplary to draw conclusions but were conducted successfully; due to covid pandemic long-term tests couldn't be realized; Results of the customer survey (very similar results for customer living in SFH and MFH) showed high acceptance of dynamic tariffs if there is the chance of lower prices during low demand periods (approx. 70% of customer), but very low acceptance for higher prices during high demand periods (approx. 10%); the acceptance of room wise heating control is higher (approx. 60%) than to share data on heat demand and power with the utility (approx. 50%). 60% of customer would accept the installation of a thermal energy storage in their homes to increase flexibility is approx. 60%;

Digitizing DH supply infrastructure

2019-2023; Hannover, Germany

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building + thermal grid	24h daily

Collaboration Detail	Survey on customer readiness for digitally supported heat flexibilization measures to clarify data protection.
Technology Detail	District heating stations were equipped with measurement and communication technology.
Control Detail	Is developed in the project, three different control mechanisms are used for testing to achieve load smoothing, The flow temperature is controlled at the heat exchanger using the volume flow on the primary side as the control variable.

Digitizing DH supply infrastructure

2019-2023; Hannover, Germany

Project: completed | Implementation: completed | System boundary: building + thermal grid | Time scale: 24h daily

Energy in Buildings and Communities Programme

Best Practices / Lessons Learned:

- Several DHW charging process in short period can lead to reduced indoor temperatures (reaching the setpoint indoor temperature takes more time)

Digitizing DH supply infrastructure

References and further information

Project: completed
Implementation: completed
System boundary: building + thermal grid
Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

- https://www.agfw.de/smartheat
- https://www.iee.fraunhofer.de/de/projekte/suche/2019/smartheat.html

DH networks within hybrid energy systems

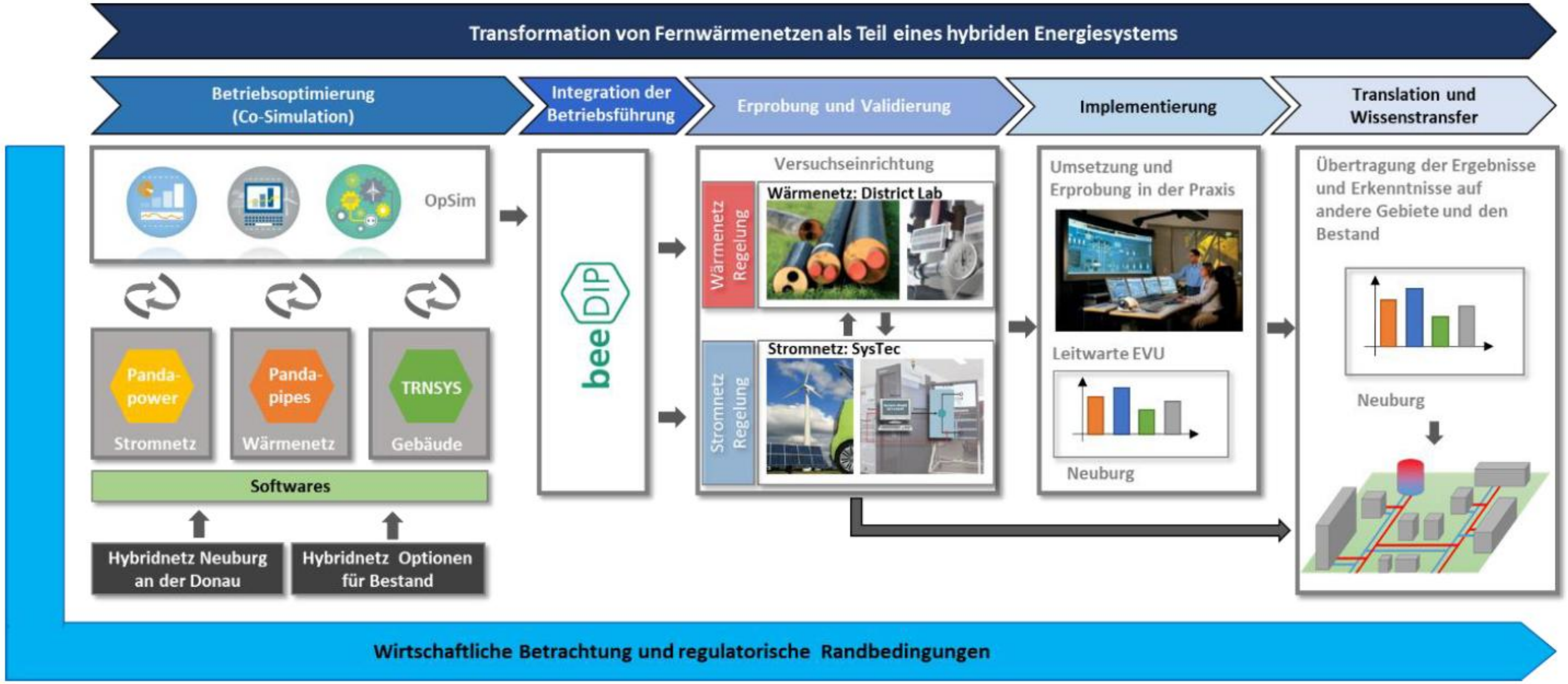
2021-2025; Neuburg a. Donau, Germany

Project: in progress | Implementation: in preparation | System boundary: building + thermal grid | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Subject

Investigate the potential for the operational optimization of heating networks as part of hybrid energy systems with the background of the transformation of district heating networks.



Ref.: Wett, 2022, URL

DH networks within hybrid energy systems

2021-2025; Neuburg a. Donau, Germany

Project: in progress | Implementation: in preparation | System boundary: building + thermal grid | Time scale: 24h daily

EBC Energy in Buildings and Communities Programme

Subject	Investigate the potential for the operational optimization of heating networks as part of hybrid energy systems with the background of the transformation of district heating networks.
Overview	Two physically separated systems are developed, heat and power grid (hybrid energy network). The decision which network being used will be made by the heat supplier as well as by the in the project introduced district manager.
Objective	The project's ("HybridBOT_FW") main objective is to demonstrate the potential for operational optimization of heat networks as part of a hybrid energy system, within the context of the necessary transformation of district heating. The investigations focus on developing a grid-friendly operation of two existing physically separated energy systems in the electricity sector (electric energy systems) and heat sector (thermal energy systems), so-called hybrid energy network.
Scope	82 buildings, existing and new buildings with year of construction between 1940 and 2025, total heat demand approx. 2000 MWh/a
System boundary, Time scale	Building + thermal grid, daily
Building	Existing/renovated and new buildings with residential and non-residential use. Building type includes apartment, terraced and semi-detached
Network	SH + DHW, 3rd and 4th Generation
Heat Source of DH-Network	Fossil-based heat and waste heat (waste heat coming from CHP plant supplies a thermal sub-grid)

DH networks within hybrid energy systems

2021-2025; Neuburg a. Donau, Germany

Project: in progress | Implementation: in preparation | System boundary: building + thermal grid | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Storage	Decentralized battery storage and decentralized thermal storage, water-based short-term buffer, building mass
DSM	Active, direct and automatic DSM for load shift and use of on-site generation with limited, indirect involvement of customer
Intended Benefits	Utilize a hybrid energy network, shift loads between energy sectors, use generation at the building (PV, heat pump, direct electric heating).
Who is benefitting?	DH grid operator and customer
Results	Simulation shows by switching off the grid in the summer months using a constant sliding temperature control, a 26% reduction in heat losses in the grid was achieved. Electricity consumption for operating the network pumps was reduced by 22%. The heating network can be completely switched off in the summer months if all connected buildings are supplied with decentralized heat, because 98% of the heat demand can be covered by local PV surplus production.

DH networks within hybrid energy systems

2021-2025; Neuburg a. Donau, Germany

Project: in progress

Implementation: in preparation

System boundary: building + thermal grid

Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Collaboration Detail	Establishment of a stakeholder called “district manager” who decides which energy network is best to use to achieve the lowest possible heat price at a given time. This stakeholder is the heat supplier for the district as well as the one making the decision whether the thermal or the electricity grid is used. There might the problem of opportunistic interests in thermal and electricity grid operators.
Technology Detail	Each building is equipped with a district electric heater or a heat pump contributing to the DH grid in supplying heat to the building.
Control Detail	District manager decides which network (electrical or heat) is connected to supply demand, information must be measured and made available to the district manager.

DH networks within hybrid energy systems

2021-2025; Neuburg a. Donau, Germany

Project: in progress | Implementation: in preparation | System boundary: building + thermal grid | Time scale: daily

EBC
Energy in Buildings and Communities Programme

Best Practices / Lessons Learned:

- Simulation shows relatively small energy savings compared to the total energy consumption (2690 MWh/a), though in areas with lower population density, heat losses can make up a significantly larger portion of the network supply (15-35%)
- Project is still in progress ...

DH networks within hybrid energy systems

References and further information

Project: in progress | Implementation: in preparation | System boundary: building + thermal grid | Time scale: 24h daily

EBC Energy in Buildings and Communities Programme

- BMWK FKZ: FKZ 03EN3041 A bis F
- https://www.agfw.de/forschung/hybridbot
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Renewable energy integration in DH grid

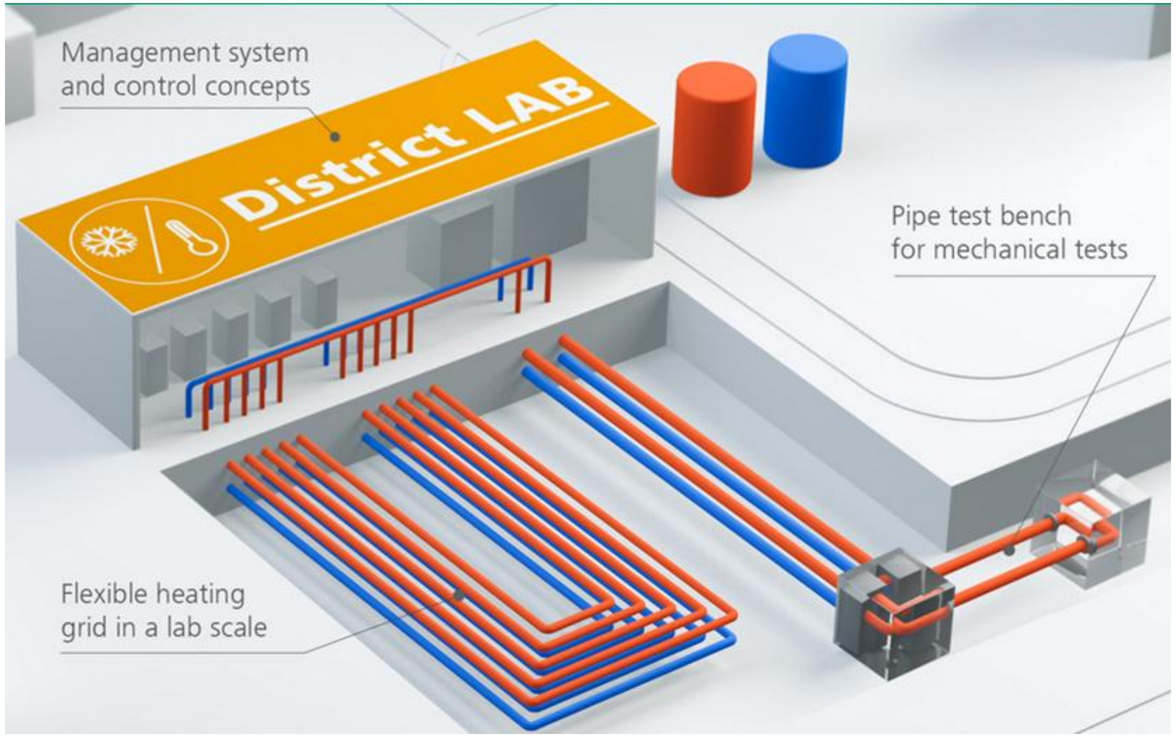
2018-2025; Kassel, Germany

Project:	Implementation:	System boundary:	Time scale:
in progress	in preparation	building + thermal grid	24h daily

Energy in Buildings and Communities Programme

Subject

Exploring the potential of transforming district heating infrastructure for renewable energy integration considering technical and economic issues



Ref.: Kallert et al., 2021, URL

Renewable energy integration in DH grid

2018-2025; Kassel, Germany

Project:	Implementation:	System boundary:	Time scale:
in progress	in preparation	building + thermal grid	24h daily

Energy in Buildings and Communities Programme

Subject	Exploring the potential of transforming district heating infrastructure for renewable energy integration considering technical and economic issues
Overview	The project "UrbanTurn" analyzes the influence of innovative measurement and control system solutions in the digitalization of district heating systems in a laboratory facility (District LAB, to be commissioned in mid-2024). It involves examining system performance, developing design criteria, analyzing the impact of measurement and control systems, and developing operational strategies for heat networks.
Objective	Develop new design criteria for district heating systems and network components as well as novel operating and control strategies for heating networks.
Scope	Lab facility with actual district heating network and hardware-in-the-loop units, heat demand of a district will be simulated
System boundary, Time scale	Building + thermal grid, daily
Building	Generic building with residential and non-residential use. Building type includes apartment, terraced and semi-detached.
Network	SH + DHW, 2nd and 4th Generation
Heat Source of DH Network:	Central and decentralized feed in of waste heat/solar heat

Renewable energy integration in DH grid

2018-2025; Kassel, Germany

Project: in progress | Implementation: in preparation | System boundary: building + thermal grid | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Storage	Centralized thermal storage, water-based shorter-term buffer
DSM	Active, direct and automatic DSM for load shed, load shift and generation
Intended Benefits	Decentralized feed-in of renewable heat, morning peak shaving (through load shift and/or load shed)
Who is benefitting?	DH grid operator and customer indirectly
Results	No results yet
Collaboration Detail	None investigated.
Technology Detail	District LAB: 5 substations (Hardware-in-the-Loop units)
Control Detail	To be developed: novel operational and control strategies for heat networks, considering a multivalent and volatile utilization of heat sources

Renewable energy integration in DH grid

2018-2025; Kassel, Germany

Project:	Implementation:	System boundary:	Time scale:
in progress	in preparation	building + thermal grid	24h daily

EBC
Energy in Buildings and Communities Programme

Best Practices / Lessons Learned:

- Project is still in progress …

Renewable energy integration in DH grid

References and further information

Project:	Implementation:	System boundary:	Time scale:
in progress	in preparation	building + thermal grid	24h daily

- A. Kallert, D. Lottis, M. Shan, and D. Schmidt, ‘New experimental facility for innovative district heating systems—District LAB’, Energy Reports, vol. 7, pp. 62–69, Oct. 2021, doi: 10.1016/j.egyr.2021.09.039.
- S. Hay, A. Kallert, D. Lottis, R. Ziegler, I. Weidlich, and S. Dollhopf, ‘Existing District Heating Networks in Context of German Climate Goals: Potentials for “UrbanTurn”’, in Conference Proceedings ISEC 2nd Sustainable Energy Concerence 2022, Congress Graz Austria, pp. 196–203.
- A. Kallert and D. Lottis, ‘Praxisnahe Fernwärmeforschung im Quartiersmaßstab - Versuchs- und Experimentiereinrichtung District LAB’, bbr, no. 03–2022, pp. 24–29.
- Fraunhofer IEE: https://www.iee.fraunhofer.de/de/presse-infothek/Presse-Medien/Pressemitteilungen/2021/UrbanTurn.html
- AGFW: https://www.agfw.de/forschung/urbanAturn

Flexible and innovative DH grid operation

2013-2018; Freiburg, Germany

Project: completed | Implementation: completed | System boundary: building + thermal grid | Time scale: 24h daily

Energy in Buildings and Communities Programme

Subject

Flexible operation of local DH network with integrated decentralized solar thermal systems and a central combined heat and power plant

Ref.: © Triolog Freiburg, Fraunhofer ISE, URL

Flexible and innovative DH grid operation

2013-2018; Freiburg, Germany

Project: completed | Implementation: completed | System boundary: building + thermal grid | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Subject	Flexible operation of local DH network with integrated decentralized solar thermal systems and a central combined heat and power plant
Overview	New building area in Freiburg realized with novel operation of DH. Decentralized solar thermal energy will be used to be able to switch off the DH grid during the summer.
Objective	Primary aim of this case study within the project "EnWiSol" is to implement, verify and derive general rules for the long-term use and integration of solar thermal energy in comparable urban residential districts under the conditions of the current and future energy market. The implementation of developed solutions into the local district heating network in Gutleutmatten is planned.
Scope	38 buildings with 525 living units, 1.350 inhabitants
System boundary, Time scale	Building + thermal grid, daily
Building	New building. Building type include apartment and terraced.
Network	SH + DHW, 4^{th} Generation (40 < T < 70°C)
Heat Source of DH-Network	Decentralized solar thermal system and CHP plant owned by DH utility (renewable and fossil-based heat)

Flexible and innovative DH grid operation

2013-2018; Freiburg, Germany

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building + thermal grid	24h daily

Storage	Decentralized thermal storage, water based short-term buffer
DSM	Active, direct and automatic DSM for load shift and use of on-site generation; limited, indirect involvement of customer
Intended Benefits	Shift loads between members of the district heating grid, use locally produced solar heat
Who is benefitting?	DH grid operator and customer indirectly
Results	Results of the simulation shows that the share of renewable energies could be forecast of over 20% for heat supply.

Flexible and innovative DH grid operation

2013-2018; Freiburg, Germany

Project: completed | Implementation: completed | System boundary: building + thermal grid | Time scale: 24h daily

Energy in Buildings and Communities Programme

Collaboration Detail	Not indicated
Technology Detail	Inlet to buffer storage coming from a HEX fed by solar heat, outlet of buffer storage to two HEX: one for space heating, one for DHW.
Control Detail	Novel operation controls (mainly for summertime): 1) cooperation of decentralized storages within buildings, if there is a storage almost fully loaded and another almost empty, the control can use this storage to send a heat pulse to heat the other storage. Connection of the system components to the internet (mobile internet, Wi-Fi and Lan connections), Smart Heat Grid (was developed because of the project), 2) intermittent operation of the central CHP plant, to send heat pulses in case a decentralized thermal energy storage is almost empty

Flexible and innovative DH grid operation

2013-2018; Freiburg, Germany

Project: completed | Implementation: completed | System boundary: building + thermal grid | Time scale: 24h daily

Best Practices / Lessons Learned:

- Adaption of the heat network control to reduce the distribution losses in the heat network because of the supply security (reason to developing Smart Heat Grid)
- Integration of solar thermal systems into the district heat system could be reduce the demand of fossil and critical energy carriers
- Consumer could deliver heat to each other through the Smart Heat Grid
- The smart heat grids can supply heat as heat pulses, which avoids heating up network strings
- Development of an evaluation procedure to better analyze power grid interaction

Flexible and innovative DH grid operation

References and further information

Project: completed | Implementation: completed | System boundary: building + thermal grid | Time scale: 24h daily

EBC Energy in Buildings and Communities Programme

- Dissertation: Mehmet Elci, Smarte und Dezentrale Solare Fernwärme, ISBN: 978-3-8396-1397-9, http://publica.fraunhofer.de/dokumente/N-515184.html
- IEA SHC Task 52, Solar Heat and Energy Economics in Urban Environments, http://task52.iea-shc.org
- Project report, http://publica.fraunhofer.de/documents/N-549554.html
- Presentation on the "Berliner Energietage 2021": https://www.energie.fraunhofer.de/content/dam/energie/de/documents/03_PDF_Messen-Veranstaltungen/dokumente_messen_2021/2021-04-21-BET_Innovative_Betriebsfuehrungsstrategien.pdf
- Homepage: https://www.ise.fraunhofer.de/de/forschungsprojekte/enwisol.html

Acceptance of fluctuating indoor temperatures

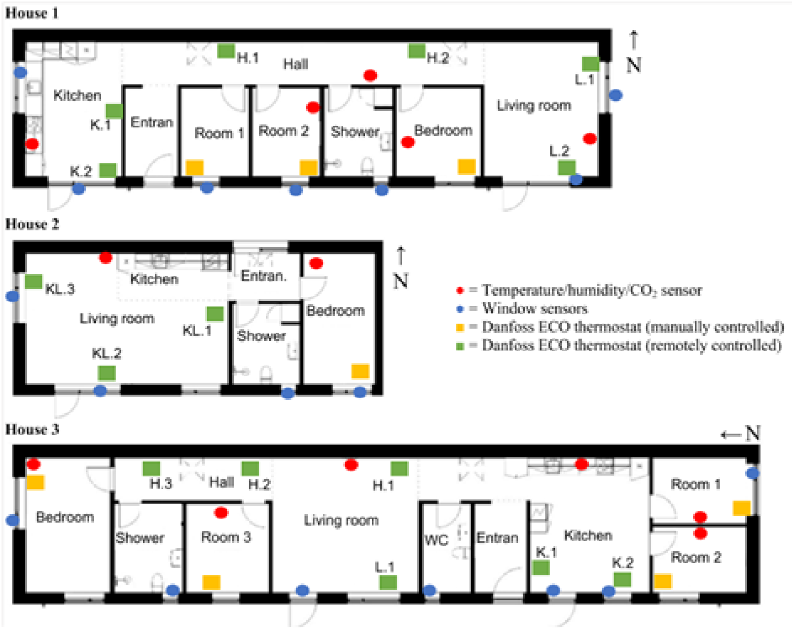
2019-2023; Aarhus, Denmark

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC Energy in Buildings and Communities Programme

Subject

The project examined mainly the acceptance of the residence regarding the fluctuating indoor air temperature behavior of the E-MPC space heating



Ref.: Christensen et al., 2023, URL

Acceptance of fluctuating indoor temperatures

2019-2023; Aarhus, Denmark

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Subject	The project examined mainly the acceptance of the residence regarding the fluctuating indoor air temperature behavior of the E-MPC space heating
Overview	Exploitation of thermal mass in residential buildings for demand response purposes in district heating system in practice. The living lab features three one-story houses located in Denmark equipped with technology enabling remote actuation of radiator thermostats and real time collection of heating energy use and various indoor environmental data.
Objective	Assessing the residentials` reaction to the fluctuating indoor air temperature caused by the simulated behavior of an E-MPC. Four different temperature boosts were used on the radiators which simulated the typical behavior of an E-MPC. The derived DR (peak shift) is secondary.
Scope	3 one-story residential houses
System boundary, Time scale	Building + thermal grid, daily
Building	Existing/renovated, semi detached buildings with residential use
Network	SH + DHW, 3rd Generation (70 < T < 100°C)
Heat Source of DH-Network	Mix of the local district heating company

Acceptance of fluctuating indoor temperatures

2019-2023; Aarhus, Denmark

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building	24h daily

EBC Energy in Buildings and Communities Programme

Storage	Decentralized thermal storage, building mass
DSM	Active, direct and automatic DSM for load shift with indirect involvement for building owner and direct involvement of occupant; four different temperature boost interventions tested: (1) heating off for 2h, (2) +2°C for 2h, (3) +2°C for 1h, (4) +1°C for 2h
Intended Benefits	Economical benefits for the DH operator, also distributed to the end-user; CO2-reduction
Who is benefitting?	DH grid operator and customer
Results	The residents accepted the conditions when they were clarified about the financial and environmental benefits of the system; guaranteeing the fluctuations of indoor temperature don't make them feel "too cold"
Collaboration Detail	no business model researched; hardware/software is developed with the company Neogrid; data collecting through semi-structured interviews of the residents; experiments show what user would make accept the fluctuating indoor temperatures: prospect of saving money, environmental benefits, or a combination of both
Technology Detail	Technology enabling remote actuation of radiator thermostats and real time collection of heating energy use and various indoor environmental data.
Control Detail	E-MPC, any type of control of radiator thermostats can be done (uses 4 different temperature boost)

Acceptance of fluctuating indoor temperatures

2019-2023; Aarhus, Denmark

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Best Practices / Lessons Learned:

- Explaining the system to the residents should consider the diversity in current preferences, expectations and level of technological pre-knowledge
- Explaining the benefits of an E-MPC convinced the inhabitants to accept the manipulation of their heating system
- Challenge to run the remote system in a robust way

Acceptance of fluctuating indoor temperatures

References and further information

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

- Louise R.L. Christensen, Thea Hauge Broholt, Verena M. Barthelmes, Dolaana Khovalyg, Steffen Petersen. A mixed-methods case study on resident thermal comfort and attitude towards peak shifting of space heating. Energy and Buildings 276 (2022), 112501, https://doi.org/10.1016/j.enbuild.2022.112501.
- Louise R.L. Christensen, Thea Hauge Broholt, Steffen Petersen. Are bedroom air temperatures affected by temperature boosts in adjacent rooms? 2022: CLIMA 2022 The 14th REHVA HVAC World Congress, Link.
- Louise R.L. Christensen, Steffen Petersen. Mixed-methods case studies on residents' acceptance of temperature fluctuations from model predictive control. Energy & Buildings, https://doi.org/10.1016/j.enbuild.2023.113405.

Remote control of radiator thermostats

2017-2020; Aarhus, Denmark

Project: completed

Implementation: completed

System boundary: building + thermal grid

Time scale: 24h daily

Energy in Buildings and Communities Programme

Subject

Demand management of private households by smart thermostats controlled during the morning peak and evaluation of occupants' acceptance

Ref.: Project Website "RESPOND", URL

Remote control of radiator thermostats

2017-2020; Aarhus, Denmark

Project: completed | Implementation: completed | System boundary: building + thermal grid | Time scale: 24h daily

EBC Energy in Buildings and Communities Programme

Subject	**Demand management of private households by smart thermostats controlled during the morning peak and evaluation of occupants' acceptance**
Overview	This case study considers only the Aarhus pilot. Energy consumption should be reduced in times of peak demand in exchange for financial incentives. In total the project "RESPOND" evaluates three pilot sites in different countries.
Objective	Shutdown heating by briefly switching off the radiator thermostats during certain period to shift the load and reduce the morning peak without reducing the comfort of the users; investigate the effects on DH load and room temperature; DH supplier has several reasons to reduce peak demand, most important: delivering enough heat during peak hours, would like to avoid upgrading existing pipes
Scope	This case study focuses on 10 three-storey multi-family houses
System boundary, Time scale	Building + thermal grid, daily
Building	Existing/renovated buildings with residential use. Building type is semi-detached
Network	SH + DHW
Heat Source of DH-Network	Not indicated

Remote control of radiator thermostats

2017-2020; Aarhus, Denmark

Project: completed | Implementation: completed | System boundary: building + thermal grid | Time scale: 24h daily

EBC – Energy in Buildings and Communities Programme

Storage	Decentralized thermal storage, water-based short-term buffer, building mass
DSM	Active, direct and automatic DSM for load shed and load shift with indirect involvement for building owner and direct involvement of customer; three different DR tested (each Mon-Fri, 2 weeks in a row): 1) 1h off 7-8am, 2) 2h preheating +1°C 4-6am and 3h off 6-9am, 3) 3h off 6-9am (no preheating); in phases with shutdown heating ("off") the setpoint of the thermostat was set to 16°C
Intended Benefits	Implementing load shift and shed is a cheaper alternative to supply all households, compared to costly renewal of pipes
Who is benefitting?	DH grid operator and customer indirectly
Results	Interviews indicate: 1) economic incentives are important, but important to observe that saving money is not the only element that motivates; 2) knowing the plan and intention behind a DR scheme can make occupants more acceptant to changes of their indoor temperature; 3) even more acceptance if households believe their participation is part of a collective action (neighborhood) and support societal goals like avoiding the need for upgrading DH pipes or mitigate climate change; with the right incentives, manual measures can encourage participants to adapt their daily activities to achieve savings; DR actions has proven to be very effective in saving energy and rescheduling demand: approx. 50% realized heating reduction during DR (in all three DR tested); 14.4% energy savings was achieved in the entire case study period for the tested buildings, sort by DR method: 1) 6.3% energy savings and 33 kWh load peak reduction, 2) 9.4% energy savings and 30 kWh increase and 30 kWh reduction of load peak, 3) 27.5% energy savings and 90 kWh load peak reduction

Remote control of radiator thermostats

2017-2020; Aarhus, Denmark

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building + thermal grid	24h daily

EBC
Energy in Buildings and Communities Programme

Collaboration Detail	"RESPOND" has been carried out by an interdisciplinary committee, Tenants were informed and took part in the DR process via a smartphone app, DR tested as "blind trials": Tenants didn't know specifically what happened
Technology Detail	Smart thermostats, remotely controllable, smartphone app to interview occupants
Control Detail	Installed thermostats controlling the heating, all thermostats are following the same plan, except the thermostats in the bathroom (not remotely controlled), users were able to adjust the setback temperature in the active DR process

Remote control of radiator thermostats

2017-2020; Aarhus, Denmark

Project: completed | Implementation: completed | System boundary: building + thermal grid | Time scale: 24h daily

Energy in Buildings and Communities Programme

Best Practices / Lessons Learned:

- Occupants had around two months before the event for adjusting the thermostats to their own preference (baseline)
- The user's comfort must be respected, as situations such as indoor overheating may let the user afraid of automated actions. On the other hand, with the right incentive, manual actions can make the participant adapt their daily activities to achieve savings.
- The DR schemes should be designed in a way that allows occupants to adjust the temperature level to their preference allow for some freedom to adjust the setback scheme and accepted temperature fluctuations according to their individual needs
- Residents' acceptance can be increased by informing them about the plan. In addition, financial incentives and the collective achievement of social goals play an important role in connecting residents to the project
- Thermostats in the bathroom were not remote controlled to meet a desire for maximum thermal comfort and not to increase the risk for mold growth
- Thermostats are not totally turned off, to ensure the temperature doesn't fall "too low", due to two reasons: 1) users' acceptance, 2) avoid condensation on walls and molds
- Heat DR schemes based on control of individual thermostats/radiators implies a high level of technical complexity and needs to be weighted against more simple and robust DH solution (i.e., based on central control)
- Individual ownership of PV panels resulted in higher engagement in the DR actions

Remote control of radiator thermostats

References and further information

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building + thermal grid	24h daily

- EU Project website „RESPOND": URL.

Temperature optimisation for LTDH

2018; Brescia, Italy

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

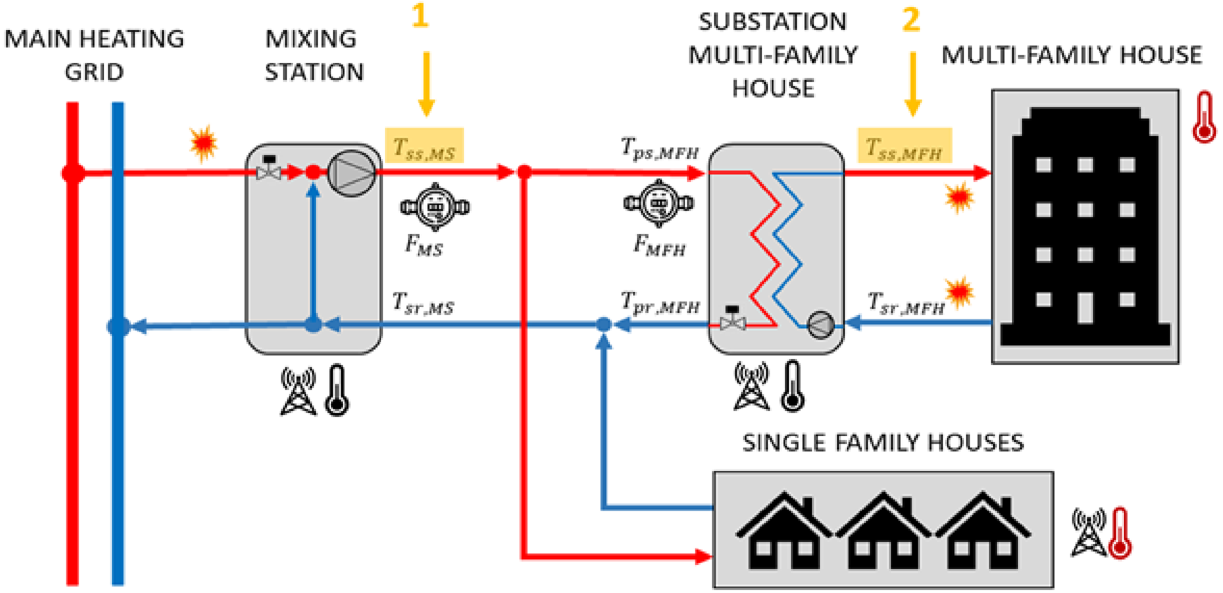
Energy in Buildings and Communities Programme

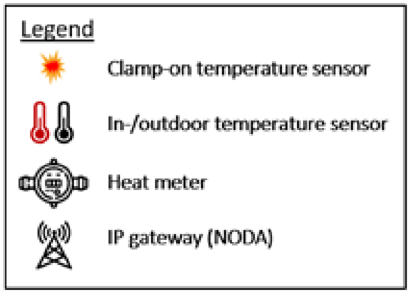
Subject

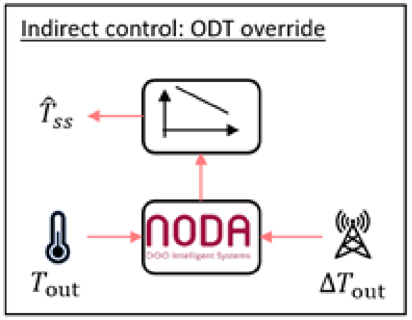
Impact of dynamic supply temperature control with the STORM controller in Brescia's DH Network on an apartment building's supply

Controlled variables: Supply temperature

1. @ mixing station → "supply temperature control"
2. @ apartment building → "building load control"







Ref.: Van Oevelen et al., 2021, URL

Temperature optimisation for LTDH

2018; Brescia, Italy

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building	24h daily

EBC Energy in Buildings and Communities Programme

Subject	**Impact of dynamic supply temperature control with the STORM controller in Brescia's DH Network on an apartment building's supply**
Overview	The case study is part of the project "TEMPO" (Temperature Optimization) and was conducted in multi-story residential apartment building with 43 buildings in the main DH network in Brescia. It took place in 2018. In the experiment the network supply temperature to the building was dynamically controlled.
Objective	In our case study, the objective was to reduce the peak energy consumption of the DH network branch by demand response in the apartment building, since these power peaks are expensive to provide by the peak production plants.
Scope	Apartment building with 43 flats, located in a peripheral branch of the network. A mixing station is installed between the main network, allowing for mixing hot supply water of the main network with return water from the buildings.
System boundary, Time scale	Grid, daily
Building	Existing/renovated apartment building
Network	SH and DHW, 2^{nd} Gen (>120°C); DH network in Brescia currently supplies about 1,000 GWh of heat to more than 21,500 customers; Supply temperature varies between 90°C and 130°C (dependent on outdoor temperature); Return temperature is about 60°C.
Heat Source of DH Network	CHP and Peak boiler with Natural gas and Waste incineration

Temperature optimisation for LTDH

2018; Brescia, Italy

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Storage	Decentralized thermal storage, building mass
DSM	Active, direct and automatic DSM for load shift and shed with limited, indirect involvement of customer
Intended Benefits	Peak Shaving, reduce the expensive fossil-based peak boiler operation
Who is benefitting?	DH operator, customer indirectly
Results	1) First test period with outdoor temperatures between 8 and 14°C (fall), the daily peak energy was reduced by 330 kWh on average, up to 700 kWh. This represented a 60 to 70% reduction compared with the baseline; supply temperature kept near 80°C lower limit, except for early morning and afternoon increases for network charging preemptively before anticipated peak demand periods; after "charging actions," supply temperature lowered to release stored energy, aiming to flatten daily thermal power profile and minimize peak load energy generation. 2) Second test period with outdoor temperatures between 1 and 6°C (winter) unfortunately, the substation behaved unexpectedly, results could not be attributed to control algorithm behavior, caused by capacity problem in the heat exchanger: supply temperature set point could not be met in those conditions, even in occasions when the demand response controller was not active; Due to colder weather and increased heat demand, the controller frequently set the supply temperature above the lower limit (80°C) for extended periods, especially during peak demand times in the morning and evening; This indicates the controller's anticipation of the need for higher supply temperatures to ensure adequate heat transfer to customers for maintaining thermal comfort.

Temperature optimisation for LTDH

2018; Brescia, Italy

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building	24h daily

EBC
Energy in Buildings and Communities Programme

Collaboration Detail	Implicit involvement of the customer (besides in this research project), direct control of network supply temperature at mixing station Multiple stakeholders involved: network operator, building owner, tenants; installation of indoor temperature sensors required a lot of tenant communication and consultation, some sensors were removed or relocated; building owner's consent needed for substation access, parameter changes by owner without notifying the network operator led to weird and unexplainable substation behavior.
Technology Detail	Indoor temperature sensors were installed in some apartments (9 in the beginning of the project, 2 at the end; Temperature sensors at supply and return temperature on secondary side of substation (building heating circuit), heat meter data of primary side (supply, return temperature, flow rate, energy) All data recorded at a 15-minute frequency was collected in a NODA-platform (Swedish company); Data was exchanged (via an API) between this platform and the controller platform of VITO; on VITO controller platform (MPC) control signals were calculated (based on measurements and energy forecasts), and then send back to demo site through the NODA platform;
Control Detail	To influence building energy consumption, outdoor temperature measurement was manipulated with offsets, to achieve peak shaving; manipulated readings influence heating curve of building, altering secondary supply temperature set point and therefore temporarily influence the heat intake; decreasing the outdoor temperature measurement results in higher heat consumption due to higher secondary supply temperature set point and vice versa

Temperature optimisation for LTDH

2018; Brescia, Italy

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC Energy in Buildings and Communities Programme

Best Practices / Lessons Learned:

- Multiple stakeholder involved in practical implementation, communication and consultation necessary
- Indoor temperature sensors can be removed or relocated

Temperature optimisation for LTDH

References and further information

Project: completed | Implementation: completed | System boundary: building | Time scale: daily

EBC
Energy in Buildings and Communities Programme

- EU Project website: URL.

- Project website TEMPO: URL.
- Demonstration site in Brescia: URL.

- T Van Oevelen, L Scapino, J Al Koussa, D Vanhoudt. A case study on using district heating network flexibility for thermal load shifting. Energy Reports. 7, 4, 2021, 1-8, https://doi.org/10.1016/j.egyr.2021.09.061.
- T Van Oevelen, T Neven, A Brès, R-R Schmidt, D Vanhoudt. Testing and evaluation of a smart controller for reducing peak loads and return temperatures in district heating networks. Smart Energy 10, 100-105.
- D Vanhoudt. Digitalisation in district heating networks: the TEMPO-project. European Energy Innovation, Autumn 2019
- D Vanhoudt, J Desmedt. New Management Systems for DHC Networks, HOT | COOL, Spring 2019.

Energy and cost savings in office building
2020/21; Lyngby, Denmark

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Subject Investigation of the energy and cost savings in an office building by changing the control of the existing heating system

Ref.: Benakopoulos et al., 2022, URL

Energy and cost savings in office building

2020/21; Lyngby, Denmark

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Subject	Investigation of the energy and cost savings in an office building by changing the control of the existing heating system
Overview	Study aims to investigate energy and cost savings of two different control strategies of an existing heating system in an office building on the DTU campus. Control strategies tested include 1) continuous high-temperature operation, 2) high temperature operation with night setback, 3) continuous low-temperature operation. Typical motivation tariffs for lower return temperatures used by Danish DH utilities were considered.
Objective	The scope of this investigation was to compare night setback control and continuous heating with minimized supply temperature curves by simulating and testing the proposed strategies in a Danish office building
Scope	One office building
System boundary, Time scale	Building, daily
Building	Existing/renovated building with non-residential use, Office building
Network	SH, 4th Generation (40 – 70 °C)
Heat Source of DH Network	-

Energy and cost savings in office building

2020/21; Lyngby, Denmark

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building	24h daily

EBC Energy in Buildings and Communities Programme

Storage	-
DSM	Passive DSM; Adaption of three control strategies tested: 1) continuous high-temperature operation, 2) high temperature operation with night setback reducing the supply temperature by 20 K between 6 pm and 6 am, 3) continuous low-temperature operation
Intended Benefits	1) Reduced annual energy consumption and 2) reduced return and supply temperatures by avoiding night-setback
Who is benefitting?	DH operator and customer
Results	The implementation of motivation tariff policies for low-temperature operation in DH networks in different countries towards LTDH may provide additional economic incentives to be considered besides energy savings, this result has been tested and evaluated in one specific office building in Denmark and DH systems with motivational tariffs for low-temperature operation. An energy-weighted average return temperature of 43.7 °C could be achieved, 12 °C lower than initial operations. Dynamic simulations demonstrated that strategy 2) and 3) both yielded energy savings of approx. 11%. Due to lower return temperatures and motivational tariffs, cost savings of 23.1% for the continuous low-temperature heating and 18.6% for the night setback strategy were realized.

Energy and cost savings in office building

2020/21; Lyngby, Denmark

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building	24h daily

EBC
Energy in Buildings and Communities Programme

Collaboration Detail	Promotion of the low-temperature district heating by Implementation of a bonus or penalty for end-users in form pf a motivation tariff
Technology Detail	-
Control Detail	Building is controlled by a building management system (BMS), night setback strategy with a sufficient temperature reduction, due to the high supply temperature used in the building case, under the night setback strategy, the supply temperature of the initial weather compensation curve was reduced by 20 °C from 18:00 to 6:00. After 6:00, the supply temperature was restored to the daytime setting,

Energy and cost savings in office building

2020/21; Lyngby, Denmark

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Best Practices / Lessons Learned:

- The implementation of motivation tariff policies for low-temperature operation in DH networks in different countries towards LTDH may provide additional economic incentives to be considered besides energy savings.

Energy and cost savings in office building

References and further information

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

- Benakopoulos et al. (2022): Energy and cost savings with continuous low temperature heating versus intermittent heating of an office building with district heating. https://doi.org/10.1016/j.energy.2022.124071

DSM in smart homes: living-lab experiments

2019; Copenhagen, Denmark

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Subject Lowering the heating demand in the morning hours by installing a remote control in individual rooms in real-world apartments

Ref.: Christensen et al., 2020, URL

DSM in smart homes: living-lab experiments

2019; Copenhagen, Denmark

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building	24h daily

EBC

Energy in Buildings and Communities Programme

Subject	**Rule-based demand-side-management for shaving peak demand in the morning hours by installing a remote control in individual rooms in real-world apartments**
Overview	The case study is part of the project "EnergyLab Nordhavn" and was conducted in multi-story residential apartment building. It took place in March 2019 in the heating season. In the experiment supervisory control of individual room temperature was applied to provide direct demand response for district heating grids
Objective	Goal was to demonstrate how to remotely control the heating system in individual rooms in real-world apartment to lower heating demand in morning peak hours and to show that a significant amount of heating load can be shifted from the peak hours.
Scope	Building consisting of 72 apartments ranging from 47 to 209 m² and 2 to 10 heated rooms including living room/kitchen, bedrooms, bathrooms, toilets and depots
System boundary, Time scale	Building, daily
Building	Existing/renovated building with residential use
Network	SH and DHW, 4th Generation (40-70 °C), HOFOR DH Network in Copenhagen
Heat Source of DH Network	-

DSM in smart homes: living-lab experiments

2019; Copenhagen, Denmark

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Storage	Decentralized storage, building mass
DSM	Active, direct and automatic DSM for load shift and shed (peak shaving) with limited, indirect involvement of customer Two rule-based penalty signals were implemented, 100% reduction of heating with and without pre-heating; Early tests showed that pre-heating was unnecessary due to the high thermal inertia of the building. As a result, we gradually reduced the pre-heating, from a few hours to ultimately a pure peak-shaving where no pre-heating was applied; toilets and bathrooms were excluded from this penalty signal. In the end, a 6-h heating reduction period was tested to reduce the morning peak demand (6am-12pm).
Intended Benefits	Reduce morning peak demand
Who is benefitting?	Utility, DH operator
Results	The results show that there is a significant potential for flexible energy consumption in homes based on smart home systems. It was found that when using a simple time-based penalty signal, on average, the peak-hour energy consumption was reduced by 85% with little impact on overall energy consumption and indoor temperature.

DSM in smart homes: living-lab experiments

2019; Copenhagen, Denmark

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building	24h daily

Collaboration Detail	-
Technology Detail	Apartments use a radiant floor heating system, warmwater is supplied from individual shunt loops that regulate the temperature supplied to the apartments to a maximum of 35 °C; heat delivered to each apartment is individually metered through measuring volumetric flow, forward and return temperatures of the water supplied to the shunt loops The algorithm was implemented in Python and run on a linux machine using CRON jobs to schedule the execution time of the script. The BMS used KNX, the python script and KNX were connected via MQTT (Message Brokering) and logged data to a database and real time monitoring platform (PowerLabDK, InfluxDB and Grafana)
Control Detail	Control signals were applied to the individual floor heating system via the BMS (KNX) in about 90 rooms to reduce heating demand in peak load hours, flowrate of warm water and the resulting heat is controlled by local thermostats controllers, opening and closing of valves are based on the current temperature in individual rooms and user-adjustable set-point for that room

DSM in smart homes: living-lab experiments

2019; Copenhagen, Denmark

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Best Practices / Lessons Learned:

- Practical experience from the early tests of the system and dialogue with the users revealed that the loss of control was experienced negatively by the residents. They had especially strong objections against loss of control for the bathroom in the morning hours. Therefore, we omitted control of bathrooms and toilets from the experiment.
- The heating power in the hours from 12 to 6 (after penalty signal) is higher on some days. This is due to rebound effect as some heating demand was shifted to these hours after the penalty period.

DSM in smart homes: living-lab experiments

References and further information

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

- Christensen et al. (2020): Demand side management of heat in smart homes: Living-lab experiments https://doi.org/10.1016/j.energy.2020.116993
- Project website “EnergyLab Nordhavn”: URL.

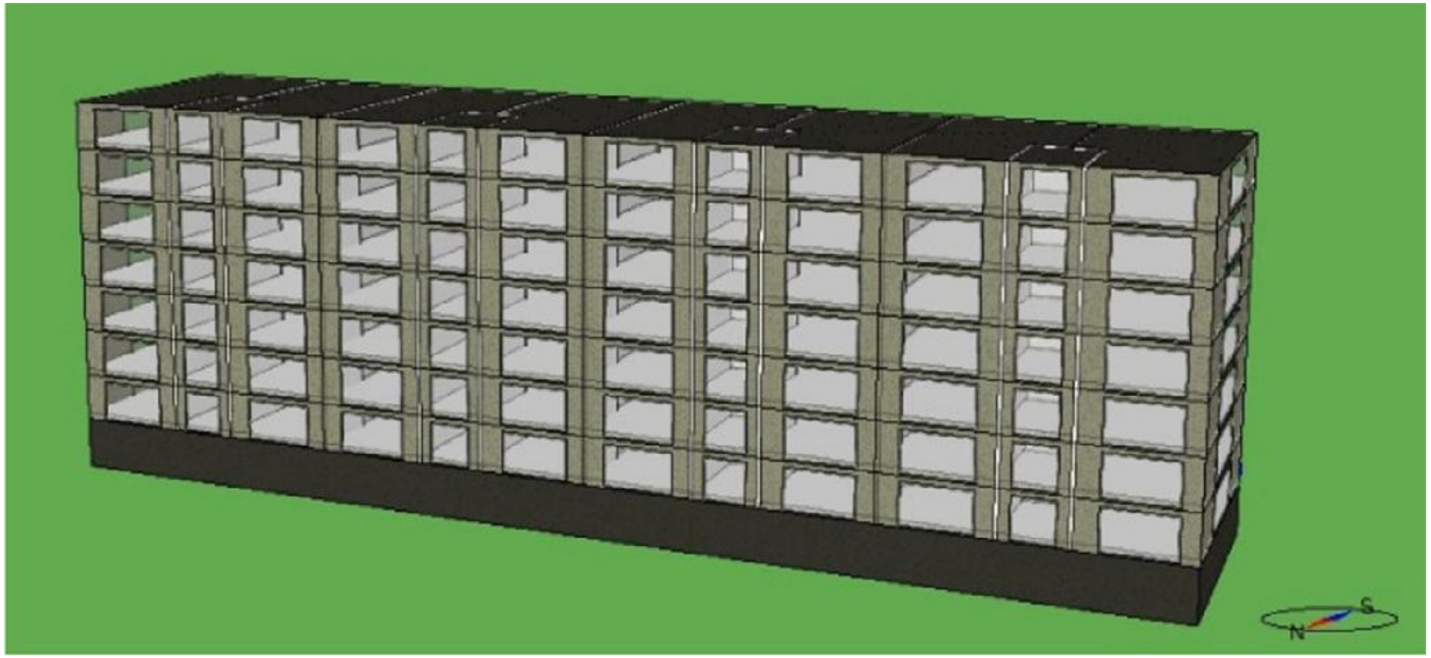
Energy flexibility of low-energy buildings

2018; Copenhagen, Denmark

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Subject Using the building mass as storage to shift the heat load to reduce peak load and energy costs



Ref.: Foteinaki et al., 2020, URL

Energy flexibility of low-energy buildings

2018; Copenhagen, Denmark

Project: completed
Implementation: completed
System boundary: building
Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Subject	Using the building mass as storage to shift the heat load to reduce peak load and energy costs
Overview	The case study is part of the project "EnergyLab Nordhavn". Aim is to evaluate the potential for low-energy residential building to be operated flexibility, according to the needs of heating system. Scenarios with different control signals are determined to achieve load shifting.
Objective	Evaluation of the storage of the building structure. The aim is to demonstrate the potential of the building for flexible operation, to shift heat load in time, avoiding peak load periods and utilizing heat during periods that heat production is less expensive. For this, 10 temperature set-point schedule were evaluated.
Scope	Apartment floor area of 6272 m^2, consists of 7 floors with 8 apartment each, unheated basement
System boundary, Time scale	Building, daily
Building	Existing/renovated building with residential rooms
Network	SH and DHW, 4^{th} Generation (40-70 °C), HOFOR DH Network in Copenhagen
Heat Source of DH Network	Typical Danish energy mix for district heating production including renewable, waste and fossil-based heat

Energy flexibility of low-energy buildings

2018; Copenhagen, Denmark

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building	24h daily

EBC

Energy in Buildings and Communities Programme

Storage	Decentralized storage, building mass
DSM	Active, indirect and automatic DSM for load shed and shift with limited, indirect involvement of the customer; simulated tariff signals from historic time series 4 fixed temperature setpoint schedules: shifting heating load to the night and early afternoon, as these times are favorable to for the DH system with and without preheating. 6 dynamic temperature setpoints: aim of these strategies is to shift energy to hours with low heat costs; two thresholds are defined: a low and high price, according to which the building modulates the temperature setpoints; If the price signal was lower than the lower threshold setpoint was increased, if the signal was higher than the higher threshold -> setpoint was decreased to discharge stored heat; if the signal was between the two thresholds an interpolation for the setpoint was used (with a dead band of 0.5 °C).
Intended Benefits	Reduced carbon-intensive and expensive peak boiler operation
Who is benefitting?	DH grid operator and customer (energy demand and cost decrease)
Results	In all scenarios energy use during the morning peak hours is reduced between 40% and 87%. Some fixed temperature setpoint schedule achieved 15% heating cost reduction except scenarios with increased preheating on cold days due to increased heat losses. Most scenarios reduced energy demand in total heating season by 11%, few scenarios increased energy demand by up to 2% with less heating costs.

Energy flexibility of low-energy buildings

2018; Copenhagen, Denmark

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

Energy in Buildings and Communities Programme

Collaboration Detail	Two indirect load control strategies were studied assuming first the non-existing and second the existence of a communication platform between the building/occupants and the supplier: 1) Assuming no communication platform (for fixed temperature schedules): implementation of constant strategy, 1-2 flexibility events daily, indirect control via monetary incentives to occupants, simulation of occupants setting lower temperatures when the heat cost is high and vice versa, fixed temperature set-points based on historic heat load/cost profiles 2) Assuming a communication platform (for dynamic temperature schedules): signal to the building from the supplier to communicate the need for load adjustment, home management system modulates temperature according to this signal, these schedule are also based on historic hourly marginal heat cost
Technology Detail	-
Control Detail	Reference operation of the building was defined with thermostatic control with constant air temperature set-point at 22 °C. Different Signals triggered an increase or decrease of the air temperature set-point to charge or discharge the thermal mass

Energy flexibility of low-energy buildings

2018; Copenhagen, Denmark

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Best Practices / Lessons Learned:

- With load shifting higher energy use may occur, it occurs mostly at times when the city heat load is lower and heat production is less expensive and less carbon intensive.
- Higher energy use may be considered acceptable, as it costs less to be produced and can be beneficial for the environment as it less carbon-intensive
- The study showed that there is potential in low-energy residential buildings to be operated flexibly achieving peak load shav- ing and cost reduction in the district heating system
- With the implemented strategies, new peaks in the heating load of the building were created. However, since they occurred during low load hours and were within the installed capacity of the building heating system, they are not considered as an impediment to the proposed strategies.
- The thermal environment was changed, as a wider temperature range and/or more frequent fluctuations in the indoor temperature occurred.

Energy flexibility of low-energy buildings

References and further information

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

Energy in Buildings and Communities Programme

- Foteinaki et al. (2020) - Evaluation of energy flexibility of low-energy residential buildings connected to district heating. https://doi.org/10.1016/j.enbuild.2020.109804
- Project website “EnergyLab Nordhavn”: URL.

Buildings as thermal energy storage in DH grids

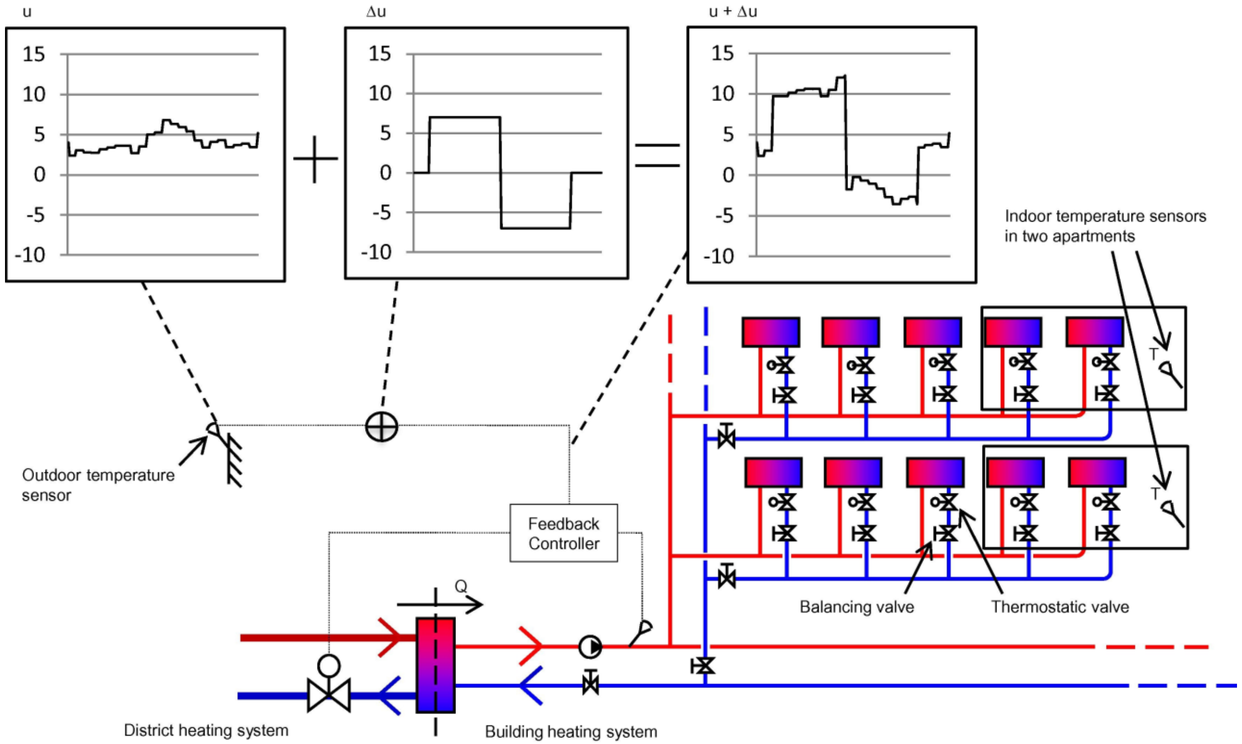
2010/11; Gothenburg, Sweden

Project: completed
Implementation: completed
System boundary: building
Time scale: 24h daily

Energy in Buildings and Communities Programme

Subject

Investigating buildings' capacity for thermal energy storage in DH systems



Ref.: Kensby et al., 2015, URL

Buildings as thermal energy storage in DH grids

2010/11; Gothenburg, Sweden

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Subject	**Investigating buildings' capacity for thermal energy storage in DH systems**
Overview	This case study reports on a pilot test exploring thermal energy storage capabilities in five multifamily residential buildings in Gothenburg, Sweden. During 2010 and 2011, over a period of 52 weeks, outdoor temperature sensor signals were varied in different cycles, with both the delivered heat and indoor temperatures monitored throughout the experiment.
Objective	The objective of this study is to evaluate the magnitude of thermal energy storage (TES) capacity that can be utilized in residential buildings while still maintaining a good indoor climate.
Scope	5 apartment buildings with 3-5 floors
System boundary, Time scale	Building, Daily
Building	Existing/renovated buildings with residential use, each with between 19 and 25 apartments; buildings used radiator heating systems, its supply temperature is set based on the outdoor temperature and a control curve; buildings constructed between 1939 and 1950 with a heating demand of approx. 150 kWh/m²a
Network	SH
Heat Source of DH Network	Heat Generation in Gothenburg including waste heat and fossil-based heat

Buildings as thermal energy storage in DH grids

2010/11; Gothenburg, Sweden

Project: completed
Implementation: completed
System boundary: building
Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Storage	Decentralized storage: Building mass
DSM	Active, direct and automatic DSM for load shift with limited, indirect involvement of the customer The signals from the outdoor temperature sensors were adjusted in different tests by this the heat delivery to the buildings were either increased or reduced, such as: to discharge a building, 7 °C is added to the outdoor temperature signal, the real outdoor temperature is 3 °C, but the control system receives the signal 10 °C (3°C+7°C). By periodically overheating and underheating building, causing small variations indoor temperature, building thermal inertia can be utilized for thermal energy storage. Five different tests each with three distinct periods: 1) charge period (CP): the building receives more heat, 2) discharge period (DP): the building receives less heat than and normal operation period (NOP): the building heating system operates normally. There are five tests including 21h-cycles (see Fig. 3): 1) CP for 9h by +7°C, followed by NOP for 12h; 2) CP for 9h by +7°C, followed by DP for 9h by -7°C and NOP for 3h, 3) CP for 9h by +5°C, followed by DP for 9h by -5°C and NOP for 3h, 4) CP for 9h by +3°C, followed by DP for 9h by -3°C and NOP for 3h, 5) CP for 9h by +7°C, followed by DP for 9h by -3°C and NOP for 3h
Intended Benefits	-
Who is benefitting?	-

Buildings as thermal energy storage in DH grids

2010/11; Gothenburg, Sweden

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Results	Heavy buildings, with a structural core of concrete can tolerate relatively large variations in heat deliveries with still maintaining a good indoor climate. Heavy buildings like those in this study can then be utilized for short term TES with these restrictions and controlled by direct load control without continuous measurements of indoor temperature. There was only one light building tested in this study, and it demonstrated smaller potential for being utilized for short-term TES than the heavy buildings. With the restriction of max. ±7°C, the thermal energy storage capacity can then be measured in degree hours [°Ch]. The thermal energy storage capacity of the heavy building in this case is then simplified to 63 °Ch (7°C x 9 h). The benefit with measuring the thermal energy storage capacity in degree hours is that this unit is universal and does not depend on factors such as the size of the building or the local climate. It is also directly related to the parameters in a buildings control system and should be easy to implement. Degree hours can also easily be translated into kWh for any given building by studying its energy signature, the relation between outdoor temperature and heating power. For Building A, which has an energy signature of 1.8 kW/°C, the thermal energy storage capacity is 113 kW h (63 °Ch x 1.8 kW/°C) or approximately 0.1 kW h/m² floor area.
Collaboration Detail	-
Technology Detail	The heat delivery was increased and reduced during periods of time, and the indoor temperature, T, was measured in two apartments in each building. The temperature meters were placed on the wall in the hall in each apartment.
Control Detail	The signals from the outdoor temperature sensors were adjust in different cycles during a total of 52 weeks. Adjusting the power by controlling the supply temperature in the pilot test was done using a conventional feedback controller.

Buildings as thermal energy storage in DH grids

2010/11; Gothenburg, Sweden

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Best Practices / Lessons Learned:

- Study demonstrated that a fixed time constant is not accurate enough to describe the variations in indoor temperature caused by the utilization of the buildings as short-term thermal energy storage
  - Degree hours is instead proposed as a simple yet adequate measurement for the thermal energy storage capacity in buildings
- The light building demonstrated smaller potential for thermal energy storage, but the magnitude of the difference is difficult to estimate, further investigations are necessary.
- A building's time constant is also directly related to the building's thermal mass, but it describes how fast a building will be affected by an adjustment in heat delivery, whereas the degree hour value describes the quantity of thermal energy that can be stored in the building. An increase in insulation level will increase the time constant, whereas the heating energy demand will be decreased.

Buildings as thermal energy storage in DH grids

References and further information

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

- Kensby et al. (2015) - Potential of residential buildings as thermal energy storage in district heating systems – Results from a pilot test.
  http://dx.doi.org/10.1016/j.apenergy.2014.07.026

Thermal conditions and flexibility potential

Nov 2018-Apr 2019; Aalborg and Copenhagen, Denmark

Project: completed

Implementation: completed

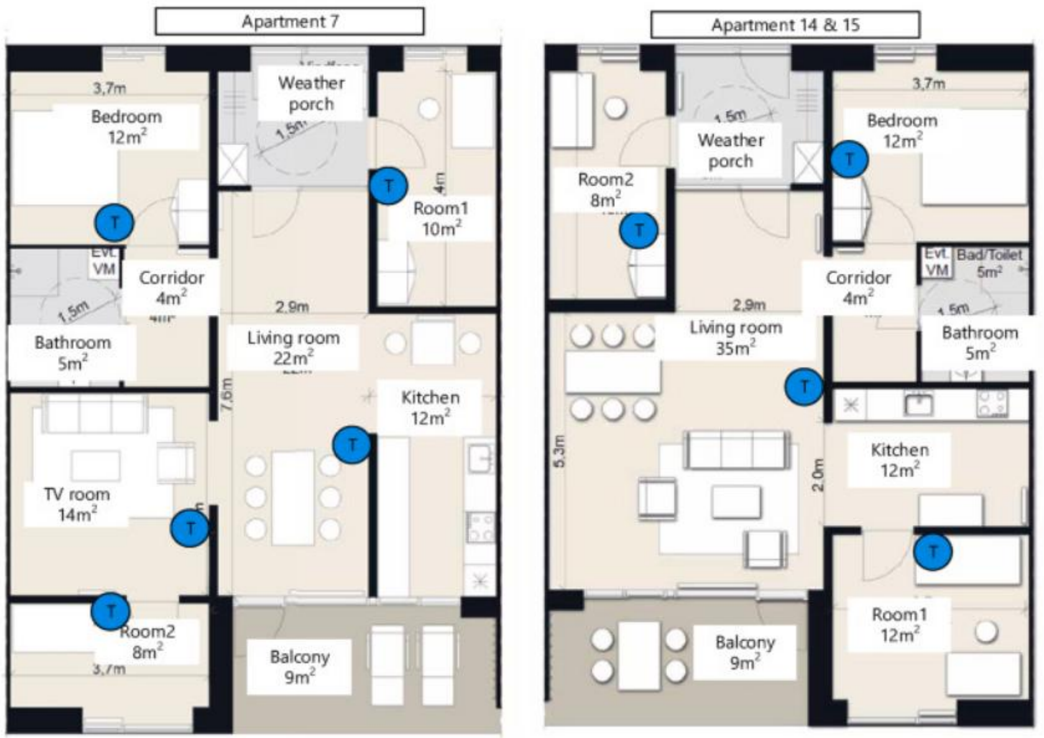
System boundary: building

Time scale: No DSM

EBC
Energy in Buildings and Communities Programme

Subject

Analysis of quantitative and qualitative data from two different field studies on thermal conditions and heating practices in apartment households



Ref.: Marszal-Pomianowska et al., 2021, URL

Thermal conditions and flexibility potential

Nov 2018-Apr 2019; Aalborg and Copenhagen, Denmark

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building	No DSM

EBC
Energy in Buildings and Communities Programme

Subject	**Analysis of quantitative and qualitative data from two different field studies on thermal conditions and heating practices in apartment households**
Overview	There is little specific knowledge of actual temperature conditions in buildings. This paper contributes with results from a detailed long-term monitoring campaign of temperature conditions in 17 households in Aalborg. These measurements are combined with qualitative interviews on their heating practices with 22 occupants in 16 households in Copenhagen.
Objective	Aim of the study was to present the variations of temperature conditions in the households using quantitative and qualitative methods, and thereby question if the current approach to model the thermal conditions in homes when evaluating and quantifying the flexibility potential of residential building stock is realistic enough.
Scope	For the monitoring campaign: 17 households with different area (67-130m^2) and size (1-4 occupants); Interviews: with occupants in four different multi-family buildings with varying unit area (35–210 m2) and size (1-4 occupants)
System boundary, Time scale	Building, daily
Building	For the monitoring campaign: one multi-family building, renovated in 2015 to NZEB standard; Interviews: four multi-family buildings with construction year in 2016-17 (three) and 2004 (one)
Network	-
Heat Source of DH Network	-

Thermal conditions and flexibility potential

Nov 2018-Apr 2019; Aalborg and Copenhagen, Denmark

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building	No DSM

EBC
Energy in Buildings and Communities Programme

Storage	Decentralized storage, building mass
DSM	None (data analysis on flexibility potential)
Intended Benefits	-
Who is benefitting?	-

Results 1

- The temperature conditions in the monitored apartments are diverse and not in line with thermal comfort conditions of 22°C recommended by the standards.
- Activities performed by occupants within and outside of the home result in spatiotemporal variations of temperature conditions, such as: temperature in the kitchen and bedroom follow typical occupants' daily routines (ventilation of bedroom in the morning, cooking)
- For 12 households the mean operative temperature is above 22 °C, Occupants in two apartments keep temperatures close to 25 °C. For most of the apartment, in 15 households, for 95% of the heating season the area weighted operative temperature varies less than 1K. Of course, they are single hours with either high or low peaks, but they constitute less than 5% of the heating season.
- This result could indicate that occupants with high temperature preferences are stricter with controlling the conditions inside their spaces.

Thermal conditions and flexibility potential

Nov 2018-Apr 2019; Aalborg and Copenhagen, Denmark

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building	No DSM

EBC
Energy in Buildings and Communities Programme

Results 2

- The presented results indicate that temperature conditions vary in time, space and between households. The in-depth interviews show that these temperature preferences are shaped by difficult to model aspects, namely the activities performed; the caring for things, others and oneself; the natural and material surroundings and general feeling of comfort in particular space

Collaboration Detail

-

Technology Detail

For the monitoring campaign: each apartment, depending on its size and layout, from four to five rooms, including kitchen, living room and bedrooms, were equipped with LAN-WMBUS sensors [33] monitoring indoor environment quality (IEQ) (i.e. operative temperature, relative humidity, CO2 level) and window open/close status. The location of the sensors was selected to eliminate the local temperature increase due to direct solar gains, see Fig. 1. The IEQ data were logged with a time step of 15 min and accuracy of ±0.3 ◦C, ±3% RH and ±(50 ppm + 3%). The monitoring period included 16 months, i.e. November 2018–March 2020.
Heat in the apartments is distributed through underfloor heating in hallways and bathrooms and radiators in the remaining rooms. Heat emitters are equipped with thermostats.

Control Detail

In all the occupants' homes, heating was controlled by a smart home technology setup, convenient for users to adjust the temperature set-point according to their comfort level, only manual control of the thermostats, no central control.

Thermal conditions and flexibility potential

Nov 2018-Apr 2019; Aalborg and Copenhagen, Denmark

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building	No DSM

EBC Energy in Buildings and Communities Programme

Best Practices / Lessons Learned:

- Including occupants in future experiments can be a way to reach the full potential to a renewable energy sources dependent energy system
- The results indicate that the applied control strategies of preheating the whole building area during the night-time with the same temperature increase to modulate heat demand during daytime is not realistic.
- The way we model the temperature conditions is too simple, the results presented in this paper show that reality is much more complex. The standard values are based on approaches to comfort grounded in laboratory settings, implying that the values may be too optimistic, as the reality is much more complex and building occupants are not driven only by the physical parameters.
- If using the full potential of buildings flexibility potential rather than approaching buildings in a uniform manner, a relevant approach could be to include occupants more in deciding and managing the settings for delivering energy flexibility.

Thermal conditions and flexibility potential

References and further information

Project: completed | Implementation: completed | System boundary: building | Time scale: No DSM

EBC
Energy in Buildings and Communities Programme

- Marszal-Pomianowska et al. (2021) - Thermal conditions in households and assessment of building's flexibility. https://doi.org/10.1016/j.buildenv.2021.108353
- Project website "INTERHUB": URL.

Occupant fade-out from demand response

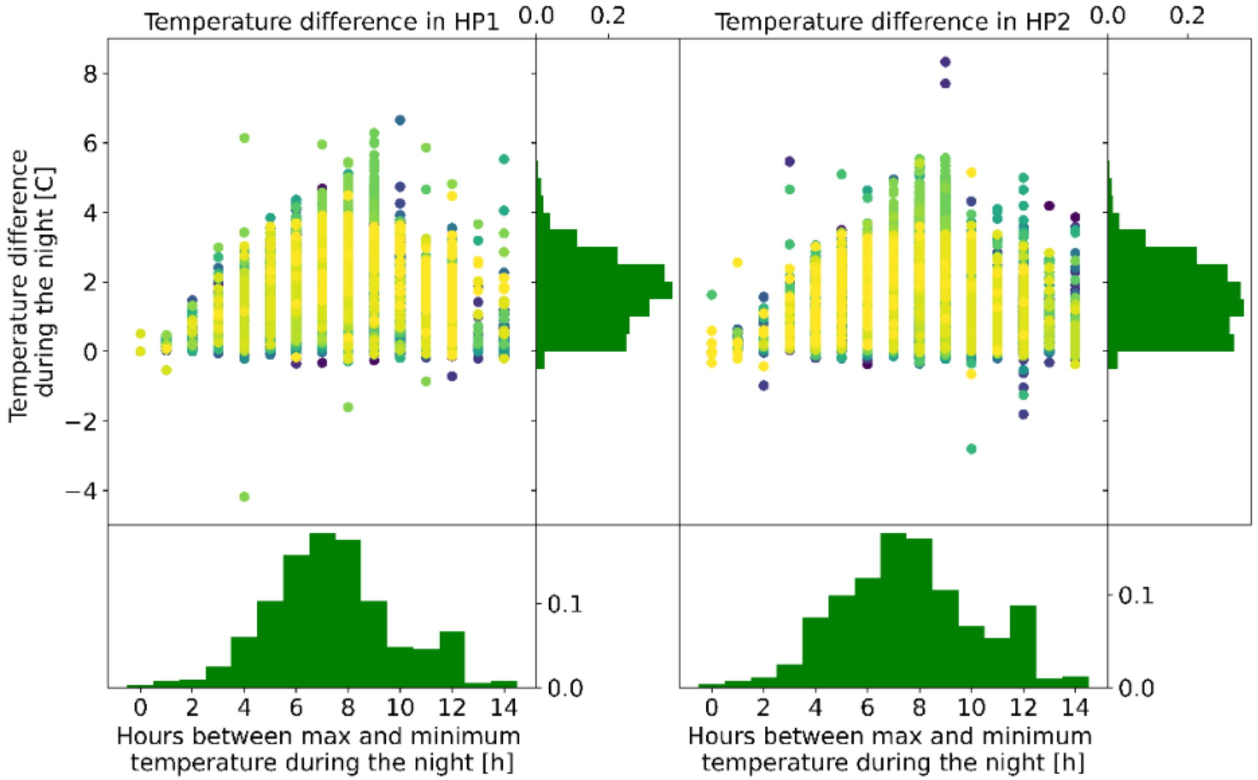
2012-2015; Southern Denmark

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Subject

Evaluation of the occupant fade-out from demand response in long-term study



Ref.: Marszal-Pomianowska et al., 2023, URL

Occupant fade-out from demand response

2012-2015; Southern Denmark

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Subject	**Evaluation of the occupant fade-out from demand response in long-term study**
Overview	In the field study (part of the Smart Energy I Hjemmet (SEIH) project) including 72 single-family houses connected to the 3GDH network in southern Denmark, the DR strategy "night setback" was applied for two heating periods. The occupants controlled the DR events settings and could at any time stop utilization of the night setback strategy.
Objective	Aim is to reach an implicit DR action to reduce the energy use for space heating during nighttime.
Scope	72 single-family houses (also connected to DH network), with 1-5 occupants each
System boundary, Time scale	Building, Daily
Building	72 single-family houses from 80m² row houses to 250m² detached units, built before 1990, houses with different heat sources (not only district heating, but also boilers) participated in the project
Network	3rd Generation DH grid in southern Denmark
Heat Source of DH Network	-

Occupant fade-out from demand response

2012-2015; Southern Denmark

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Storage	Decentralized storage: Building mass (used as short-term thermal energy storage)
DSM	Active, direct and automatic or manual DSM with indirect or direct involvement of the customer/occupant; occupants can control DR event in combination with automated night setback The houses were equipped with control and monitoring equipment, which allowed the deactivation of the heating system while monitoring the indoor temperature, so it does not drop below the defined value. Heat demand profiles has been modulated by overheating and underheating the building.
Intended Benefits	Buildings can deliver short-term thermal energy storage to energy systems. Knowledge from real-life case studies on how residents participate in demand management campaigns is crucial for the successful utilization of buildings' flexibility potential for minimizing bottlenecks in the daily operation of DH systems.
Who is benefitting?	-
Results 1	▪ The participation in the DR program of night setback decreased by 8% from heating period 1 to 2 (HP1 and HP2). All 72 participants activated the DR event during both heating periods, yet during fewer nights in HP2. The biggest fade-out effect of 41% was in the farmhouses. The households with either one or five persons were more reluctant to activate the night setback in HP2 and decreased their participation time by around 15%. ▪ The participation time decreased from 89% to 81%. The lowest participation rate was noted for the farmhouse, 60% and 9% of HP1 and HP2, respectively. In around 60% of the DR events, the night setback strategy was activated at 20:00.

Occupant fade-out from demand response

2012-2015; Southern Denmark

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Results 2

- In the oldest houses, which expect to have the worst thermal properties of the building envelope, and therefore, be more sensitive to the space heating turn-off periods than the other buildings, the time with activated night setback increased, while in the other age groups it decreased. The size of the building is not a key building characteristic, as for all sizes the fade-out effect is around 10%. The main reason for the decreased participation time could be the mean outdoor temperature in HP1 and HP2, which was 5.1 C and 4.6 C, respectively.
- From the DR event starting hour, the indoor temperature in the living space dropped successively for the period between 2 to 12 hours, with the period of 7h being the most common night setback window during weekdays. During weekends, the occupants had extended the DR event window to even up to 14h. Moreover, the decrease in the indoor temperature during the space heating stop ranges from 0.5 to 4K. This could be interpreted that for the occupants the indoor temperature is the main control parameter for the DR strategy and the length of the DR window is the output of the min. indoor temperature, the building thermal inertia characteristics and the outdoor temperature.

Collaboration Detail

The occupants controlled the DR events settings and could at any time stop utilization of the night setback during both heating periods. The occupants had access to monitored data and control options via SEIH homepage, where each house had a user account and control settings could have been modified according to individual household preferences (e.g. night setback start and end hour, definition of the min. indoor temperature below which heating should be turned on).

Technology Detail

Houses were equipped with control and monitoring equipment which allowed the deactivation of heating system while monitoring the indoor temperature, so it does not drop below the defined value. Each home in the trial was equipped with flow and temperature sensors at the DH substation unit to monitor energy use for space heating in the house.

Control Detail

The data collected by the sensors were fed into the Passive System control system located in each home to send a communication signal to close or open the supply of heat from the DH network.

Occupant fade-out from demand response

2012-2015; Southern Denmark

Project: completed | Implementation: completed | System boundary: building | Time scale: daily

EBC
Energy in Buildings and Communities Programme

Best Practices / Lessons Learned:

- The four factors of successful application of DSM in residential buildings connected to DH systems identified in [10], namely (1) set indoor climate conditions, (2) timing and magnitude of the load shifts, (3) individual control and (4) communication, have been indirectly confirmed by our study.
- The occupants were in full control over the DR events and could easily adjust the DR settings according to the household’s demands. This could be the reason why they continued to apply the night setback DR strategy for both heating periods.
- Moreover, it delivers an important message to the DH utilities that buildings and their occupants should not be considered as a simple load point/demand -side variable but as individuals capable of enabling systemic interventions and delivering short-term storage and/or flexibility, thus speeding up the process towards carbon-neutral systems.
- However, this result does not explain the participants’ motivations and priorities when it comes to the control of their heating system.

Occupant fade-out from demand response

References and further information

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

- Marszal-Pomianowska et al. (2023) - Do the customers remember? The fade-out effect from the demand response applied in the district heating system in Denmark. https://doi.org/10.1088/1742-6596/2600/13/132003

Application of the STORM controller in Rottne

2018; Rottne, Sweden

Project: completed | Implementation: completed | System boundary: thermal grid | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Subject Testing and evaluation of the peak shaving algorithm of the STORM controller in Rottne DH network

Ref.: STORM Project Website, 2021, URL

Application of the STORM controller in Rottne

2018; Rottne, Sweden

Project:	Implementation:	System boundary:	Time scale:
completed	completed	thermal grid	24h daily

EBC Energy in Buildings and Communities Programme

Subject	**Testing and evaluation of the peak shaving algorithm of the STORM controller in Rottne DH network**
Overview	The case study is part of the project "STORM" and was conducted in 2018. The objective was to test and evaluate the peak shaving control strategy of the STORM controller (MPC).
Objective	In our case study, the objective was to reduce the peak energy consumption of the DH network above a prescribed peak heat production power threshold by demand response in the nine buildings.
Scope	Nine of the largest customer substations in the network of Rottne, representing 34% of the total heat consumption in Rottne and a heat load of 1.7 MW during an outdoor temperature of -14 °C, when the heat load of the entire grid would be 4.4 MW.
System boundary, Time scale	Grid, daily
Building	Existing/renovated residential and non-residential buildings, apartment buildings, semi detached and terraced houses
Network	SH and DHW, 3rd Gen; plants in DH network produce about 12,8 GWh of heat; Supply temperature varies between 75°C and 110°C (dependent on outdoor temperature);
Heat Source of DH Network	Two biomass boiler and one peak boiler (wood and bio-oil)

Application of the STORM controller in Rottne

2018; Rottne, Sweden

Project: completed | Implementation: completed | System boundary: thermal grid | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Storage	Decentralized thermal storage, building mass
DSM	Active, direct and automatic DSM for load shift, shed with limited, indirect involvement of customer
Intended Benefits	Reduced peak demand, reduced operation times of expensive fossil-based peak boiler
Who is benefitting?	DH operator, customer indirectly
Results	1) The controllable heat load (subset of the total heat load, only tested buildings) was lower than the reference in all months except April (Mar 2018 to Jan 2019). Overall, the controllable heat load decreased by 12.7 MWh. 2) The total heat load was higher than the reference in all months except November. Overall, the total heat load increased by 69.1 MWh, as result of an increase of the uncontrollable heat demand of 81.8 MWh. Unfortunately, this interferes with the peak shaving testing and disturbs the evaluation. 3) Despite the overall heat load increase, the overall peak heat production was reduced by 7.4 MWh (3.1%) compared to the reference period without STORM. The peak heat production was lower in all months except January, when the peak heat production increased inexplicably by 12.4 MWh (together with an overall heat demand increase of 48.4 MWh). For the other test months, absolute peak load reductions up to 7.9MWh have been obtained monthly. Together, the reduction in peak heat production is 19.8 MWh (12.7%) during these months, which paints a brighter picture than the currently reported result.

Application of the STORM controller in Rottne

2018; Rottne, Sweden

Project: completed | Implementation: completed | System boundary: thermal grid | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Collaboration Detail Implicit involvement of the customer (besides in this research project)

STORM system is installed in nine demonstration buildings. The data of the STORM controller tests in both demonstration sites was accessed through the NODA EnergyView dashboard (Swedish control company). The control hardware and a basic demand-side management system were already present before the start of the project.

Technology Detail The STORM controller consists of four main components: The Forecaster predicts the future heat demand profile and estimates the thermal flexibility available in the buildings. This information is used by the Planner to create an optimized heat load control plan, considering system constraints and the choice of control strategy. The Tracker will use the heat load control plan to dispatch control signals towards individual building agents (vDERs) to try to follow the heat load control plan. Each vDER (virtual Distributed Energy Resource) interacts with the Tracker to negotiate how much it can contribute to the heat load control plan, considering local constraints.

Control Detail The peak shaving control strategy aims to reduce the amount of heat produced by peak units with higher fuel costs. It assumes that base load units are activated first until their full capacity, and that peak units deliver the heat above this power level. In other words, the peak shaving control strategy tries to shift heat loads above the base load capacity threshold towards times with lower heat load.

Application of the STORM controller in Rottne

2018; Rottne, Sweden

Project:	Implementation:	System boundary:	Time scale:
completed	completed	thermal grid	24h daily

EBC
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Best Practices / Lessons Learned:

- Reduction of operational costs: e.g. by replacing consumption of expensive fuels by cheaper fuels or maximizing CHP revenues
- Reduction of CO_2 emission: e.g. by replacing CO_2 intensive heat production by more sustainable heat sources
- Increase in system capacity: e.g. by shaving peaks and maximizing thermal energy exchange

Application of the STORM controller in Rottne

References and further information

Project: completed | Implementation: completed | System boundary: thermal grid | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

- EU Project website "Self-organising Thermal Operational Resource Management": URL.
- Case study description: URL.

- T Van Oevelen, D Vanhoudt, C Johansson, E Smulders. Testing and performance evaluation of the STORM controller in two demonstration sites. Energy 197, 2020 https://doi.org/10.1016/j.energy.2020.117177

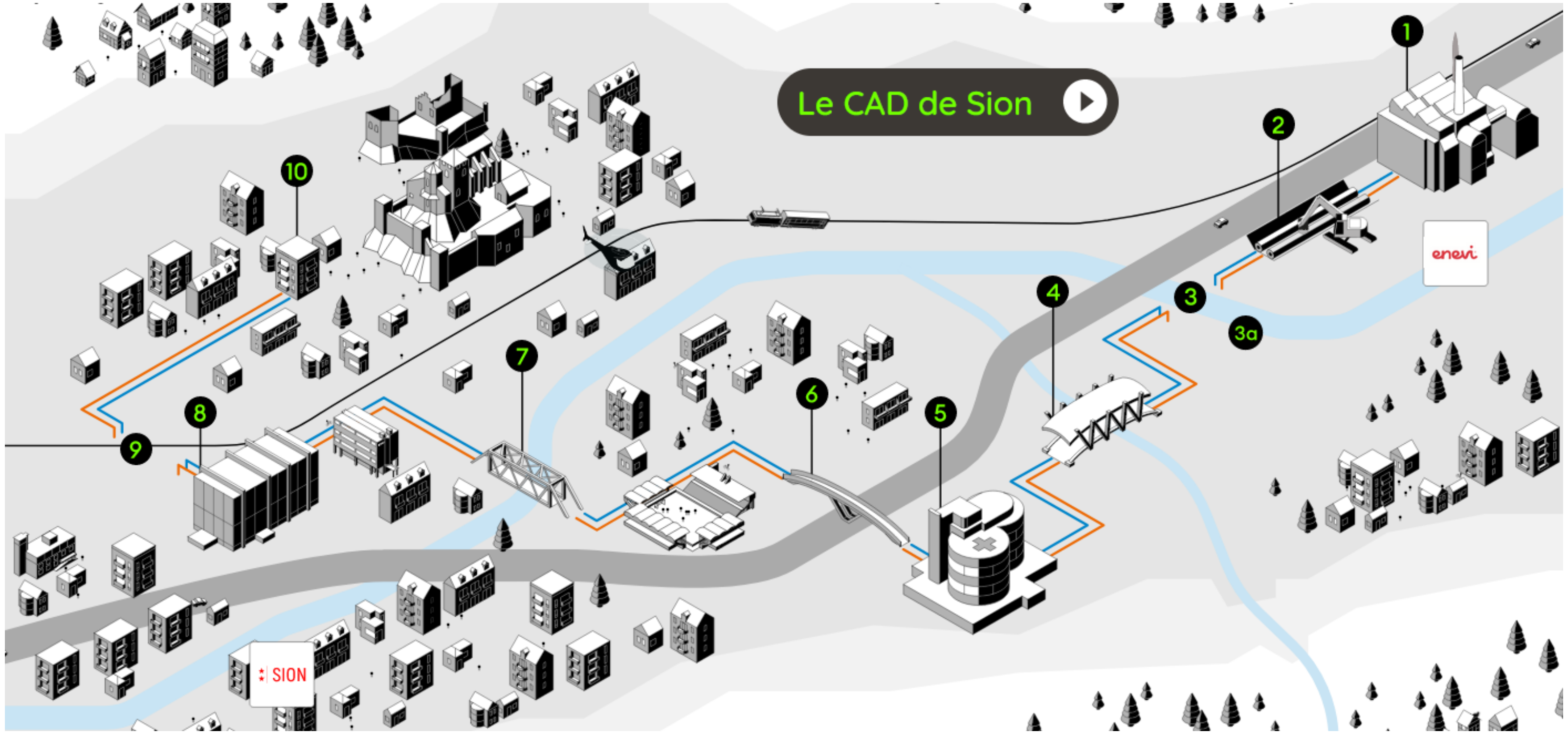
Optimal dispatch of heat in DH grid

2018; Sion, Switzerland

Project: in progress | Implementation: in preparation | System boundary: thermal grid | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Subject Optimising heat dispatch in new DH grid to reduce CO_2 emissions and fossil-based boilers



Ref.: Boghetti et al., 2024, URL

Optimal dispatch of heat in DH grid

2018; Sion, Switzerland

Project:	Implementation:	System boundary:	Time scale:
in progress	in preparation	thermal grid	24h daily

Energy in Buildings and Communities Programme

Subject	Optimising heat dispatch in new DH grid to reduce CO_2 emissions and fossil-based boilers
Overview	As the construction of the DH network in Sion still at the beginning, demand side management is not necessary right now. However, as DH grid will utilize local waste heat from the previously unused waste incineration plant, three water-based thermal energy storages should be used for optimally dispatching heat.
Objective	In this case study the objectives include the reduction of CO_2 emissions, increase of waste heat use and DH customer connections. Soon, load shifting and peak shaving could be implemented by remotely managing the primary control of all substations and the secondary control of the biggest customers.
Scope	DH network still under construction, right now 50 customer are connected, targeting 400 consumer in 2035.
System boundary, Time scale	Thermal grid, daily
Building	Existing/renovated residential and non-residential buildings, multi-storey apartment buildings
Network	3rd Generation DH network, heating only, supply temperature
Heat Source of DH Network	Waste incineration and back-up/peak gas boiler

Optimal dispatch of heat in DH grid

2018; Sion, Switzerland

Project: in progress | Implementation: in preparation | System boundary: thermal grid | Time scale: 24h daily

Storage	Centralized thermal energy storage, water-based buffer storage
DSM	No active or passive DSM in buildings, method of dispatching heat will be optimized to reduce CO_2 emissions by fossil-based boilers and use the favorable waster incineration plant (Soon, peak shaving and load shifting could be implemented)
Intended Benefits	Reduce the expensive fossil-based peak boiler operation and CO_2 emissions
Who is benefitting?	DH operator
Results	(No results yet, project still in progress)
Collaboration Detail	The waste incineration plant and DH network are owned by separate companies.
Technology Detail	-
Control Detail	-

Optimal dispatch of heat in DH grid

2020-24; Sion, Switzerland

Project: in progress | Implementation: in preparation | System boundary: thermal grid | Time scale: 24h daily

Best Practices / Lessons Learned:

- Project still in progress ...

Optimal dispatch of heat in DH grid

References and further information

Project: in progress | Implementation: in preparation | System boundary: thermal grid | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

- Boghetti, R and Kämpf, J H. "Verification of an Open-Source Python Library for the Simulation of District Heating Networks with Complex Topologies". Energy 290 (March 2024): 130169. https://doi.org/10.1016/j.energy.2023.130169

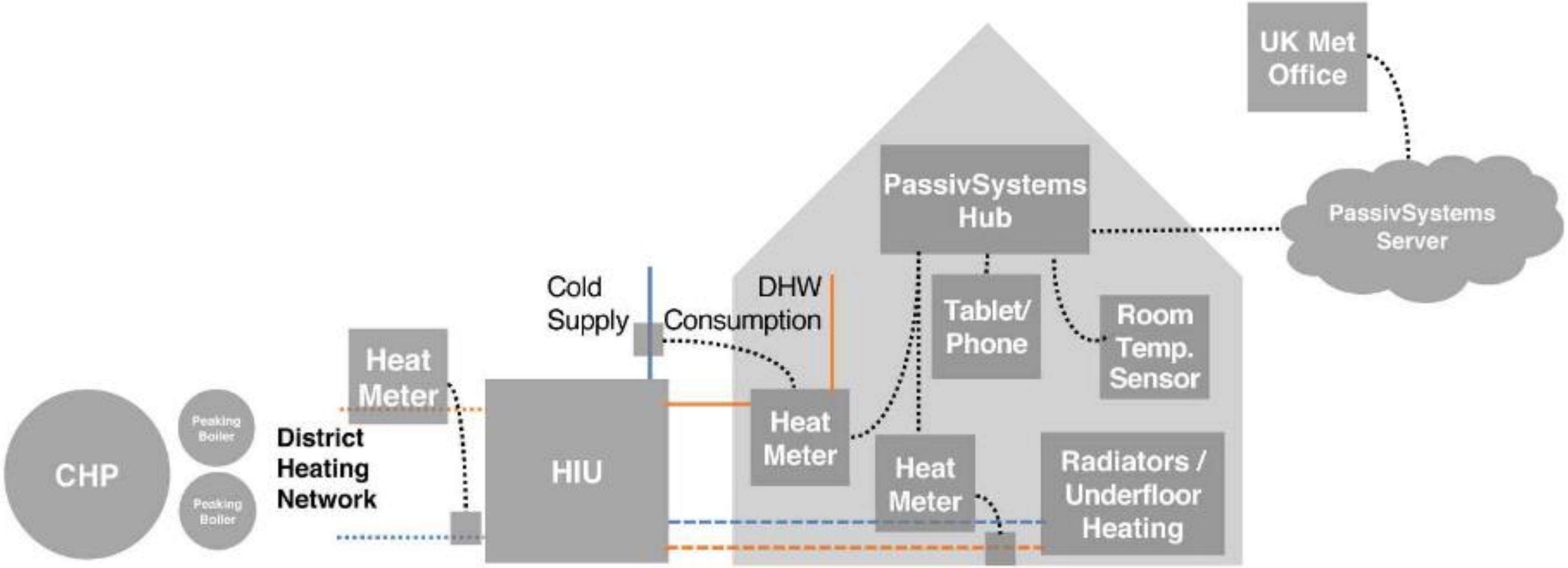
Load shifting in buildings connected to DH

2015/16; South-West, England

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Subject Utilization of a HEMS for Demand-Side-Management in residential buildings connected to DH



Ref.: Sweetnam et al., 2019 , URL

Load shifting in buildings connected to DH

2015/16; South-West, England

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

Energy in Buildings and Communities Programme

Subject	**Utilization of a HEMS for Demand-Side-Management in residential buildings connected to DH**
Overview	This study presents the results of a field study that deployed a prototype demand-shifting technology on a sample of homes connected to an operational DH network in the south-west of England over the winter of 2015/16.
Objective	The primary aim of the field trial was to gain an understanding of the impact of HEMS (Home Energy Management System) and the demand coordination service on the heat-demand profiles and thermal comfort of participating households.
Scope	28 Homes located in apartment and detached residential buildings
System boundary, Time scale	Building, Daily
Building	New buildings with residential use (completed between 2010 and 2015)
Network	-
Heat Source of DH Network	-

Load shifting in buildings connected to DH

2015/16; South-West, England

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building	24h daily

EBC
Energy in Buildings and Communities Programme

Storage	Decentralized thermal storage, Building mass
DSM	Active, direct and automated DSM for load shift and shed (peak shaving, even load curve) with limited, indirect involvement of customer 1) Following the baseline period with simple timer and thermostat operation, the HEMS's predictive control features were activated (optimizing mode). This involved active treatment with demand-shaping signals, aiming to reduce demand peaks and optimize DH network operation. Predictive control considered external temperatures, target temperatures, time-varying energy costs, and demand constraints to minimize energy use while maintaining thermal comfort. 2) Active shaping periods were remotely controlled, with demand constraint signals calculated by demand-coordination software and sent to controllers. The objective was to even out demand while ensuring energy consumption remained efficient and did not compromise participants' thermal comfort.
Intended Benefits	Reduced operational costs by increasing the coverage of the primary plant, reduced heat losses and pumping energy
Who is benefitting?	DH grid operator
Results 1	▪ Increased load factor of participating homes from 0.29 to 0.44; increased energy demand by 3%; estimated network cost savings exceed this amount; ▪ There is a clear reduction in demand during the morning and afternoon peaks, with consequent increases in demand during the overnight and afternoon periods

Load shifting in buildings connected to DH

2015/16; South-West, England

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Results 2

- The introduction of the optimized control leads to 1) a reduction in the mean measured temperature accompanied by an increase in the range of recorded temperatures, particularly at the lower end of the scale, 2) principally more overnight operation and a more gradual ramp up of demand in the morning, outcome of this is that the morning peak is reduced, and the load factor is increased from 0.29 to 0.41 before any active demand shaping.
- When demand shaping and the use of thermal inertia of the home is introduced, there is 1) an increase the mean room temperature slightly and reduces the range, it also has a clear influence on the shape of the profile, reducing overnight cooling and pre-heating in the afternoon between 12 and 16 h; 2) a further small reduction of the morning and afternoon peak demand and a small increase in the load factor to 0.44.

Collaboration Detail

-

Technology Detail

The HEMS developed by PassivSystems Ltd (Newbury, UK), consists of an internet connected in-home hub and a cloud-based demand coordination service. In addition to providing a user interface, the hub runs an optimizing control algorithm that aims to deliver the households comfort requirements while minimizing energy use and respecting any demand constraints. The demand coordination service calculates a demand-shaping signal for each of the participating homes to shape network level demand in a coordinated and, optionally, fair manner by equalizing the impact of increased overnight temperatures, for example.

Control Detail	Participants could control their heating via a tablet, mobile phone or web portal. No active heat storage was installed in the homes. The predictive control algorithm can consider time-varying energy costs and/or respect demand constraints, which determine maximum or minimum demand for a given period, can be passed to the HEMS via internet. Periods with demand coordination service and demand constraints were in place are name "active shaping", periods of active shaping were determined and enabled/disabled remotely by the researchers; when active shaping is in place, demand constraint signals are calculated remotely by demand-coordination software and passed to half the controllers alternately in a crossover experiment. No altered behavior was required of the homeowner, and they were not aware whether their controller was in optimizing or in active-shaping mode. The demand-shaping signals were generated using a coordinated control algorithm that aimed to reduce demand peaks and optimize the operation of the DH network. As DHW was provided instantaneously, the basic aim was to construct a set of constraints that ensured space heating demand did not coincide with DHW demand so that total demand was as flat as possible while respecting the thermal comfort requirements of the participants and ensuring energy consumption was not excessively increased. The algorithm incorporated a simple techno-economic model of the DH network that returned the cost of delivering a given heat-demand profile. This allowed the minimum cost combination of load profile and total energy demand to be found.

Load shifting in buildings connected to DH

2015/16; South-West, England

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Best Practices / Lessons Learned:

- While some participants noted the altered operation of their heating systems and expressed concern, the majority indicated they would be willing to participate in a commercial scheme for a small financial reward (2-10 pounds saving per month)
- …

Load shifting in buildings connected to DH

References and further information

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

- Sweetnam et al. (2019) – Domestic demand-side response on district heating networks. https://doi.org/10.1080/09613218.2018.1426314

Perceptions of indoor climate during DR

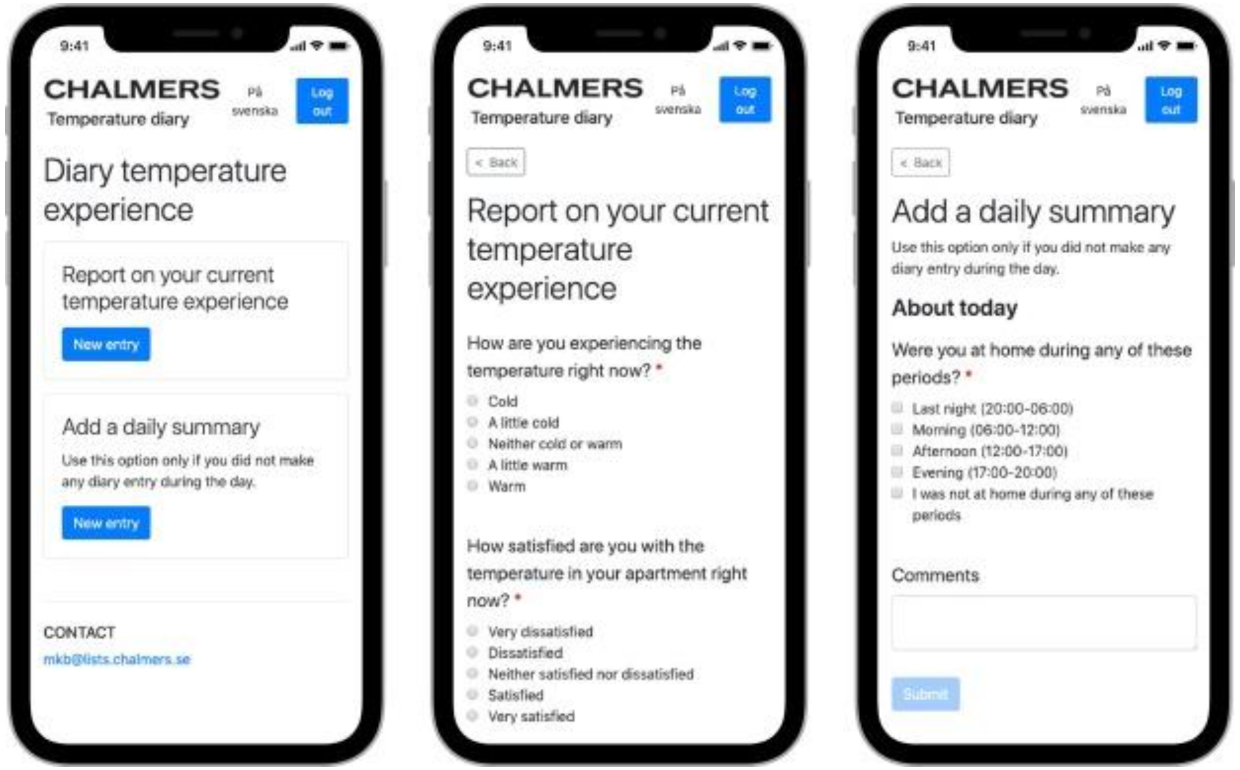
2019; Malmö, Sweden

Project: completed | Implementation: completed | System boundary: building | Time scale: daily

Energy in Buildings and Communities Programme

Subject

Investigation of the tenants' thermal perceptions in apartment buildings connected to DH during Demand-Side-Management



Ref.: Hagejärd et al., 2021, URL

Perceptions of indoor climate during DR

2019; Malmö, Sweden

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Subject	Investigation of the tenants' thermal perceptions in apartment buildings connected to DH during Demand-Side-Management
Overview	This case study was conducted during Nov/Dec 2019 in apartment buildings connected to district heating in Malmö, Sweden. It was divided into three phases: Registration and initial survey, two-week trial including power control applied to DH and diary of indoor temperature perception and closing survey.
Objective	Evaluation of the thermal perception among tenants in 33 multi-residential buildings during periods with centrally controlled load shifts. Within a two-week trial in early winter 8 of 33 buildings have been part of load shift events while tenants recorded their thermal sensation and satisfaction in a diary.
Scope	93 participants in 33 buildings registered, 8 buildings with power control/load shifts (40 tenants), 50% have been informed about load shifts, 50% have not been informed (directly before the load shift event)
System boundary, Time scale	Building, Daily
Building	Apartment buildings with residential use, construction year between 1949 and 1973 (with three being refurbished)
Network	-
Heat Source of DH Network	-

Perceptions of indoor climate during DR

2019; Malmö, Sweden

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Storage	Decentralized thermal storage: building mass
DSM	Active, direct and automatic DSM for load shift and shed (peak shaving) with limited, indirect involvement of customer ▪ The Customer Energy and System Optimization (CESO) system uses the thermal inertia of the building to enable load shifting. Indoor temperature are allowed to change by +/- 0.5°C, typically allows for a 75% power reduction for two hours or a 25% power reduction for six hours. Aim of the CESO systems is to reduce peak generation by approx. 5-10% of installed heat output. ▪ 6 different load shift tests have been executed between 2019-11-18 and 2019-12-01, following load shifts have been tested: -50% for 1 or 3h, -100% for 0.5h, -25% for 3h, +25% for 1h
Intended Benefits	Reduce peak generation by approx. 5-10% of the nominally installed heat output of the DH system
Who is benefitting?	DH operator
Results 1	▪ Between the days with and without load shifts, no statistically significant difference was found in thermal sensation or thermal satisfaction. However, significantly fewer participants could imagine allowing more variation in temperature at home to save energy after the trial than before. ▪ Major temperature reductions during times perceived as particularly cold and major temperature increases during times perceived as particularly warm should both be avoided. Mornings were perceived as colder than other times of the day.

Perceptions of indoor climate during DR

2019; Malmö, Sweden

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Results 2	▪ Results indicated a demand for more control over the indoor temperature as well as a positive correlation between perceived control and willingness to accept larger temperature variations. ▪ Communication about upcoming load shifts may play an important role in promoting acceptance of demand-side management and ensuring a well-functioning heating system. ▪ Factors that may influence the perception and acceptance of DSM in residential space heating, including: (1) set indoor climate conditions, (2) timing and magnitude of the load shifts, (3) individual control and (4) communication.
Collaboration Detail	Prior to the trial, the participants living in the buildings with load shifts were randomly divided into groups A and B, with participants of both groups represented in all buildings. The difference was that group A received notifications in advance of the load shifts, but group B did not. Notifications were sent approximately 30 min before the shifts.
Technology Detail	The CESO (Customer Energy and System Optimisation) system gives a warning if a planned load shift is calculated to impact the temperature by more than 0.5°C. However, it does not actually measure actual indoor temperature changes.
Control Detail	-

Perceptions of indoor climate during DR

2019; Malmö, Sweden

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

Energy in Buildings and Communities Programme

Best Practices / Lessons Learned:

- Building-related problems which cause negative experiences of the indoor climate, such as poor insulation or insufficient ventilation, should be resolved to support overall satisfaction with the indoor climate.
- Future studies are needed for insights how residents perceive the temperature at different times of the day, when and how heat-related practices take place and what implications these have for the design of demand-side management strategies.
- Another topic for future studies is to explore how greater flexibility in heating demand might be combined with greater experience of control over the indoor climate to increase residents' thermal satisfaction whilst saving energy.

Perceptions of indoor climate during DR

References and further information

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

- Hagejärd et al. (2021) - My apartment is cold! Household perceptions of indoor climate and demand-side-management in Sweden. https://doi.org/10.1016/j.erss.2021.101948

DR in Student Apartment Buildings

2018; Tampere, Finland

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

Energy in Buildings and Communities Programme

Subject Potential of prioritizing DHW demand over space heating in apartment buildings connected to DH

Ref.: Ala-Kotila et al., 2020, URL

DR in Student Apartment Buildings

2018; Tampere, Finland

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Subject	Potential of prioritizing DHW demand over space heating in apartment buildings connected to DH
Overview	Within this study a field test in northern climate in Finland was conducted and investigated the potential of a demand response system installed in the central heating systems of an existing apartment building. The results were evaluated based on reduction of annual energy consumption, greenhouse gas emissions, peak load, and energy cost saving.
Objective	The main objective of this field test has been to test the feasibility of DHW prioritizing as a DR method in apartment buildings. Additional three sub-questions: (1) Can DR reduce GHG emissions of DH? (2) Does DR enable cooperation between buildings and energy system? (3) Is DR a viable business opportunity for stakeholders?
Scope	27 apartment buildings with residential use
System boundary, Time scale	Building, Daily
Building	27 apartment buildings, owned by Tampere Student Housing Foundation (construction between 1928-2009), buildings were already equipped with a smart automation system controlling the heating system according to the weather forecast
Network	-
Heat Source of DH Network	-

DR in Student Apartment Buildings

2018; Tampere, Finland

Project: completed

Implementation: completed

System boundary: building

Time scale: 24h daily

EBC Energy in Buildings and Communities Programme

Storage	Decentralized thermal storage: building mass
DSM	Active, direct and automatic DSM for load shed (peak shaving) when there is a DHW draw-off: prioritization of DHW demand at the expense of space heating in apartment buildings connected to DH. Limited, indirect involvement of customer. The presented demand response system considers weather forecasts, indoor temperatures and decreases in space heating temperatures when demand for domestic hot water is the highest.
Intended Benefits	Reduce peak plant operation and fossil fuel usage, aim to reach National Energy and Climate Strategy objectives for 2030
Who is benefitting?	DH operator and customer (direct financial benefits for customer if power peaks are reduced)
Results	▪ Decrease in peak demand by 14-15% on average ▪ During the test (heating period Feb and March) the normalized energy consumption of eight buildings was reduced by 11%, which represents a 9% annual cut in energy, costs and GHG emissions. ▪ Demand Response (DR) heating aims to help reaching objectives of the National Energy and Climate Strategy for 2030. ▪ The fact that the case buildings had already used heat optimization services gives reason to believe that the reductions in peak load would be even larger if the buildings had not applied any modern heat optimization services before.

DR in Student Apartment Buildings

2018; Tampere, Finland

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Collaboration Detail -

Technology Detail

Continuous and real-time tap water monitoring, as well as installed indoor temperature and humidity sensors, are connected to the *Talotohtori* cloud service which can interact with the BMS. The core of the cloud-based BMS is a standardized building data model, which makes the BMS scalable and easy to operate.
The BMS architecture includes several modules: 1) user interface, 2) connection of IoT sensor interfaces for indoor air conditions monitoring, 3) access to data sources like weather forecasts and electricity spot prices for smart heating, 4) secured internet connectivity, 5) compatible with most automation brands and protocols.

Control Detail

Indoor temperature sensors send measurements to the cloud at ten-minute intervals. The BMS calculates the average temperature of all sensors and compares it to the desired room temperature. Based on this comparison, the BMS adjusts heating to the target level.
On top, the power peak shaving algorithm is executed, which is allowed to work in a predefined average indoor temperature range (typically ±0.5 °C, e.g. with a desired average temperature of 21.3 °C, the allowed range is from 20.8 to 21.8 °C). A lower limit is considered for reliability reason, to prevent too low indoor temperatures. Additionally, a weather forecast-based algorithm is applied to prevent overheating.

The algorithms of the developed DR method (to reduce the power in heating radiators when tap water-based power peaks occur) are triggered based on a continuous and real-time monitoring of tap water usage level. To effectively reduce the power peaks, the algorithm uses a trigger, which monitors the DHW valve position and district heating supply temperature, to turn peak shaving on and o at exactly the right moments.

DR in Student Apartment Buildings

2018; Tampere, Finland

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

Energy in Buildings and Communities Programme

Best Practices / Lessons Learned:

- The best impact of the smart building automation was in Building 8, which is the newest. Good impact can also be achieved in old buildings, like in Building 2, which is the oldest case building, built in 1928.
- When developing automation systems to maximize energy efficiency, cooperation between the energy provider and the service user is significant and important.
- As a conclusion, decision makers should see DR technology as a viable way to save energy and reduce greenhouse gas emissions. As a measure, we recommend that DR requirements are included in energy efficiency requirements.
- Additionally, more building automation education is needed to realize the full benefits offered by these technologies.
- ..

DR in Student Apartment Buildings

References and further information

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

- Ala-Kotila et al. (2020) - Demand Response in District Heating Market - Results of the Field Tests in Student Apartment Buildings. https://doi.org/10.3390/smartcities3020009

Thermostats overrides during DR events

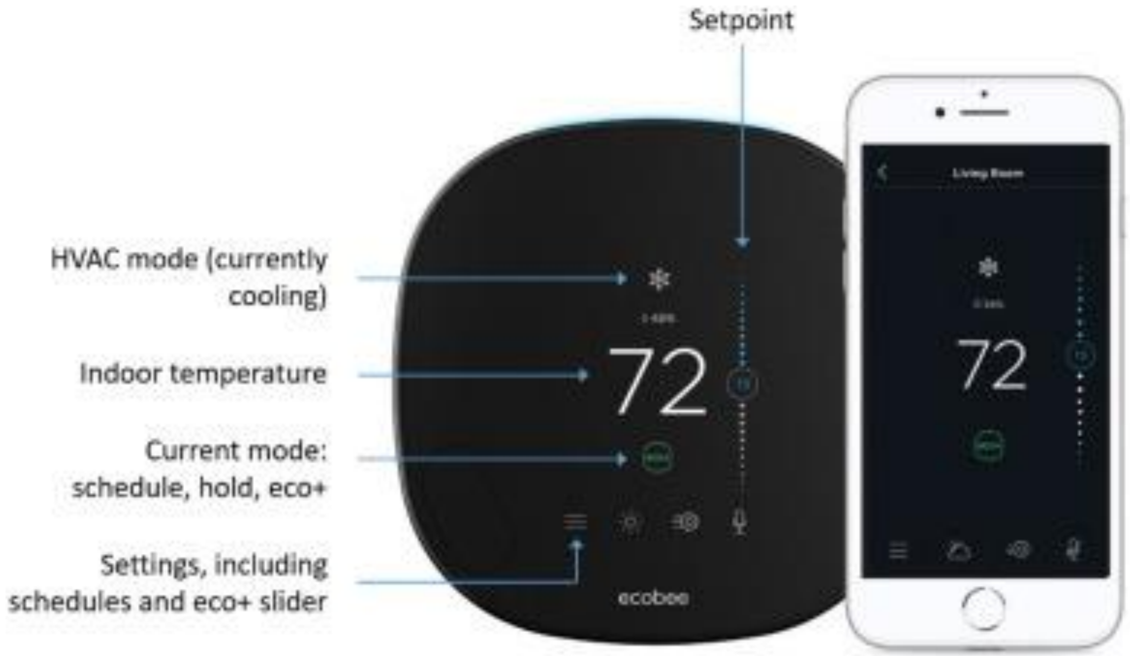
2019; United States and Canada

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC Energy in Buildings and Communities Programme

Subject

Data-driven analysis of thermostat overrides during DR events for air conditioning demand peaks in summer



Ref.: Sarran et al., 2021, URL

Thermostats overrides during DR events

2019; United States and Canada

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Subject	Data-driven analysis of thermostat overrides during DR events for air conditioning demand peaks in summer
Overview	The present study, based on data from 6,389 connected thermostats in North America in the summer of 2019, investigates users' thermostat overriding behavior during demand response events targeting their air conditioners. An average event in this dataset was triggered around 3 p.m. and lasted three hours. The overall override rate was 12.9%.
Objective	The objective is to provide new knowledge on acceptability of demand response by remote control of air conditioners, and ultimately to inform the design of more targeted demand response events with a higher success rate (less override by the user) and leading to less discomfort for participants.
Scope	Dataset consisted of 6,389 dwellings across 21 U.S. states and one Canadian province (Ontario), In total 23,352 DR events were registered, Data from August and September 2019
System boundary, Time scale	Building, Daily
Building	-
Network	-
Heat Source of DH Network	-

Thermostats overrides during DR events

2019; United States and Canada

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building	24h daily

EBC
Energy in Buildings and Communities Programme

Storage	Decentralized thermal storage: building mass
DSM	Active, direct and automatic DSM for load shift and shed with limited, indirect involvement of customer, DR events could be overridden DR events via eco+ (thermostat) consist in a precooling phase followed by a setback (load shifting events). The duration of the precooling phase is calculated individually based on historical thermal data. The amplitude of the precooling and setback phases depends on the eco+ slider level: at level 1, the event does not lead to any setpoint change, while at level 5, the precooling and the setback consist in deviations of -2.2 and +2.2 °C from the setpoint at event start, respectively. In practice, some variation in these amplitudes was observed in the data.
Intended Benefits	Demand response is acknowledged as a solution to guarantee grid stability and security of supply, less energy costs for customer
Who is benefitting?	Utilities and customer
Results 1	▪ Override rates varied from 6.3% in Oregon to 28.8% in Florida, with a mean override rate across the entire dataset of 12.9%. On average, each household in the dataset participated in 3.7 DR events during these two months; 95% of the households participated in at least two events, and 43% in at least five. ▪ On average the change in indoor temperature caused by DR events was +1.07 °C during the event (represents both overridden and non-overridden DR events) ▪ Less than 25% of the observed overrides by setpoint decrease happened within the first hour of the event, and around 75% happened within the first 2.5 h.

Thermostats overrides during DR events

2019; United States and Canada

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Results 2

- Four of the most important features alone permitted to distinguish groups with override rates ranging from 4.6% to 37%. These four features were 1) the number of overrides set in the same period of the day as the event, 2) the outdoor temperature at event start, 3) the setback duration, and 4) the number of previous DR events carried out in that household.
- However, the present study also showed that going through several DR events "teaches" occupants to let events proceed until the end. One can hypothesize that occupants either experienced less loss in comfort as they expected, got to understand and accept these programs better, adopted adaptive strategies, or adjusted their personal schedule to avoid discomfort.

Collaboration Detail

Smart Home Appliance Manufacture connects customer and utility to exchange flexibilities; in 2019, ecobee launched eco+, a free upgrade that allows the thermostat to adjust setpoints to real occupancy patterns.
The eco + feature also offers a simple interface for users to enroll in DR programs with their utility, in exchange for a financial incentive: in most cases, a one-time payment after enrollment of $50 to $100, sometimes followed by monthly or yearly rewards (ecobee, 2019).

Technology Detail

Based on temperature and motion readings from both the thermostat and optional remote sensors scattered across the house, a control temperature is computed and used to control the HVAC system centrally for the entire dwelling without individual room control, which is common practice in North America.

Control Detail

Most events had a precooling phase lasting under one hour, and a setback phase planned to last around three hours. Some events had no setback, and a few had setbacks lasting two or four hours. Most of the events were triggered between 1 p.m. and 3 p.m., and very rarely in the evening.

Thermostats overrides during DR events

2019; United States and Canada

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

Best Practices / Lessons Learned:

- Events could be made shorter in households with a larger override risk, which could be mobilized in successive groups. Indeed, the setback duration was shown to be an important feature to understand overrides, with shorter events having a lower chance to be overridden and a lesser impact on thermal comfort.
- Connected thermostat companies could provide utilities with an indicator of their customers' hold usage habits, to inform DR event design.
- A drawback of carrying out the DR event in several waves is the risk of a demand peak at the end of each wave, cancelling the effects of the DR effort. Adopting such a strategy requires some modelling work to optimally design the duration, shape and sample size of each of the subevents, for example by making the precooling and post-event recovery phases more gradual.
- The results showed that to predict whether a DR event happening, for instance, between 3 p.m. and 6 p.m. would be overridden, one could obtain a good guess by simply looking at how often occupants usually overrode their thermostat settings during 3 p.m. and 6 p.m. throughout the summer.
- […] the distribution of that feature in the dataset shows that most households spent either less than 25% of the time in a hold (override), or more than 95%.

Thermostats overrides during DR events

References and further information

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC
Energy in Buildings and Communities Programme

- Sarran et al. (2021) - A data-driven study of thermostat overrides during demand response events. https://doi.org/10.1016/j.enpol.2021.112290

DR events in a university building

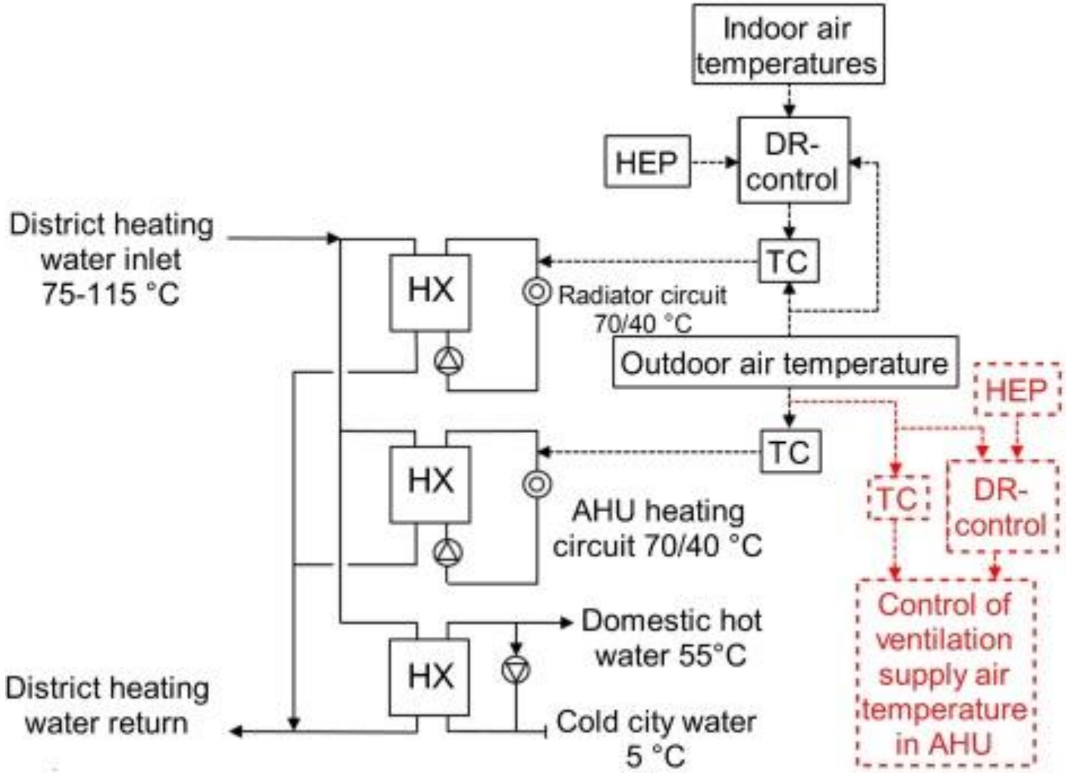
2017-2018; Helsinki, Finland

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC Energy in Buildings and Communities Programme

Subject

Field test of DR algorithms to flexibly set the space heating supply temperature in a university building



Ref.: Mishra et al., 2019, URL

DR events in a university building

2017-2018; Helsinki, Finland

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building	24h daily

Energy in Buildings and Communities Programme

Subject	**Field test of DR algorithms to flexibly set the space heating supply temperature in a university building**
Overview	This case study field-tested the effect of DSM, in the form of price based, demand response (DR) events, in the DHN catering to a university building. Responding to variations in a pricing model, the temperature of inlet water was varied from the heating water substation. Using combinations of parameters, 11 different DR scenarios were executed.
Objective	The goals were 1) examine how much deviations could be incurred in the inlet water temperature, 2) how that affected occupant perceptions, 3) test different DR strategies in field, 4) evaluate their effects on building and occupants.
Scope	One university building
System boundary, Time scale	Building, Daily
Building	Campus building constructed in 1975, refurbished in 2014 and ventilation, heating and building management upgraded, massive concrete building, mechanical supply and exhaust ventilation system with heat recovery, DH supplies space heating, domestic hot water and AHU heating; heating supply temperature controlled by heating curve
Network	DH network with supply temperature between 75 and 115 °C
Heat Source of DH Network	-

DR events in a university building

2017-2018; Helsinki, Finland

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building	24h daily

Storage	Decentralized storage: Building Mass
DSM	Active, direct and automatic DSM for load shift with limited, indirect involvement of customer In testing the DR scenarios for this study, an inherent assumption was that dynamical pricing would be available for DH and a moving 24 h, hourly price, would be known in advance, at any point in time. The hourly price was estimated for a year, based on the price data for district energy sources and the weather data from the Finnish test reference year 2012 The DR algorithms: 1) Try to reduce the inlet water temperature when the price trend is on the fall, thus, trying to lessen the burden on the DHN when prices are already high. 2) Conversely, try to increase the inlet water temperature when the price trend is rising, thus trying to load the building thermal mass while the prices are still low and before they rise and get too high. 3) When the price trend holds flat, no action is taken, and the standard inlet water temperature was used.
Intended Benefits	Utilizing building mass for heating flexibility, reduced energy price, less peak load boiler operation
Who is benefitting?	Utility and Customer

DR events in a university building

2017-2018; Helsinki, Finland

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC Energy in Buildings and Communities Programme

Results

- Different periods achieved different ranges of deviation: the inlet water temperature was reduced between -2.7 and -21.1 °C and increased between 0.8 and 10.9 °C.
- Period 7 DR showed the maximum fraction of negative deviation while Period 11 got the maximum positive deviation. Cumulative deviation was positive for all Periods except 7, 10, 12, and 13.
- The cumulative deviations (both positive and negative) were particularly noticeable for Periods 9–13. All five of these periods implemented variations of the DnH algorithm. Except for Period 9, the other four periods used a 3 day history to inform their price trend control signal.
- The occupant perception of the indoor thermal environments did not deteriorate during the DR implementations. Certain DR implementation periods even seemed to improve occupant perception over the reference periods.
- This was while wide changes were noted for the maximum and minimum room air temperatures. This wide fluctuation suggests that a decentralized strategy could be more successful in limiting the highs and lows of air temperature in certain rooms, ensuring needs of occupant comfort.
- Irrespective of how the price signal, the achieved lowering with respect to standard algorithms depended on the allowed temperature deviations. For the last two periods, temperature deviations of approx. 20 °C were achieved, compared to the default control algorithms, while measured room temperatures only infrequently exceeded defined comfort limits.

Collaboration Detail -

DR events in a university building

2017-2018; Helsinki, Finland

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

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Technology Detail	The sensing and controls aspects were handled by the BMS from Fidelix Oy, which was already responsible for day-to-day management of building HVAC systems. Room air temperatures were measured by Produal Temperature Meters (model TEHR NTC10-P, accuracy: ± 0.2 °C at 25 °C). Apart from room conditions, the heating water inlet and outlet temperatures were also measured. The BMS collected and stored all temperature measurements every 15 min. Thermocouples were used to log the hot water pipe temperature at the point in the building which was closest to the DH substation (in the basement) and at a point which was farthest from the source (on the fourth floor). Temperatures were logged using a Testo temperature logger (Model 176T4, accuracy ± 0.3 °C) and K-type thermocouples every 1 min.
Control Detail	With a falling price trend, a control signal (CS) of -1 was generated to reduce the water temperature, With a rising price trend, a CS of +1 was generated to increase the water temperature. For this work, temperature of the inlet water is adjusted at the DH substation supplying the whole building. Therefore, the DR strategy implies a centralized, building level control of heating. During any scenarios the heating water supplied to every radiator was changed, the precise controls were handled by the BMS. The water radiators themselves are equipped with thermostatic regulator valves (TRVs). The TRVs can prevent overheating of the space but are not suitable for fine control of the room air temperature. Each scenario allowed a certain degree of deviation from the water temperature the DHN would have supplied without any interference. For the first nine periods, the deviation allowed was determined as a fraction of the radiator heat output. This fraction was kept between ±10 to ±25%. However, during Periods 12 and 13, greater deviations between the standard and actual inlet water temperature were allowed: deviations of +10/–20 °C for inlet water temperature between actual and standard values.

DR events in a university building

2017-2018; Helsinki, Finland

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

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Best Practices / Lessons Learned:

- It was also found that changes made to water temperature at the substation level reflected in the rooms' radiators with minimal time delay.
- The measured temperatures in most of the rooms of the building only infrequently exceeded the defined comfort limits. This would imply that the building's thermal mass, along with the price-based implementation of the algorithms, present significant avenues of energy flexibility.

DR events in a university building

References and further information

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

Energy in Buildings and Communities Programme

- Mishra et al. (2019) – Demand response events in district heating: Results from field tests in a university building. https://doi.org/10.1016/j.scs.2019.101481

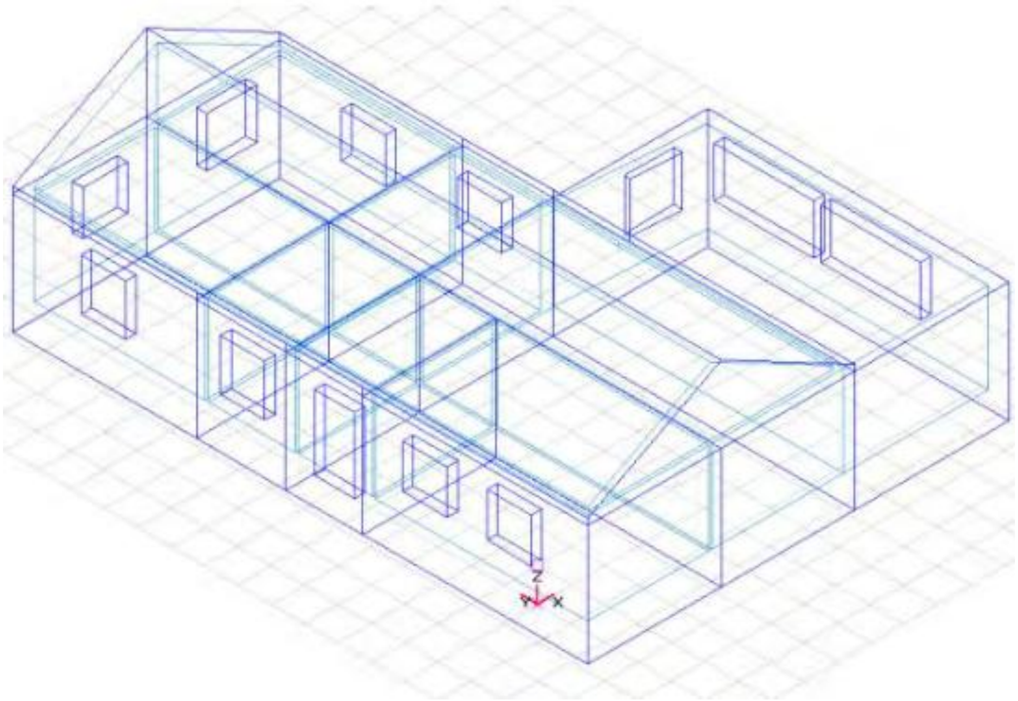
Smart grid flexibility in single-family houses

2020; Middelfart, Denmark;

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC Energy in Buildings and Communities Programme

Subject Theoretical analyses of thermal flexibility of typical detached Danish single-family houses



Ref.: Wittchen et al., 2020, URL

Smart grid flexibility in single-family houses

2020; Middelfart, Denmark;

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building	24h daily

EBC
Energy in Buildings and Communities Programme

Subject	**Theoretical analyses of thermal flexibility of typical detached Danish single-family houses**
Overview	This case study describes a theoretical analyses of typical detached Danish single-family houses' (SFH) ability to provide thermal capacity and thus flexibility. A set of archetype house models in dynamic simulations in Bsim was used.
Objective	The aim was solely a simple quantification of the amount of energy and electricity that can be moved away from daily peak periods (breakfast and cooking peaks). The analyses did not aim at exploring the potential CO2 emission reduction.
Scope	Theoretical analysis on one building and national level (with statistical data on the building stock)
System boundary, Time scale	Building, daily
Building	1) One building located in Middelfart constructed in 1966 and refurbished in 2006 with additional of cavity insulation in the walls and replacement of windows for calculating time-constants, 2) Measurement data of 140 detached SFH from the same construction period were used for validation archetype models. Models consider thermal mass, window-to-floor ratio, thermal performance of the building envelope, size of heating system, ventilation and internal loads.
Network	-
Heat Source of DH Network	-

Smart grid flexibility in single-family houses

2020; Middelfart, Denmark;

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

EBC Energy in Buildings and Communities Programme

Storage	Decentralized storage: Building mass
DSM	Theoretical analysis of an active and direct DSM for load shift and shed Aim: move as much energy demand for space heating away from the peak-periods, still maintaining an acceptable indoor temperature (20-22 °C). Three different control strategies are tested: (1) Fixed indoor temperature of 22 °C (reference), (2) Turn off heating at the start of the peak-periods and let the indoor temperature drop towards 20 °C, i.e., 2 °C temperature setback. (3) Pre-heating (for 1 or 2 hours) or charging of the thermal mass to 23 °C the house 1 and 2 hours in advance of the peak periods with temperature setback to 20 °C during peak-periods.
Intended Benefits	-
Who is benefitting?	-
Results 1	▪ Analyses showed that up to 99 % of the energy demand for space heating within peak hours can be moved outside peak hours, with acceptable influence on the indoor temperature. ▪ The 1966 house show the longest time-constant, 50.8 hours, which indicates a thermally heavy house with good insulation level and air-tightness. ▪ Reference: 26,729 kWh/a, 10.7 kW; Control 2: -589 kWh/a, +3.7 kW; Control 3: -407 kWh, +3.7 kW (1h pre-heating) or -96 kWh/a, +3.7 kW (2h pre-heating)

Smart grid flexibility in single-family houses

2020; Middelfart, Denmark;

Project:	Implementation:	System boundary:	Time scale:
completed	completed	building	24h daily

Results 2

- The relative reduction in annual net heating demand within the peak-periods is significantly higher than for the whole year. In this way, it is possible to move up to 99% (5 480 kWh) of the net heating demand away from the peak-periods.
- The 2h pre-heating strategy proved to have limited influence on the overall heating demand and maximum power demand, but significant influence (reduction) on the number of hours with indoor temperatures below 22 °C.

Collaboration Detail

The control can either be based on price signals or forecasts of the weather and thus an advance simulation of the indoor climate and the availability of renewable energy in the grid.

Technology Detail

-

Control Detail

-

Best Practices / Lessons Learned:

- Even with a control strategy aiming at a constant indoor temperature of 22 °C, there are some hours with indoor temperature in the living area below the set-point (Figure 5 and Table 1). This points to a slightly undersized heating system. That is a normal situation in houses constructed in this period as the heating system is laid out for a constant indoor temperature of 20 °C when the outdoor temperature is -12 °C.
- On a national level: If energy use is being moved away from peak periods, then there will be a new, but smaller peak just after the traditional peak period. The simulations are carried out for single houses, but in reality, these are almost 0.5 million individual houses all with their own individual use and dynamic behavior. The new peak period will therefore be scattered over the hours after the traditional peak.
- When houses are being renovated, the time-constant and hence the potential for flexibility will increase. A house that are being renovated will typically have unchanged thermal capacity (except for internal insulation), but lower transmission and ventilation losses due to added insulation and potentially implementation of mechanical ventilation with heat recovery.

Smart grid flexibility in single-family houses

References and further information

Project: completed | Implementation: completed | System boundary: building | Time scale: 24h daily

Energy in Buildings and Communities Programme

- Wittchen et al. (2020) - Analyses of thermal storage capacity and smart grid flexibility in Danish single-family houses. BuildSim-Nordic 2020

Contact and Project Information

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National Research Project „EnOB:Trans2NT-TWW“ (ID: 03EN1027A)
Analysis and development of necessary measures to reduce the domestic hot water temperature in low-temperature supply systems

IEA EBC Annex 84 - Demand Management of Buildings in Thermal Networks
Subtask D „Experimental case studies of building heat demand response in existing DHC networks“

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