ANNEX 84

EBC

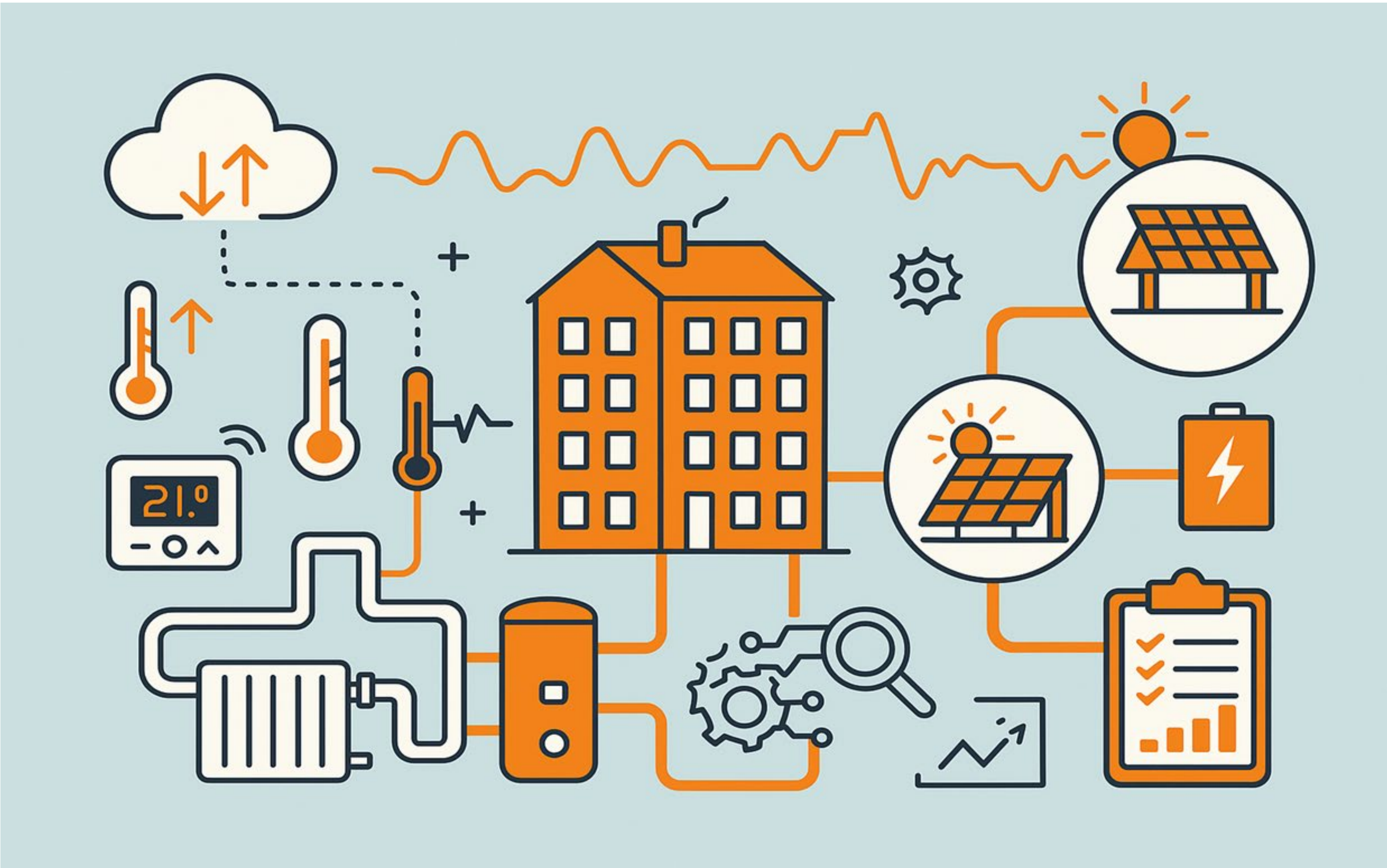
Energy in Building and Communities Programme

International Energy Agency

Demand Management of Buildings in Thermal Networks (Annex 84) - Deliverable WI B.2 Supply, Storage and distribution of heat, cold, domestic hot water, and electricity on building level for demand response and flexibility option

Energy in Buildings and Communities Technology Collaboration Programme

March 2025



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Preface

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 30 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes (TCPs). The mission of the IEA Energy in Buildings and Communities (IEA EBC) TCP is to support the acceleration of the transformation of the built environment towards more energy efficient and sustainable buildings and communities, by the development and dissemination of knowledge, technologies and processes and other solutions through international collaborative research and open innovation. (Until 2013, the IEA EBC Programme was known as the IEA Energy Conservation in Buildings and Community Systems Programme, ECBCS.)

The high priority research themes in the EBC Strategic Plan 2019-2024 are based on research drivers, national programmes within the EBC participating countries, the Future Buildings Forum (FBF) Think Tank Workshop held in Singapore in October 2017 and a Strategy Planning Workshop held at the EBC Executive Committee Meeting in November 2017. The research themes represent a collective input of the Executive Committee members and Operating Agents to exploit technological and other opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy technologies, systems and processes. Future EBC collaborative research and innovation work should have its focus on these themes.

At the Strategy Planning Workshop in 2017, some 40 research themes were developed. From those 40 themes, 10 themes of special high priority have been extracted, taking into consideration a score that was given to each theme at the workshop. The 10 high priority themes can be separated in two types namely 'Objectives' and 'Means'. These two groups are distinguished for a better understanding of the different themes.

Objectives - The strategic objectives of the EBC TCP are as follows:

- reinforcing the technical and economic basis for refurbishment of existing buildings, including financing, engagement of stakeholders and promotion of co-benefits;
- improvement of planning, construction and management processes to reduce the performance gap between design stage assessments and real-world operation;
- the creation of 'low tech', robust and affordable technologies;
- the further development of energy efficient cooling in hot and humid, or dry climates, avoiding mechanical cooling if possible;
- the creation of holistic solution sets for district level systems taking into account energy grids, overall performance, business models, engagement of stakeholders, and transport energy system implications.

Means - The strategic objectives of the EBC TCP will be achieved by the means listed below:

- the creation of tools for supporting design and construction through to operations and maintenance, including building energy standards and life cycle analysis (LCA);
- benefitting from 'living labs' to provide experience of and overcome barriers to adoption of energy efficiency measures;
- improving smart control of building services technical installations, including occupant and operator interfaces;
- addressing data issues in buildings, including non-intrusive and secure data collection;
- the development of building information modelling (BIM) as a game changer, from design and construction through to operations and maintenance.

The themes in both groups can be the subject for new Annexes, but what distinguishes them is that the 'objectives' themes are final goals or solutions (or part of) for an energy efficient built environment, while the 'means' themes are instruments or enablers to reach such a goal. These themes are explained in more detail in the EBC Strategic Plan 2019-2024.

The Executive Committee

Overall control of the IEA EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA EBC Executive Committee, with completed projects identified by (*) and joint projects with the IEA Solar Heating and Cooling Technology Collaboration Programme by (☼):

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design of Communities (*)
Annex 7: Local Government Energy Planning (*)
Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: ☼ Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: ☼ Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: ☼ Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: ☼ Towards Net Zero Energy Solar Buildings (*)
Annex 53: Total Energy Use in Buildings: Analysis and Evaluation Methods (*)
Annex 54: Integration of Micro-Generation and Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance and Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy and CO_2 Emissions Optimization in Building Renovation (*)
Annex 57: Evaluation of Embodied Energy and CO_2 Equivalent Emissions for Building Construction (*)

Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements (*)
Annex 59: High Temperature Cooling and Low Temperature Heating in Buildings (*)
Annex 60: New Generation Computational Tools for Building and Community Energy Systems (*)
Annex 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings (*)
Annex 62: Ventilative Cooling (*)
Annex 63: Implementation of Energy Strategies in Communities (*)
Annex 64: LowEx Communities - Optimised Performance of Energy Supply Systems with Exergy Principles (*)
Annex 65: Long-Term Performance of Super-Insulating Materials in Building Components and Systems (*)
Annex 66: Definition and Simulation of Occupant Behavior in Buildings (*)
Annex 67: Energy Flexible Buildings (*)
Annex 68: Indoor Air Quality Design and Control in Low Energy Residential Buildings (*)
Annex 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings
Annex 70: Energy Epidemiology: Analysis of Real Building Energy Use at Scale
Annex 71: Building Energy Performance Assessment Based on In-situ Measurements
Annex 72: Assessing Life Cycle Related Environmental Impacts Caused by Buildings
Annex 73: Towards Net Zero Energy Resilient Public Communities
Annex 74: Competition and Living Lab Platform
Annex 75: Cost-effective Building Renovation at District Level Combining Energy Efficiency and Renewables
Annex 76: ☼ Deep Renovation of Historic Buildings Towards Lowest Possible Energy Demand and CO_2 Emissions
Annex 77: ☼ Integrated Solutions for Daylight and Electric Lighting
Annex 78: Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications
Annex 79: Occupant-Centric Building Design and Operation
Annex 80: Resilient Cooling
Annex 81: Data-Driven Smart Buildings
Annex 82: Energy Flexible Buildings Towards Resilient Low Carbon Energy Systems
Annex 83: Positive Energy Districts
Annex 84: Demand Management of Buildings in Thermal Networks
Annex 85: Indirect Evaporative Cooling
Annex 86: Energy Efficient Indoor Air Quality Management in Residential Buildings
Annex 87: Energy and Indoor Environmental Quality Performance of Personalised Environmental Control Systems
Annex 88: Evaluation and Demonstration of Actual Energy Efficiency of Heat Pump Systems in Buildings
Annex 89: Ways to Implement Net-zero Whole Life Carbon Buildings
Annex 90: EBC Annex 90 / SHC Task 70 Low Carbon, High Comfort Integrated Lighting
Annex 91: Open BIM for Energy Efficient Buildings
Annex 92: Smart Materials for Energy-Efficient Heating, Cooling and IAQ Control in Residential Buildings
Annex 93: Energy Resilience of the Buildings in Remote Cold Regions
Annex 94: Validation and Verification of In-situ Building Energy Performance Measurement Techniques
Annex 95: Human-centric Building Design and Operation for a Changing Climate
Annex 96: Grid Integrated Control of Buildings
Annex 97: Sustainable Cooling in Cities

Working Group - Energy Efficiency in Educational Buildings (*)
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)
Working Group - HVAC Energy Calculation Methodologies for Non-residential Buildings (*)
Working Group - Cities and Communities
Working Group - Building Energy Codes

Summary

Work Item B.2 under Subtask B of the IEA EBC Annex 84 explores innovative technologies that enable demand response (DR) and flexibility at the building level, focusing on the supply, storage, and distribution of thermal energy and electricity. The objective is to identify, assess, and document technologies and strategies that can improve energy efficiency, support sustainability goals, and facilitate integration with district heating and cooling (DHC) systems.

The report concentrates on four main activities:

1. Collection of case studies and best practices
   Real-world demonstrations and research projects were gathered across three key domains: supply, storage, and distribution. These examples provide insights into technical and economic performance and the feasibility of DR in buildings connected to DHC networks.

2. Evaluation of storage technologies
   Emphasis was placed on less mature technologies (TRL <6), such as phase change materials (PCM), for their potential to store thermal energy and shift demand. A highlighted case study from South Korea demonstrated a 59.9% reduction in peak load deviation through latent heat storage integration in apartment buildings.

3. Assessment of distribution technologies
   Technologies such as decentralized substations, smart heat interface units (HIUs), and hydronic radiators were evaluated. Smart HIUs showed the ability to lower system temperatures and enhance DR potential, while field tests of hydronic radiators in Denmark demonstrated successful room-level load shifting.

4. Analysis of supply technologies
   Innovations like electric resistance heaters (as Power-to-Heat systems) and control solutions like the PreHeat system were studied. Electric boosters proved capable of reducing peak loads by up to 48%, and control solutions yielded up to 20% energy savings in monitored buildings.

The report emphasizes that while many high-TRL technologies are already deployed and well-documented, the real value lies in examining novel, field-tested solutions with strong links to control strategies and cross-sector integration. Technologies enabling real-time response to grid signals—supported by Internet of Things (IoT), smart metering, and advanced control algorithms—are pivotal in making buildings active participants in energy flexibility markets.

Overall, Work Item B.2 provides a comprehensive foundation for advancing energy flexibility at the building level, aligning building operation with broader energy system needs through smart thermal and electrical integration.

Table of content

Abbreviations

Abbreviations	Meaning
CO_2	Carbon dioxide
DH	District heating
DHC	District heating and cooling
DHW	Domestic hot water
e-MPC	Economic Model Predictive Control
ESSU	Executive Committee Support Services Unit
FBF	Future Building Forum
HIU	Heat interface unit
IAQ	Indoor air quality
IoT	Internet of Things
KPI	Key performance indicator
LVN	Low voltage network
MFH	Multi-family houses/homes
PCM	Phase change materials
P2H	Power-to-heat
SCOP	Seasonal coefficient of performance
SH	Space heating
TRL	Technology Readiness Level
TRV	Thermostatic radiator valve

2. Scope and Objectives

2.1 Overview of Subtask B and Work item B.2

The objective of Subtask B is to

- Collect which technological options exist to enable demand response in buildings connected to thermal grids
- Evaluate their current market readiness resp. research status
- Evaluate their technical / economic potential
- Highlight limitations and bottlenecks
- Collect examples
- Evaluate in how far demand response by selected technical options – in combination with each other and in combination with a control strategy and system – improves the performance of a DHC system

Subtask B is organized in five Work Items:

- B.1 – Classification of building types connected to DHC systems
- B.2 – Supply, storage and distribution of heat, cold, domestic hot water, and electricity on building level for demand response and flexibility option
- B.3 – Role of DHC substations as element in demand response option on building scale
- B.4 – Role of monitoring, sensoring and control technology
- B.5 – Evaluation and summary

Work Item B.2 aims to comprehensively investigate and understand the technologies and strategies that can enhance energy efficiency, sustainability, and demand response in buildings connected to DHC networks. Therefore, this work item includes the collection of case studies and best practices, the evaluation of thermal storage, the assessment of distribution technologies, and the examination of supply technologies in buildings.

It should be noted that the storage technologies addressed in this work item are not related to the substation (e.g., PCM, building thermal mass, thermally activated components etc.) (see Figure 1).

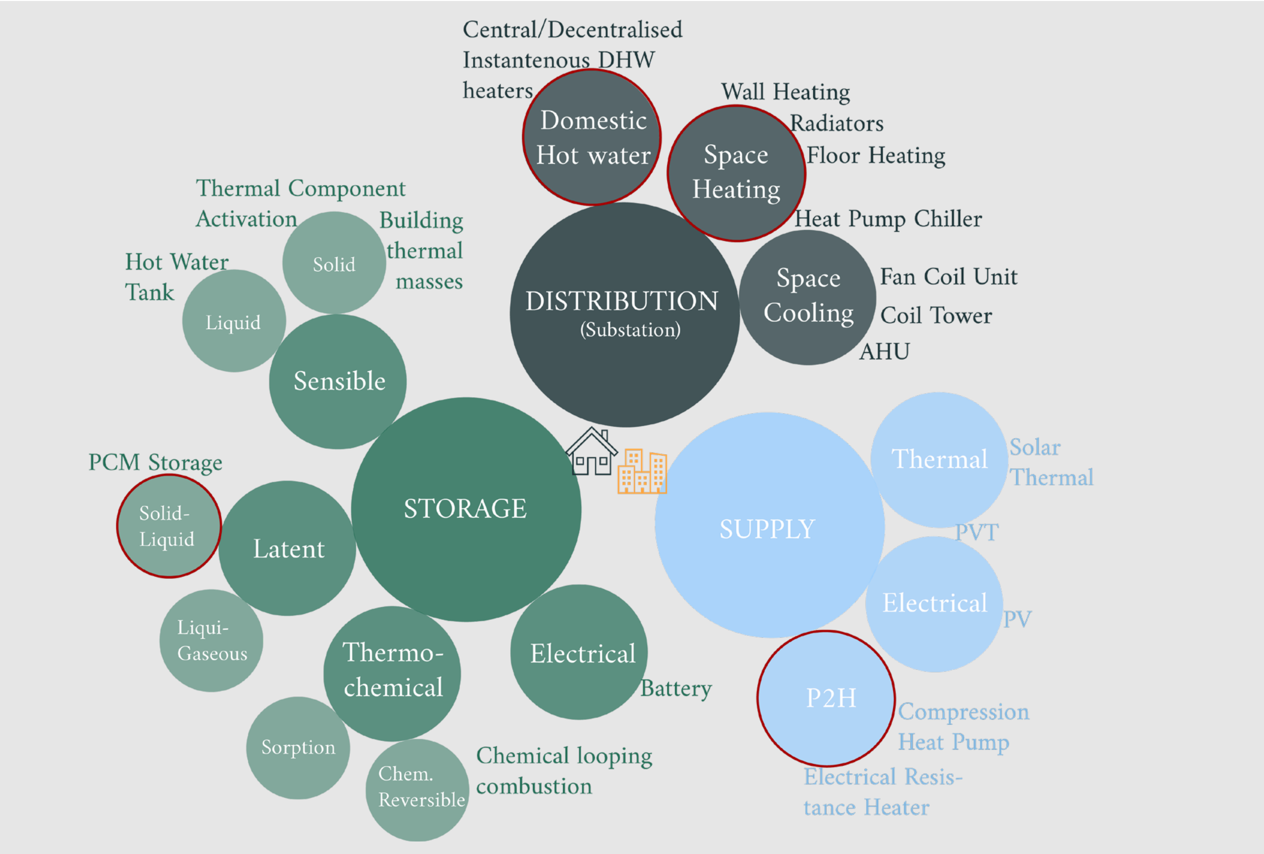

Figure 1: Overview potential technologies and interventions

The work in Work Item B.2 concentrated on the following aspects:

Activity 1: Collection of case studies, research projects and results and Best-Practice Examples.
The work in this activity was to each of the three key areas – supply, distribution and storage of heat, cold, domestic hot water (DHW), and electricity at building level. Specific outputs include:

- Creation of templates to summarize the outcomes of case studies and research projects that focused specifically on one key technology to enable demand response in a building or cluster of buildings connected to a DHC network, including.
  - Applicability to demand response in space heating/cooling, DHW or both.
  - Technical and economic performance data.
  - Accompanying technologies, and minimum hardware requirements.

Activity 2: Overview and evaluation of technical options using thermal storage potential on building level as a demand response option in combination with a DHC system and highlight their potential and limitations.

- Creation of technology tree to classify the main existing technologies for **storing** heat at the building level (passive and active storage technologies)
- Fully mature technologies (TRL >6) were described in less detail, with a focus on:
  - Working principals, drawbacks/limitations, and minimum requirements for demand response (e.g., need for accompanying technologies)
  - These technologies are not included in this deliverable due to widely available knowledge and information
- Less mature technologies (TRL <6) were covered in greater detail, including case studies (preferably demonstrations in the field or lab tests) to show how the technology was used to enable demand response
  - Main outcomes and lessons learned from case studies

– Quantification of demand response achieved (load shifted, avoided)

Activity 3: Evaluation of state-of-the-art/under development options for distributing heat, cold and electricity on building level, which allow for demand response options in combination with a DHC system

- Creation of technology tree to classify existing technologies for **distributing** heat, cold and electricity at the building level.
- Fully mature technologies (TRL >6) were described in less detail, with focus on:
  – Working principals, drawbacks/limitations, and minimum requirements for demand response (e.g., need for accompanying technologies).
  – These technologies are not included in this deliverable due to widely available knowledge and information.
- Less mature technologies (TRL <6) were examined in greater detail, including case studies (preferably demonstrations in the field or lab tests) that show how that technology was used to enable demand response
  – Main outcomes and lessons learned from case studies.
  – Quantification of demand response achieved (load shifted, avoided)

Activity 4: Evaluation of state-of-the-art/under development options for supplying heat, cold and electricity on building level, which allow for demand response options in combination with a DHC system.

- Creation of technology tree to classify existing technologies for **supplying** heat, cold and electricity on building level.
- Fully mature technologies (TRL >6) were described in less detail, with a focus on:
  – Working principals, drawbacks/limitations, and minimum requirements for demand response (e.g., need for accompanying technologies).
  – These technologies are not included in this deliverable due to widely available knowledge and information.
- Less mature technologies (TRL <6) were examined in greater detail, including case studies (preferably demonstrations in the field or lab tests) that show how that technology was used to enable demand response:
  – Main outcomes and lessons learned from case studies.
  – Quantification of demand response achieved (load shifted, avoided)

Please, note

This deliverable only includes part of the collected information. The focus was primarily on more innovative technologies (e.g., PCMs) and aspects with strong links to other subtasks (e.g., control strategies). This approach was taken to keep the deliverable concise.

3. Content

3.1 Storage Technologies

The role of energy storage in enabling demand response in buildings connected to thermal networks is crucial for optimizing energy use, reducing costs, and enhancing overall efficiency of the energy system.

Energy storage systems, such as batteries, can store excess electricity generated from renewable sources like solar panels or wind turbines during periods of low demand and supply it during peak demand hours. In buildings connected to thermal networks, this stored energy can be used to operate heating, cooling, and other thermal systems efficiently during peak times. This reduces the strain on the grid and helps avoid costly peak demand charges for building owners.

Energy storage allows building operators to shift energy consumption to off-peak hours, when electricity prices are lower. This not only reduces energy costs but also supports grid stability by flattening demand curves. Energy storage systems enable building operators to respond quickly to demand response signals from utility providers or grid operators. They can adjust their heating and cooling systems, thermal storage, and other energy-consuming equipment to participate in demand response programs effectively providing flexibility to the system. Figure 2 shows the four types of storage technologies in buildings: sensible, latent, thermochemical, and electrical.

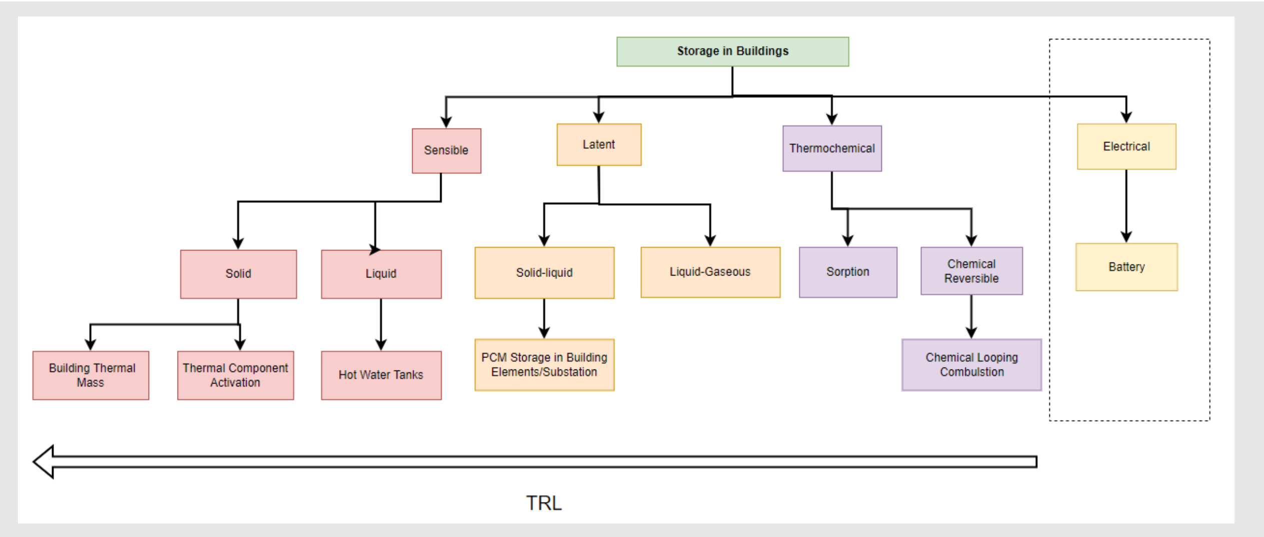

Figure 2: Storage technologies in buildings

3.1.1 Phase Change Materials in Building Envelope

Phase change materials (PCM) utilize latent heat, which can be stored and released as a material transition between states (solid to liquid, liquid to gas, and vice-versa). As the ambient temperature increases, the material undergoes a phase transformation from a solid to a liquid state, as its chemical bonds break. When the ambient temperature subsequently decreases, the PCM returns to its solid state, releasing the previously absorbed heat. This continuous cycle helps stabilize the interior temperature, reduce peak cooling demands, and lower heating requirements. PCM achieves this not by altering the thermal resistance of the building envelope but by influencing surface temperatures. PCM materials typically have a higher energy density than hot water, making them a more compact solution. Typical applications of PCM elements in buildings include:

building façade, floor heating systems, integration in the substation itself or a heat pump to provide a thermal buffer.

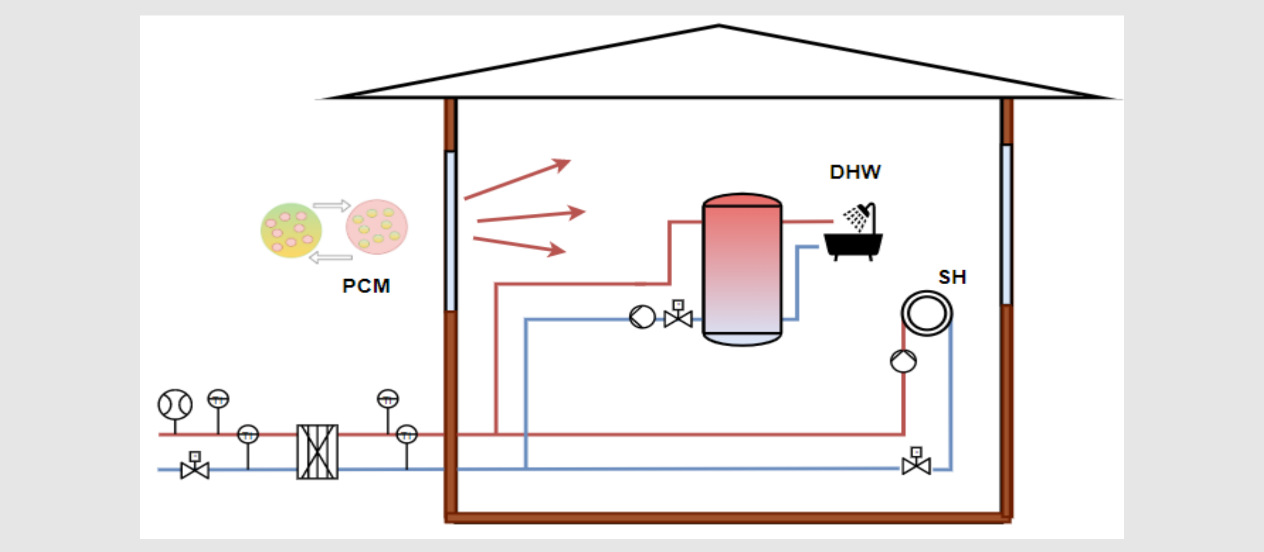

Figure 3: PCM integrated in the building scheme

Table 1: Technology 1 – PCM [1]

Technology: PCM Storage (integrated in building)	
Technology Type: Storage	**TRL:** 7-9
Technology Variant: Latent Thermal Energy Storage	**Storage Medium:** Phase Change Materials
Storage Capacity: 50-150 kWh/m^3	**Operating Temperature Range:** 80–300 °C
CAPEX: 50–100 €/kWh	**Efficiency:** 75–90%
Technical Lifetime: 15–30 years*	
Flexibility enabler for: Heating ☒ Cooling ☒ DHW ☒ Electricity ☐	
Load shifting period: Hourly ☒ Daily ☒ Weekly ☐ Seasonal ☐	
Applicability of installation: New Buildings only (during construction) ☐ Existing buildings (through renovation) ☒ Existing buildings during operation (no renovation needed) ☐	
Pros: • Relatively high energy density compared to hot water. • Low thermal losses compared to sensible heat storages. • Enabler for coupling with the electrical grid.	**Limitation/Bottlenecks:** • Not widely applied in buildings – limited knowledge operation and choice of optimal PCM for different environments. • Higher investment costs • Often embedded in facades thus not easy to install in existing buildings.
Minimum hardware requirements for Demand Response (accompanying technologies): • **Necessary:** Availability of IoT integrated components for advanced automated control and monitoring system. • **Beneficial:** Data collection of room internal room temperature/setpoint.	
Related Case Studies (more applicable for lower TRL technologies): **Literature source:** Scientific Paper	

Title: Peak Load Shifting control on hot water supplied from district heating using latent heat storage system in apartment complex
Citation: https://doi.org/10.1016/j.csite.2022.101993

Case Study Type: Demonstration in the field	**Building Type:** Large Apartment Complex (Suwon, South Korea) – 126 apartments participating in peak shaving

Experimental Setup: A latent heat storage system consisting of three large, insulated storage shell and tube type heat exchangers embedded with solid-liquid PCMs in a large apartment complex to obtain shifting of peak loads from the connected district heating system. The latent storage element was designed to store heat for more than 100 hours and is in the basement parallel to the heat transfer station which connects the building complex to the district heating system. In addition to shifting peak loads, the latent heat storage system should be able to serve as a backup heat source allowing the building to fulfil its heating and domestic hot water demand for several days in the case of an emergency or major fault with the district heating grid.

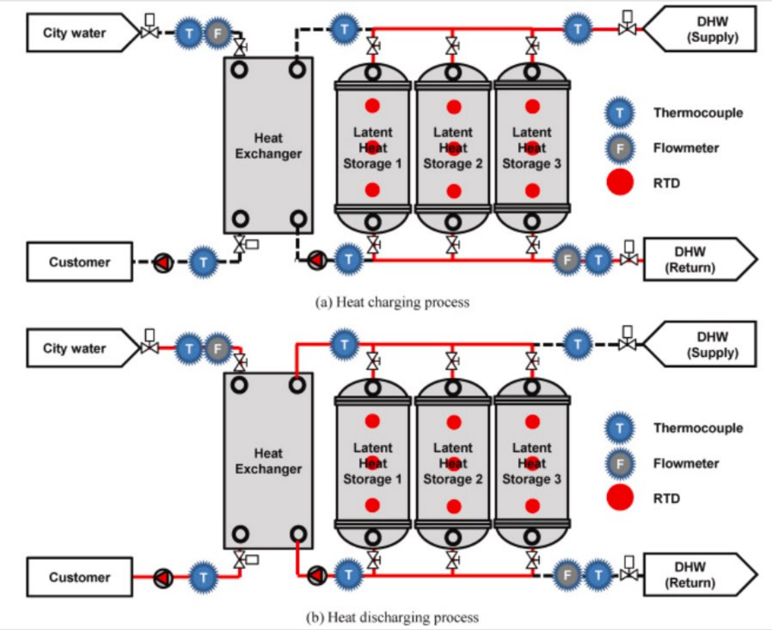

Figure 4: System Concept including Latent Heat Storages integrated on the primary side of the buildings substation [1]

Location of Storage: Underfloor ☐ Facade ☐ DHC Substation ☒ Radiator/AHU ☐ Other

Storage Properties

Melting Temperature	78 °C
Latent Heat Capacity	285.1k J/kg
Thermal Conductivity	0.6 W/m.K
Density	2180 kg/m³
Total Storage capacity of PCM:	284.5 kWh

Test Results:

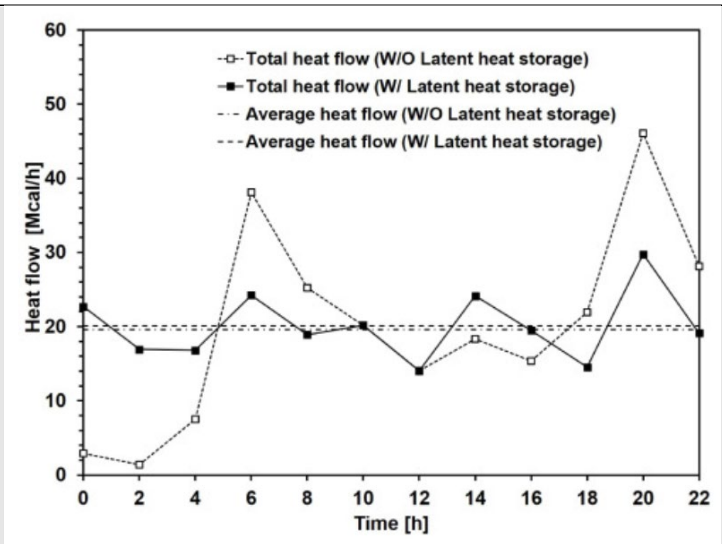

Figure 5: Measured heat flow with and without inclusion of latent heat storage for demand response [1]

Field tests demonstrated over the monitoring period from March to June that with effective charging and discharging of the latent heat storages during estimated periods of high and low heat demand (based on whether instantaneous loads are higher or lower than a daily average value) significant peak load shifting could be obtained. This makes latent heat storage applications in this context, a promising technology to enable thermal demand-side management.

Performance indicators measured	
Reduction in daily standard deviation in load due to PCM	59.9%
Reduction in total heat load due to PCM	2.6%

Limitations of Study: The plumbing arrangement consisted of three PCM storages connected in parallel with the substation.

3.2 Distribution of heat, cold, domestic hot water

The role of distribution technologies is to enhances energy efficiency, flexibility, and the ability to respond to changing energy demands while still meeting the comfort and operational needs of buildings. The technologies are illustrated in Figure 6.

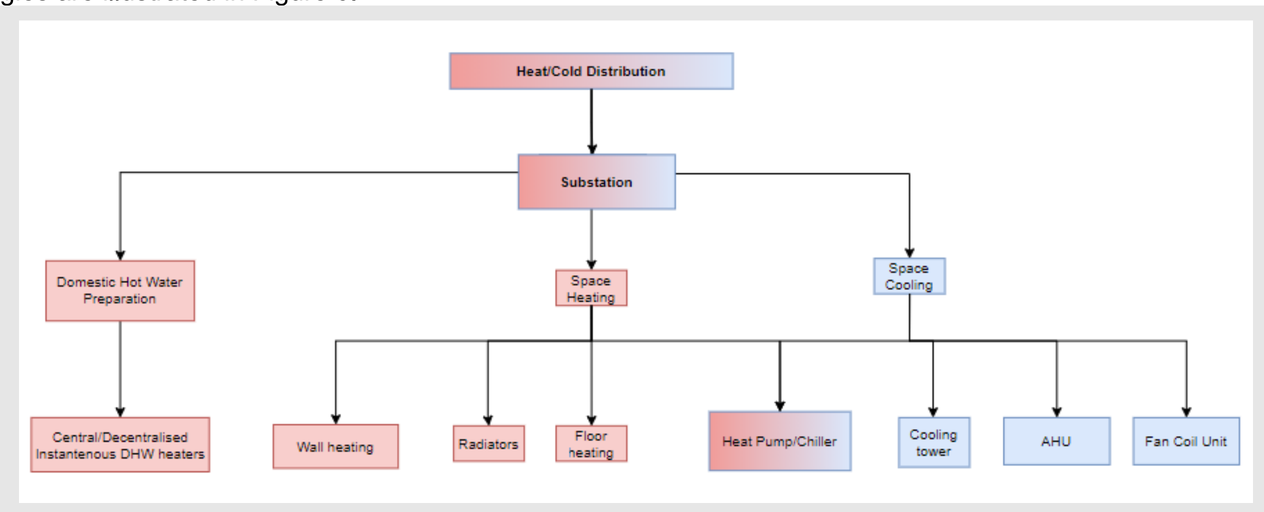

Figure 6: Distribution of heat, cold, domestic hot water at building level

3.2.1 Decentralized Substation

A substation is a unit where thermal energy from the district heating (DH) grid is transformed from a higher to a lower energy level, in terms of pressure and temperature. Additionally, energy transfer can be interrupted in case of disturbance and/or for repair. The key technology elements in a substation are heat exchangers and/or mixing equipment performing the lowering of temperature, and control valves. The heat power or mass flow rate are also limited by control equipment. The temperature and pressure level must be lowered to allow for the use of less expensive equipment within the building. District heating substations are usually placed inside of the supplied building (house substation). The ownership of the substation varies by the building owner-owned or the utility company-owned. In some countries (e.g., in Germany) shared ownership is also common.

Hydraulic separation in substations can be accomplished in multiple ways. Generally, two main types of connections exist: direct connection to the district heating grid and indirect connection via a heat exchanger. Figure 7 illustrates the difference between direct and indirect connections. It must be noted that the schemes are simplified, because control equipment is not indicated.

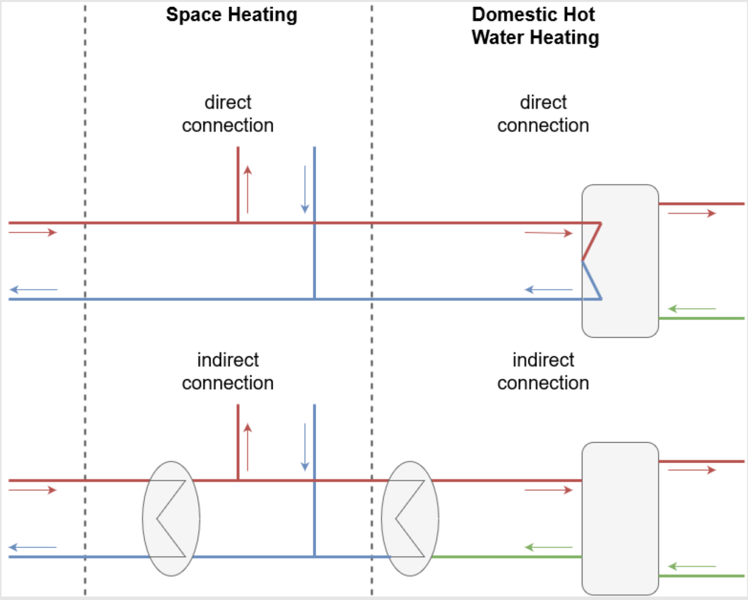

Figure 7: Difference between direct and indirect connection of the space heating and domestic hot water heating circuit

The key distinction between the two types of connection is the presence of a heat exchanger in the case of indirect connection (heat transfer medium from DH network is hydraulically separated from the building installation) and the absence of this component in the case of direct connection (heat transfer medium from DH network flows through the building installation). Heat exchangers are always connected in counter-current flow, since this leads to the most significant cooling of the return temperature of the primary side, resulting in a larger Delta T and/or lower supply temperature.

In some cases, mixed options are possible. DHW can be connected directly, while the space heating circuit is connected indirectly, and vice versa. It is also possible that only space heating or only DHW is connected. When connecting DH substation to the district heating network, the technical connection conditions of the network operator must be observed. In many German supply areas, for example, only indirect connections are permitted.

Table 2: Technology 2 – Decentralized Substation [2], [3]

Technology: DHC Substation

Technology Type: Distribution	**TRL:** 9
Technology Variant: (building) substation connected to pressurized water district heating networks	**Capacity Limits: n.a.**
Storage Capacity: ~60 kWh/m^3 (if DHW heating with storage/ hot water tank is connected)	**Operating Temperature Range:** primary (supply/return): ´>100/<70 °C (2G); <100/<45 °C (3G); >70/25 °C (4G) secondary: supply/return temperatures necessary for connected DHW and SH (90 - 40/20 –30 °C)
CAPEX: 175–1400 €/kW (DE), 50–700 €/kW (CH)	**Efficiency:** **> 95%**
Technical Lifetime: 20–30 years	
Flexibility enabler for: Heating ☒ Cooling ☒ DHW ☒ Electricity ☐	
Load shifting period: Hourly ☒ Daily ☐ Weekly ☐ Seasonal ☐	
Applicability of installation: New Buildings only (during construction) ☐ Existing buildings (through renovation) ☒ Existing buildings during operation (no renovation needed) ☐	
Minimum hardware requirements for Demand Response (accompanying technologies): • **Necessary:** smart heat meter (at least at primary side) • **Beneficial:** DHW storage and smart heat meter on secondary side, data collection of room temperature, additional buffer storage	
Related Case Studies (more applicable for lower TRL technologies): **Literature source:** Scientific Paper **Title**: Modelica-based simulations of decentralised substations to support decarbonisation of district heating and cooling **Citation:** https://doi.org/10.1016/j.egyr.2021.08.081	
Case Study Type: Simulation study	**Building Type:** cluster of 11 buildings in Sweden with total floor area 110,000 m^2 used for offices, conference rooms and labs, restaurants, and a sport centre.
Experimental Setup: Two different design cases are evaluated in terms of the performance of substation installations. Variant A: The heat pump evaporator inlet is connected to the chiller condenser outlet to recover waste heat. The heat pump evaporator outlet is connected to the chiller condenser inlet and serves as a cold source there. Depending on the proportion between heating and cooling demand, heat is either extracted or injected from/to the bidirectional network. Variant B: Includes all installations from Variant A plus an additional heat exchanger to enable direct cooling and reduce electric power consumption of the chiller's compressor.	

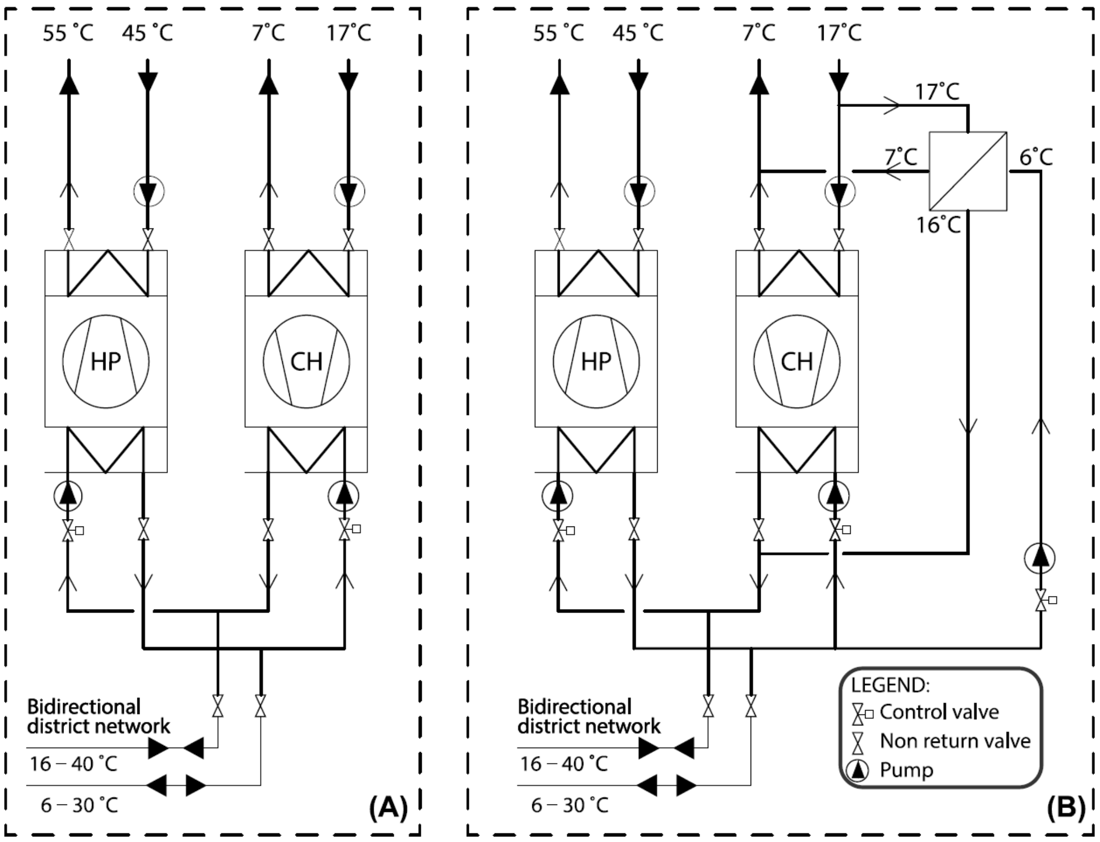

Figure 8: Schematic diagram of a substation model with installed heat pump and chiller (A) and a substation with additional heat exchanger for direct cooling (B) [2]

Interactions between heat pumps, chillers, and the direct cooling heat exchanger in a substation are investigated on an example of 11 buildings in Sweden. The building cluster has simultaneous demands for heating and cooling throughout the year, which increases the potential to exchange energy between connected buildings.

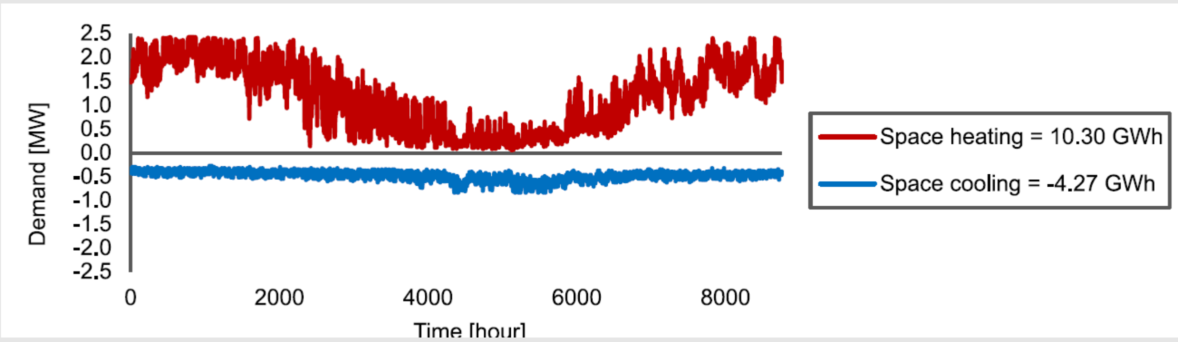

Figure 9: Yearly heating and cooling demand profiles in the building cluster (11 buildings) [2]

The analysis was performed using Modelica continuous-time simulations. Heating is injected to the network when the warm pipe temperature drops below 16 °C. When cold pipe temperature rises above 30°C, cooling is supplied to the network.

Design Parameters	
Temperature range in warm district pipe	16–40°C
Temperature range in cold district pipe	6–30°C
Design supply temperature for space heating	55°C

Design supply temperature for space cooling	7°C
Evaporator temperature difference of the heat pump (outlet - inlet)	–10 K
Condenser temperature difference of the chiller (outlet - inlet)	10 K
Temperature difference between refrigerant and water outlet in condenser and evaporator	2 K
Water pressure drops over condenser and evaporator	30 kPa
Carnot Efficiency	50%
Pump hydraulic and motor efficiencies	70%

Test Results:

Figure 11 shows cooling and heating SCOP through the year for the two design cases. Both have a low SCOP for heating. The SCOP for cooling in the case with additional direct cooling heat exchanger (right chart) is around two and a half fold of the other case without direct cooling.

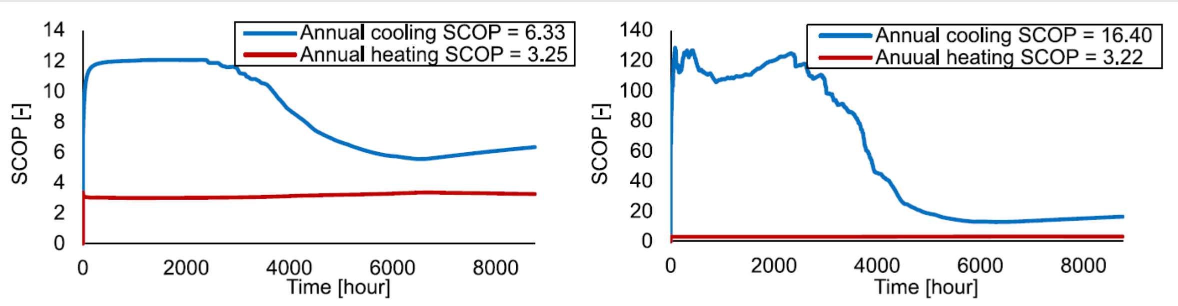

Figure 10: Variation of heating and cooling seasonal coefficient of performance for a system with no direct cooling (left) and for a system with direct cooling (right). Charts do not have a uniform scale [2]

The electric energy use of the chiller compressor in the design case with direct cooling could be reduced by about 63%. While that of the heat pump compressor stayed nearly the same.

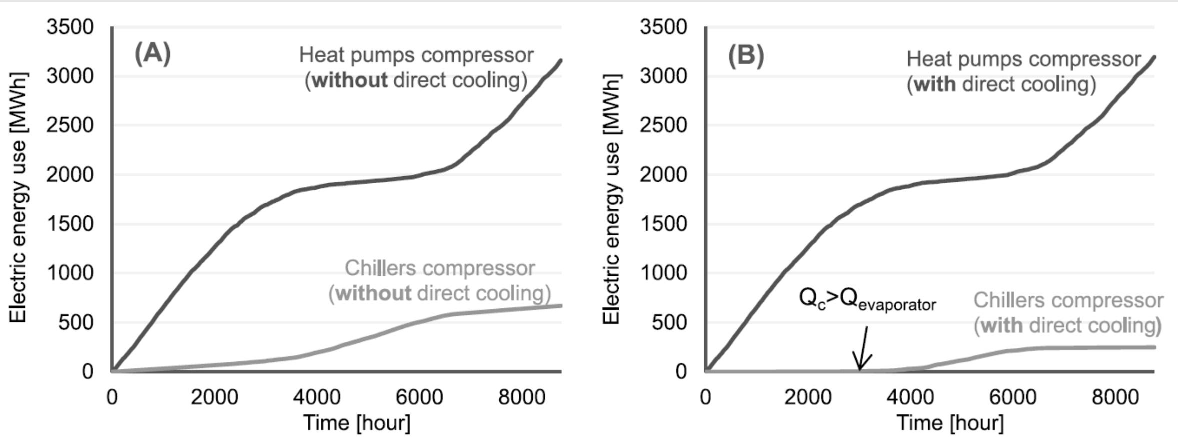

Figure 11: Substation annual electric energy use. Figures (A) and (B) compare the electric energy use in compressors between the two design cases [2]

Altogether, the results suggest that the system with direct cooling yielded a reduction of 10% of the total electric energy use.

Limitations of Study:

Results may differ from one building cluster to another depending on the simultaneity between heating and cooling demands. Other studies aim to also investigate the simultaneous demands of developed metrics such as the Diversity Index and the Demand Overlap Coefficient. With these KPI's engineers can map potentially promising clusters and therefore increase the efficiency of the thermal network system.

The authors of the study recommend implementing temperature controllers in both demand and supply sides to control the heating and cooling supply temperatures based on the outdoor temperature. This would lead to further improved substation performance. Study is only simulation of different design cases and not demonstration in the field.	
Related Case Studies (more applicable for lower TRL technologies): **Literature source**: Scientific Paper **Title**: Improved district heating substation efficiency with a new control strategy **Citation:** https://doi.org/10.1016/j.apenergy.2009.12.015	
Case Study Type: Simulation study	**Building Type:** model of a real-world villa, including its installed DH substation and total radiator-surface

Experimental Setup:

A test of new control strategies in comparison with traditional control methods has been done. The time-based simulation was carried out for three identical buildings with three different control methods:

- House 1: perfectly tuned traditional control system with a 60°C radiator supply temperature at an outdoor temperature of –30°C
- House 2: optimized control scheme correlated with the outdoor temperature
- House 3: optimal control curve based on the primary supply temperature

The outdoor climate was identical for all simulation runs, wind and sun influences were not considered. All three control methods were tested with three separate primary supply temperature schemes:

- A: conventional primary supply temperature scheme (depending on outdoor temperature)
- B: constant primary supply temperature at 100°C (too high)
- C: constant primary supply temperature at 70°C (too low)

All simulations were run for a period of 4 days. ΔT and primary flow rate were compared for all cases.

Test Results:

Figure 12 shows the simulation results. The first row shows the primary supply temperature T_{ps} and resulting primary return temperatures T_{out}. House 1–3 indicate the three different control strategies for the radiator system. The second row shows results for ΔT and the third-row results for the primary mass flow rate. It can be seen that in simulation A with the outdoor driven primary supply temperature, the control strategies of House 2 and 3 lead to increased ΔT and lowered primary flow. In simulation B with too-high primary supply temperature, the strategies of Houses 2 and 3 outperform House 1, resulting in significantly higher ΔT and lower primary flow. The strategy of House 3 (control curve based on primary supply temperature) shows the best results. In simulation C with too-low primary supply temperature, House 2 is no longer clearly superior to House 1, but the strategy of House 3 leads again to highest ΔT and low primary mass flow.

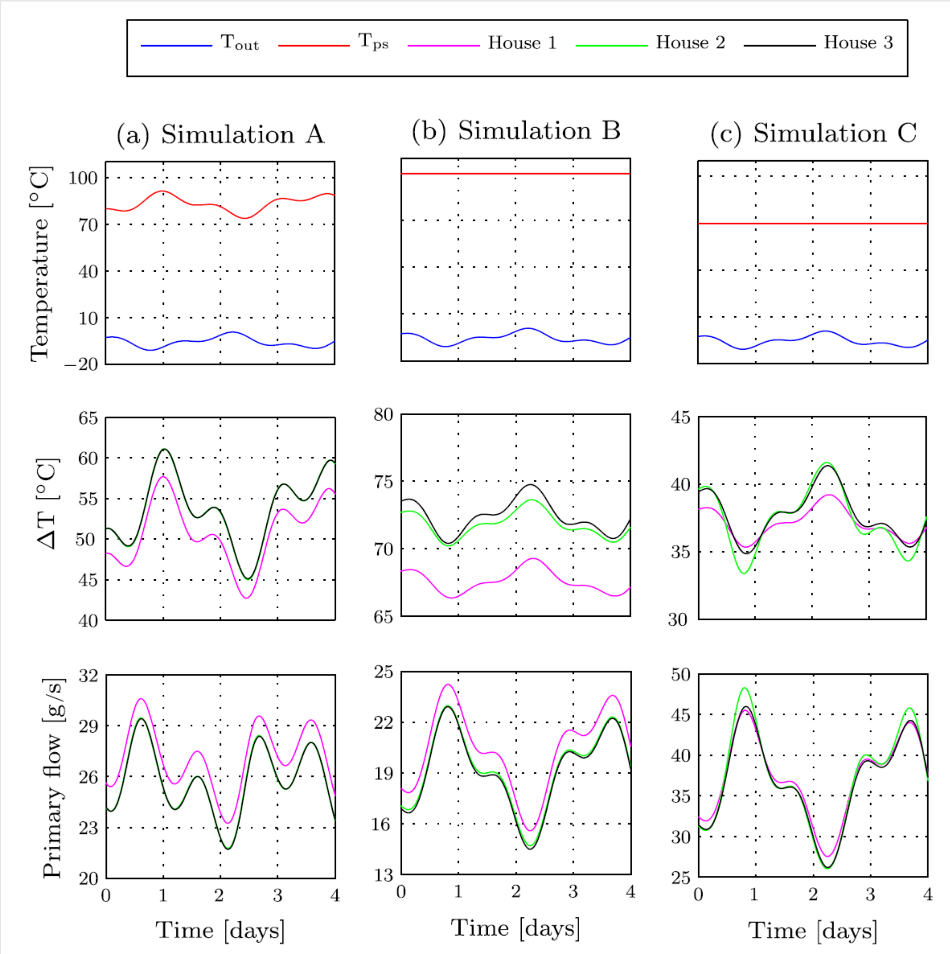

Figure 12: Resulting ΔT and flow in the primary side of a space heating heat exchanger from two independent simulation runs. In simulation A, the primary supply temperature was set to Tps-def; in simulation B and C the primary supply temperature was set to constant temperatures of 100 and 70°C. Houses 1–3 indicate thermodynamically identical houses with different radiator control methods [3]

Limitations of Study:

Most radiator control systems lack the capability to directly measure the primary supply temperature. Introducing new temperature sensors onto or within the primary supply pipe would be a costly and time-consuming endeavour. Presently, the primary supply temperature is monitored by the heat meter, primarily utilized for billing purposes. By sharing the supply temperature data from the heat meter with the radiator control system, the new control approach could be implemented without the need for additional temperature sensors.

Energy companies, particularly in Sweden, are integrating their heat meters into remote reading systems. This creates the opportunity to remotely monitor and control customers' heating systems. Outdoor temperature measurements could be centrally conducted for a group of buildings, rather than each building having its own outdoor temperature sensor. This centralization can help mitigate control errors resulting from malfunctioning or incorrectly positioned outdoor temperature sensors.

3.2.2 Smart heat interface units

The decentralization of heat supply in multi-family homes enables the collection of more detailed demand information about individual apartments, thereby supporting demand-side management in district heating networks to operate more efficiently. Furthermore, a microcontroller with electric actuators connected to a building management system can provide demand response.

The use of decentralized instantaneous water heaters can fulfil the hygiene requirements for potable hot water in an inexpensive manner without raising the water temperature to 60°C or using circulation systems, which makes them most suitable for heat pump systems with cold thermal network.

The case study in this template features a smart heat interface unit (HIU), which represents an advanced form of decentralized supply units for space heating and domestic hot water in multi-family homes. It uses information from both the demand and supply sides to regulate the entire heat flow operation, from heat generation to heat emission in space heating or water tapping in bathrooms or kitchens. This is accomplished by controlling key parameters in the heating system, including hydraulic, temperature, generator, and demand-side (user). This highly networked control concept should be addressed in the WoSta4.0 project.

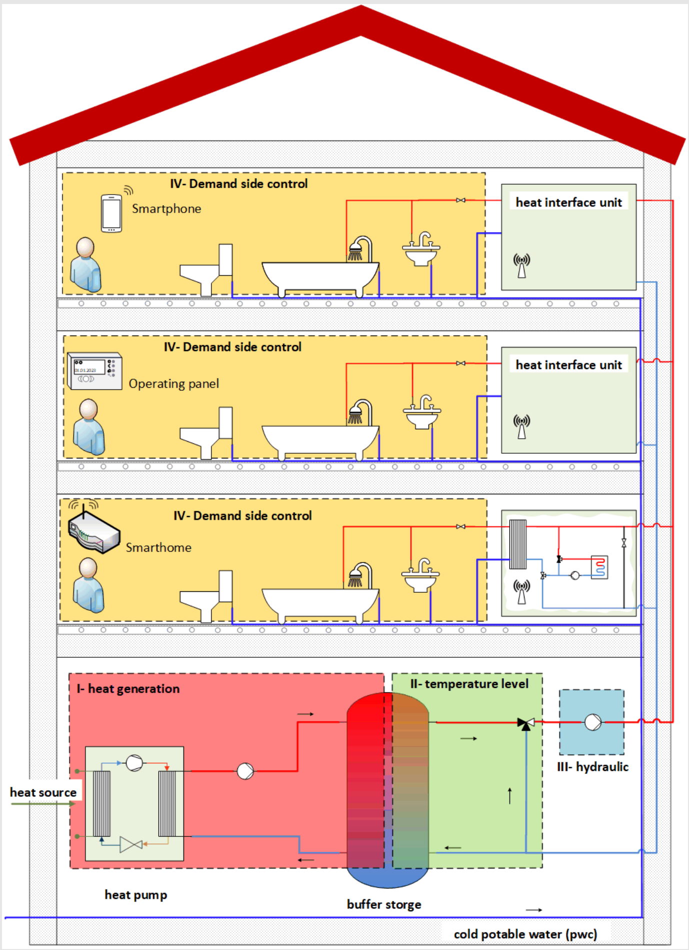

Figure 13: Smart heat interface units with the key parameters for the controlling strategy

Heat pumps and solar heat are identified as central technologies for heat generation in the project. Low-temperature district heating networks can serve as a heat source for the heat pumps in this system and conform to Annex 84. The system, consisting of heat pumps, solar heating, and low temperature district heating networks, has already been designed and is soon to be constructed and monitored as part of the WoSta4.0 project.

Table 3: Technology 3 –– smart heat interface units (HIUs) for multi-family houses (MFH)

Technology: smart HIUs integrated in MFH	
Technology Type: Distribution	**TRL: 7–9**
Technology Variant: Decentralization of heat distribution in MFH	**Capacity Limits:** ≈ 20 kW DHW, 10 kW SH
CAPEX: €/ kW ≈ 50 €/kW	**Efficiency:** ≈ 100%
Technical Lifetime: 20 years	
Flexibility enabler for: Heating ☒ Cooling ☐ DHW ☒ Electricity ☒	
Load shifting period: Hourly ☒ Daily ☐ Weekly ☐ Seasonal ☐	

Applicability of installation: New Buildings (during construction) ☒ Existing buildings (through renovation) ☒ Existing buildings during operation* (no renovation needed) ☒	
Pros: • Lowering the temperature level of heat supply systems in multi-family homes by 5 to 10 K supports the use of low temperature (low-ex) heating systems such as heat pumps, solar heat, and low temperature district heating networks. • Networking different intelligent control circuits leads to highly efficient demand-side-based operation. • These two points are expected to reduce energy consumption by 30 % and carbon emissions by 70 % compared to normal systems that use boilers. • Transparent supply and heat metering encourage sufficient consumption behaviour among users.	**Limitations/Bottlenecks:** • The networking and intelligent control can vary on many levels, depending on the data collected from the relevant components (heat generator, pumps). A highly networked and intelligent controlling concepts could be expensive on the economic and technical levels, because of the diversity of data communications protocols. • There is a shortage of monitoring data in the field regarding rebound effects and rent models.
Minimum hardware requirements for Demand Response (accompanying technologies): • **Necessary:** Availability of IoT smart HIU for advanced automated control and monitoring system. • **Beneficial:** Connection to the energy management system of the heat pump and PVT. Integration into the smart home environment of the tenant, allowing data collection of room internal temperature/setpoint.	

3.2.3 Hydronic Radiator

Hydronic radiators are one of the most common methods to provide space heating to rooms. This technology uses water or other fluids to distribute heat or cold through pipes embedded in floors, walls, or ceilings. It offers precise temperature control and can be adjusted quickly in response to demand changes. They are compatible with buildings connected to district heating systems as well as gas boilers. Hot water is distributed from the source (the substation in the case of district heating) through piping in a loop to the hydronic radiator, which has a large surface area that emits radiative heat. At the outlet, the water is cooled by approximately 15–20°C due to losses over the surface and is returned to the substation. These radiators are typically mounted on internal walls at ground level so that the emitted heat can circulate around the room.

Hydronic radiators are commonly equipped with a thermostatic radiator valve (TRV) which can be controlled manually or remotely based on external signals. Adjusting the position of the TRV controls the volume flow rate through the radiator and, consequently, the heat output into the room. The valve automatically adjusts theheat emission to maintain the desired room temperature and will shut off the heat supply once this desired temperature is reached.

Table 4: Technology 4 – Hydronic Radiator [4]

Technology: Hydronic Radiator	
Technology Type: Distribution	**TRL:** 9
Technology Variant: Space Heating	**Capacity Limits:**
	Operating Temperature Range: 30–50°C
CAPEX: n.a.	**Efficiency:** up to 90% thermal
Technical Lifetime: 10–20 years	
Flexibility enabler for: Heating ☒ Cooling ☐ DHW ☐ Electricity ☐	

Load shifting period: Hourly ☒ Daily ☐ Weekly ☐ Seasonal ☐	
Applicability of installation: New Buildings only (during construction) ☐ Existing buildings (through renovation) ☐ Existing buildings during operation (no renovation needed) ☒	
Pros: • Relatively low energy input to activate the building's thermal mass for load shifting. • Faster response time in comparison with underfloor heating system due a radiators mass being more concentrated. • Relatively cheap to install without any renovation measures being necessary.	**Limitations/Bottlenecks:** • Unlike underfloor heating, hydronic radiators do not contribute much thermal mass to the building, thus shifting loads over longer time periods is less feasible. • Less efficient means of transfer of heat compared with underfloor heating, thus resulting in higher energy demand.
Minimum hardware requirements for Demand Response (accompanying technologies): • **Necessary:** Availability of IoT for advanced automated control and monitoring systems. • **Beneficial:** Live data-logging of measured room temperatures for external party access.	
Related Case Studies **Literature source:** Scientific Paper **Name:** Room-level load shifting of space heating in a single-family house - a field experiment **Citation:** https://doi.org/10.1016/j.enbuild.2022.112750	
Case Study Type: Demo in the field	Building Type: Detached Single Family Home in Aarhus, Denmark
Test Setup: The experiment was carried out in a single-family home connected to a district heating network to assess the suitability for a hydronic radiator system to actively shift space heating loads in a building, using a setpoint schedule to mimic the behaviour of a typical economic model predictive (e-MPC) scheme. The building was equipped with remote-controlled thermostats, various temperature measuring equipment given in Figure 14 coloured red, and a heat meter logging heat energy use in high precision and temporal resolution. The space heating circuit in the home has a direct connection to the district heating grid whereas the domestic hot water circuit is separated via heat exchanger. The radiator supply temperature is regulated by a weather compensation curve. The remote-controlled thermostats were only applied in "active" rooms in the house which were deemed more suitable for load shifting purposes which were the living room, dining room and the kitchen due to them being the largest rooms with significant heat losses through external walls. The thermostats had full wireless control through a Z-wave network. The heat meter collected combined domestic hot water and space heating load information so statistical methods had to be used to separate the two loads.	

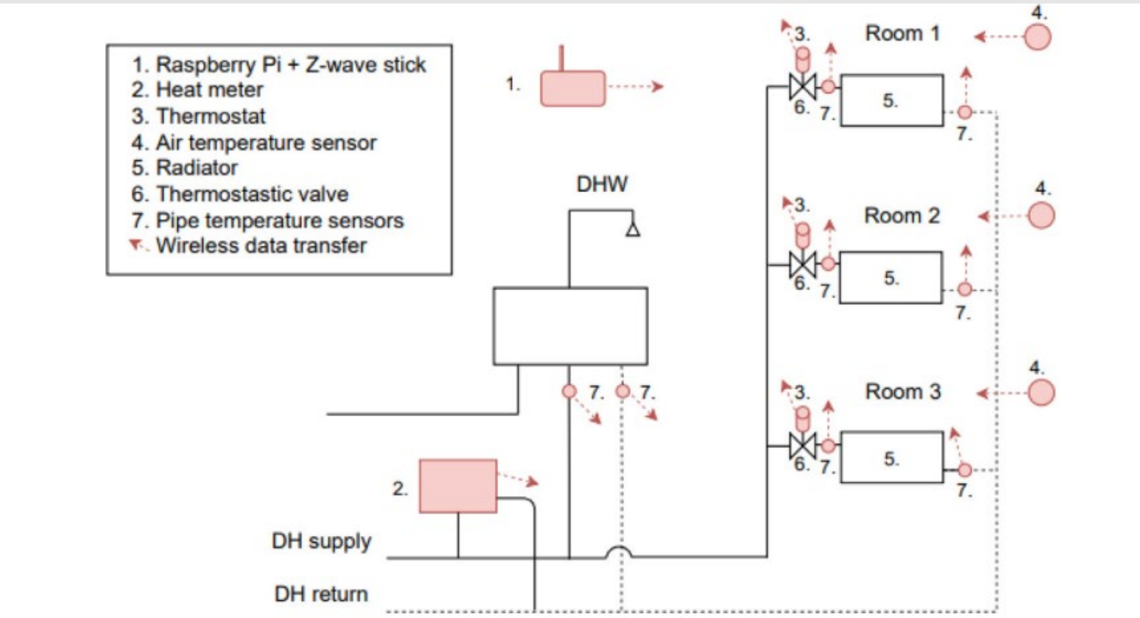

Figure 14: Diagram of the heating system and the experimental equipment (coloured in red) [4]

Three experiments were carried out on the hydronic radiators in total.

- **Experiment 1:** boosts in fixed nighttime periods using the thermostat embedded set-point control
- **Experiment 2:** random boosts during the whole day using a customized valve opening control
- **Experiment 3:** the influence of changes in radiator water flow in the active zone on the flow in the passive zone

Equipment information

Heat Meter	Kamstrup Multical 603 (5-minute reading resolution)
Thermostatic valve	ZWA021 (temperature resolution 0.1°C)
Room temperature sensors	HeatMoniSpot (0.5°C accuracy)
Home software	Raspberry Pi + Z-wave stick

Test Results: The study shows the measured temperature response of the three active zones (dining room, living room and kitchen) during a 1-hour, 3-hour and 5-hour boost to emulate an economic MPC price signal as well as the overall impact on space heating demand. Description and discussion of practical issues encountered during the experiments and suggestions for how to solve them is the main outcome of the paper.

Limitations/Issues with Study: The study outlines a few practical issues encountered during the testing. The following is a list of some of the most critical as well as potential salutations for future implementations.

- **Mounting modern thermostats on old radiator valves**: the thermostat does not fit the thread of the old Danfoss valves on the radiators. Connection could be achieved using adaptors, though careful modification of the adaptor pins was needed. Either a better adaptor system is recommended for future fittings or to replace the old valves completely with more modern ones.
- **High return temperature from radiators:** Data showed that boost periods led to high return temperatures in the radiators. For future applications a better balance between energy flexibility and return temperature can be met by customisation of the radiator set point.
- **Battery Life and stable Internet and Z-wave connection:** All of these factors led to discrepancies in the operation making it impossible to send signals to the thermostats. Battery life could be increased either through a wired connection to the thermostats or by defining a control strategy with less frequent need for mechanical regulation of the valve.
- **Occasional overheating of the area close to the radiators in the active rooms:** Supply temperature to the radiators was not weather compensated during the experiments (disabled to allow temperature boosting), thus was increased during periods of boosting to maximise the power to the radiators.

Solution could be to reduce the supply temperature and increase flow rates consequently. It should be noted that the maximum permitted flow rates through the radiators is normally limited by the pipe diameter.

- **Separation of space heating and domestic hot water data:** Statistical methods were used to separate the space heating and domestic hot water components in the heat meter readings, though due to the limitation of the heat meter resolution (0.1kWh) there still existing some uncertainty in the validity of using such statistical methods.

3.3 Supply Technologies

The role of supply technologies is to provide the necessary infrastructure and flexibility for buildings to adapt their energy consumption patterns based on demand response signals. When combined with a DHC system, these technologies enhance a building's ability to respond to changes in energy supply and demand, contribute to grid stability, reduce energy costs, and support a more sustainable and resilient energy ecosystem. Figure 15 shows the three supply technologies.

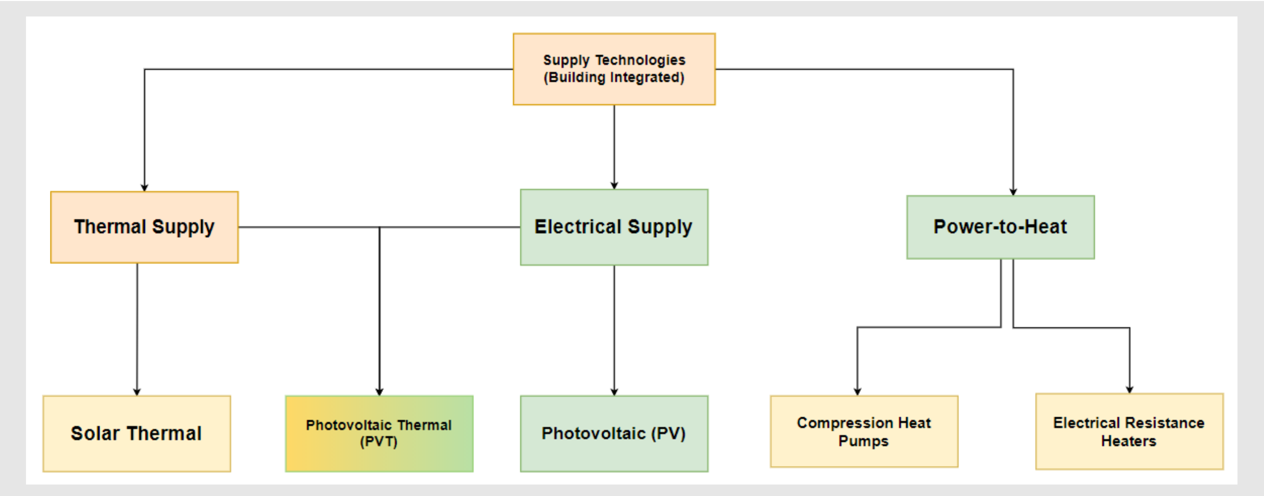

Figure 15: Supply technologies at the building level

3.3.1 Electric Resistance Heater

Electric resistance heaters are conventionally used as a standalone technology that draw electricity from the power grid and emit heat through a resistance element simultaneously. The heaters are often submerged in water vessels, where the water is heated to a set-point temperature before being distributed throughout the building This is most commonly used for domestic hot water usage but is also often integrated with space heating circuits.

Electric heaters can also be used in buildings primarily supplied by a district heating grid, serving as a booster heat source during peak load periods. This helps reduce demand peaks on the district heating grid itself, thereby enabling demand response in a building. Though their operation is simple, there have been few studies exploring the integration of electric boosters in buildings connected to thermal networks, and even fewer studies have implemented sophisticated control strategies that facilitate regular signal exchanges between the heating and power grids. As the heating and power sectors become increasingly interconnected, demand response in buildings – through fuel-switching from DH to power grid using electric resistance heaters (often referred to as booster heaters in this context) – will become more relevant in the coming years.

Table 5: Technology 5 – P2H [5]

Technology: Electric Resistance Heater

Technology Type: Supply	**TRL:** 9
Variant: Power-to-Heat	**Capacity Limits:** >100 kW (only limited by power transmission capacity to building)
CAPEX: n.a.	**Efficiency:** >90% (electrical power converted to heat)
Flexibility enabler for: Heating ☒ Cooling ☒ DHW ☒ Electricity ☒	
Load shifting period: Hourly ☒ Daily ☐ Weekly ☐ Seasonal ☐	
Applicability of installation: New Buildings only (during construction) ☐ Existing buildings (through renovation) ☐ Existing buildings during operation (no renovation needed) ☒	
Pros: • Extremely simple and cost-effective technology to implement. • Enabler for direct coupling with the electrical grid. • Can serve as a "fuel-switcher" during peak thermal loads to enable demand response.	**Limitations/Bottlenecks:** • Effective communication between thermal and electrical grids needed to implement a proper control strategy. • Above point entails further complexity with the need for many accompanying technologies. • Use of electricity is not always favourable to the DH grid for cost or CO_2 related reasons. • Ownership over power grid and heating grid is often not shared thus stronger collaboration models should be included to include all parties.
Minimum hardware requirements for Demand Response (accompanying technologies): • **Necessary:** Availability of IoT integrated components for advanced automated control and monitoring system, SCADA system, smart heat and electricity meters, distributed controller. • **Beneficial:** Detailed live temperature measurements at multiple heights in water vessel containing the electrical booster to estimate current and future state of charge.	
Related Case Studies (more applicable for lower TRL technologies): **Literature source:** Scientific Paper **Title**: Technical assessment of electric heat boosters in low-temperature district heating based on combined heat and power analysis, **Citation:** https://doi.org/10.1016/j.energy.2018.02.084	
Case Study Type: Simulation study - interfacing of technologies in the field also considered.	**Building Type:** Terraced, Single-family homes – 23 in total
Experimental Setup: A hypothetical case was develop to investigate the suitability of using electric heat boosters in building integrated hot water tanks to act as a fuel-shifting source of flexibility to reduce peak loads on the district heating grid for a range of different supply temperatures ranging from 50°C to 70°C. Power is drawn from a low voltage network (LVN) to heat the hot water tanks via the electrical resistance heater which could then be distributed to the buildings for domestic hot water purposes.	

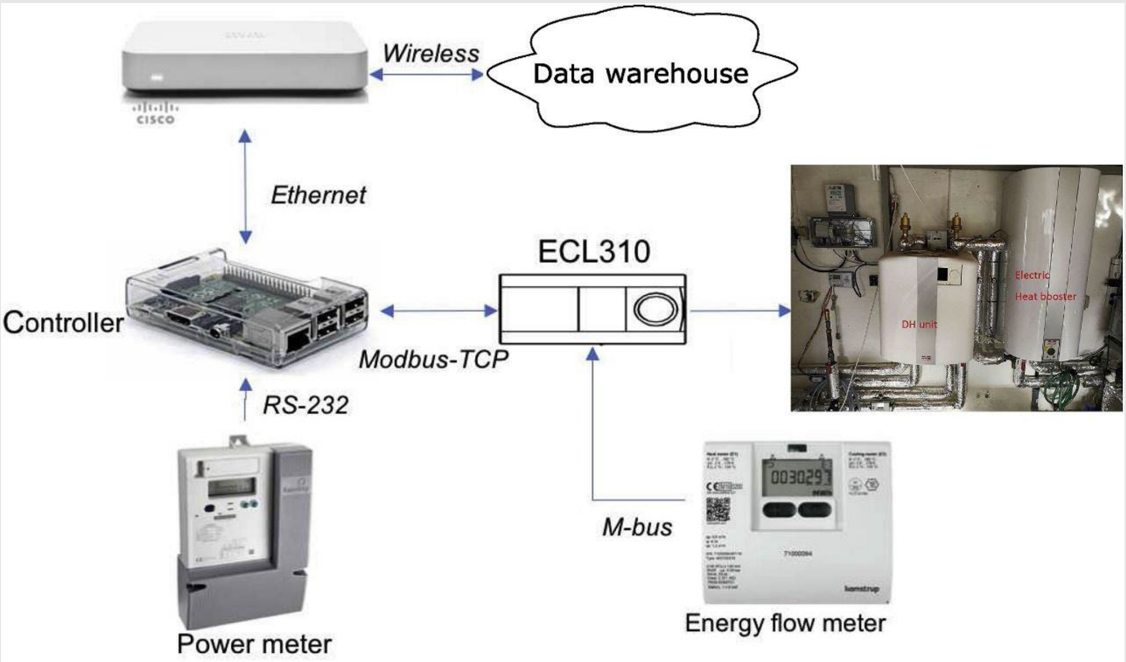

Figure 16: Foreseen Equipment and communication channels for electric booster and DH unit. [5]

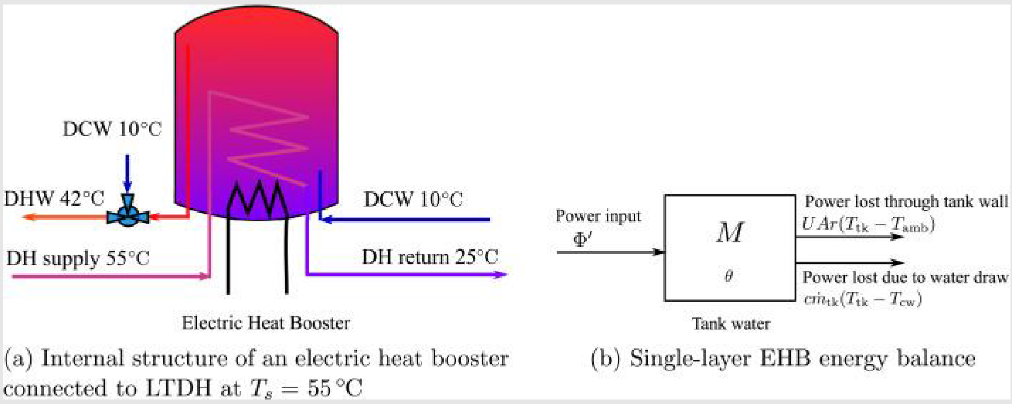

Figure 17: Concept for modelling of DHW tanks connected to both DH and electricity grid. [5]

The electric boosters are used mainly to heat the water in the DHW tanks from 50°C up to 55°C and occasionally 60°C.

Heat Booster Properties	
Electrical power capacity of boosters	3kW/400V per element
Volume of surrounding water tanks	51l and 92l
Time step of integrated controller	5 minutes
Test Results:	

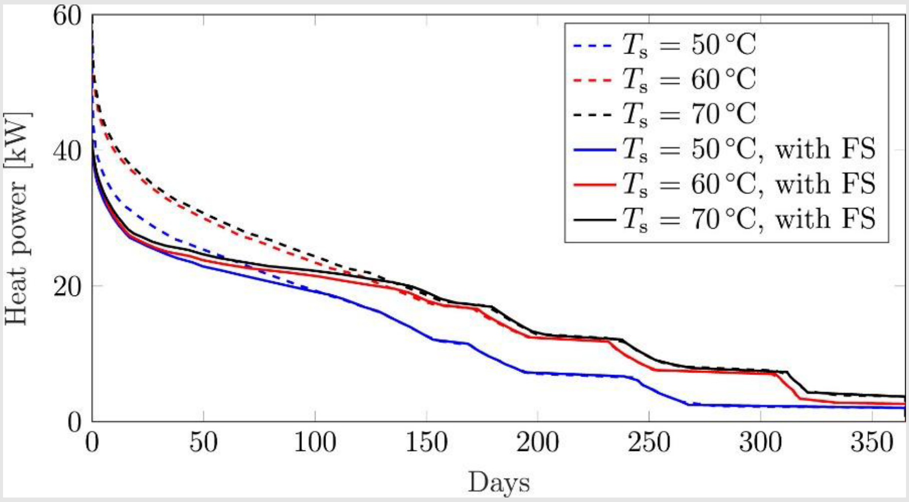

Figure 18: Achieved reduction in peak thermal load on load duration curves in building for different DH supply temperatures bot with and without fuel-shifting through electrical boosters. [5]

The results for the fuel-shift operation mode showed considerable reduction in the peak load on the DH network for all investigated supply temperatures with a maximum achieved savings in heat production of 48% from the peak load boiler in the district heating network. The results showed promising potential to implement electric heat boosters in DHW tanks to reduce the reliance on peak boilers during periods of high heat demand.

Limitations of Study: Actual implementation in the field had not been tested at the time of study, thus results are purely based on simulations, though a detailed interfacing of components had been devised and planned to be demonstrated in a real low temperature DH network in Denmark. Furthermore, the simulation model ignored dynamic behaviour in the pipes such as delays in transporting heat throughout the network.

3.3.2 Control

The PreHeat control solution consists of three main components:

- A motorized control valve installed in the DH substation at the space heating circuit
- A temperature sensor located in the heated spaces
- An IoT unit that collects data from the household, which are store in the Neogrid cloud.

Together with data from the primary side (utility data), these inputs are processed by an optimization algorithm to generate a control signal, which is then communicated to the motorised control valve. The primary control objective is to limit heat consumption for space heating during the morning and afternoon peak hours. This is achieved by closing the motorised control valve during peak hours, ensuring that district heating energy is used solely to meet the demand for DHW (see Figure 19).

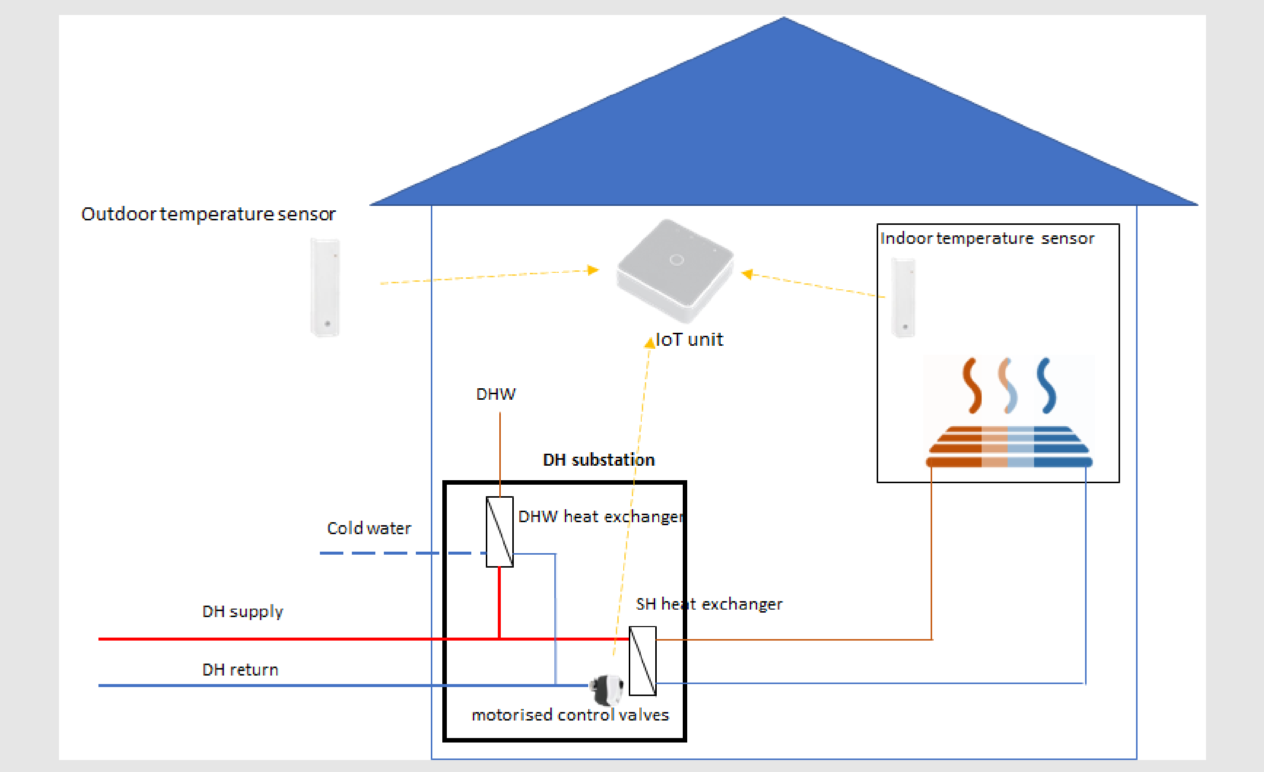

Figure 19: PreHeat Control solution

Table 6: Technology 6 – Control solution [6]

Technology: PreHEAT Control box installed at the DH substation in buildings with underfloor heating	
Technology Type: Control	**TRL:** 7-9
Technology Variant: n.a.	**Storage Medium:** Building construction
Storage Capacity: depends on the building	**Operating Temperature Range:** 20–45°C
CAPEX: n.a.	**Efficiency:** n.a.
Technical Lifetime: 40 (SBi13-30) of underfloor heating installation;	
Flexibility enabler for: Heating ☒ Cooling ☐ DHW ☐ Electricity ☐	
Load shifting period: Hourly ☒ Daily ☐ Weekly ☐ Seasonal ☐	
Applicability of installation: New Buildings only (during construction) ☐ Existing buildings (through renovation) ☐ Existing buildings during operation (no renovation needed) ☒	
Pros: • Simple and cost optimal solution suitable to new and existing buildings • Demonstrated solution • A 4G sim card is suitable to maintain the data transfer and two-way communication signals	**Limitations/Bottlenecks:** • Demonstrated only for houses with underfloor heating • Requires individual agreements with customers • Currently no option for customers to trace back the history of activation signals
Minimum hardware requirements for Demand Response (accompanying technologies): • **Necessary:** IoT Unit, Motorised control valve in the DH substation, 4G sim card, 1 temperature sensor • **Beneficial:** Data collection of room internal room temperature/setpoint.	
Related Case Studies (more applicable for lower TRL technologies):	

Literature source: Scientific Publication
Title: Demand side management of heat in smart homes: Living-lab experiments
Citation: https://doi.org/10.1016/j.energy.2020.116993

Case Study Type: Demonstration in the field	**Building Type:** Large Apartment Complex (Copenhagen, Denmark) – 90 apartments participating in peak shaving underfloor heating

Experimental Setup:

The apartments are primarily heated by radiant floor heating systems where warm water is circulated in pipes that are cast in a light layer of concrete that sits on top of an insulation layer in the floor. The light concrete layer with the heating pipes sits under wooden floors. The flowrate of the warm water, and the resulting heat delivered to the apartments is controlled by local thermostatic controllers that open and close the valves supplying the independent heating loops as can be seen from the principal diagram and typical apartment floor plan in the lower illustration in Figure 20. The details are based on the design of the experiment building as it was constructed in Copenhagen by commercial contractors. In modern apartment buildings in the Danish construction, it is customary to include thermostatic control of individual rooms including bathrooms. The opening and closing of valves is based on the current temperature in individual rooms as well as the user-adjustable set-point for that room. The warm water is supplied from individual shunt loops that regulates the temperature supplied to the apartments to a maximum of 35 Celsius. The local control system loop is shown in block diagram form in the upper illustration in Figure 20. The shunt loops are supplied by a mixing loop located in the heating substation (not shown). The substation is supplied by district heating. The heat delivered to each apartment is individually metered through heat meters that measure the volumetric flow, forward and return temperatures of the water supplied to the shunt loops.

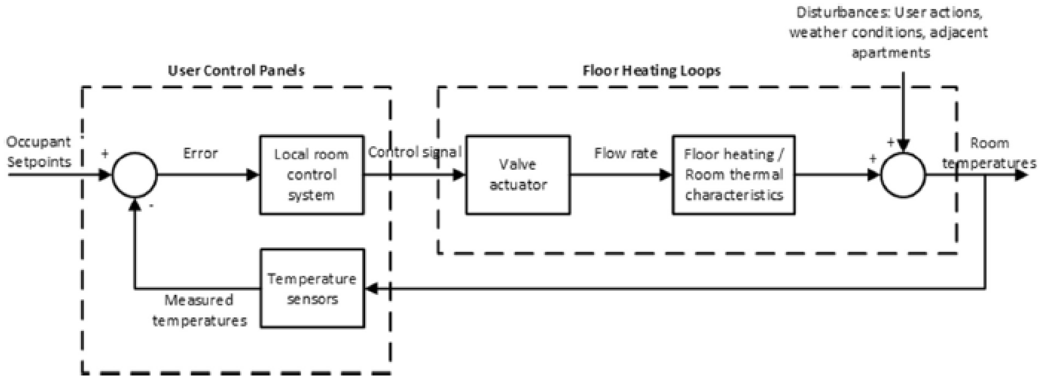

Fig. 2. Local control systems of the Smart homes controlling the indoor temperature.

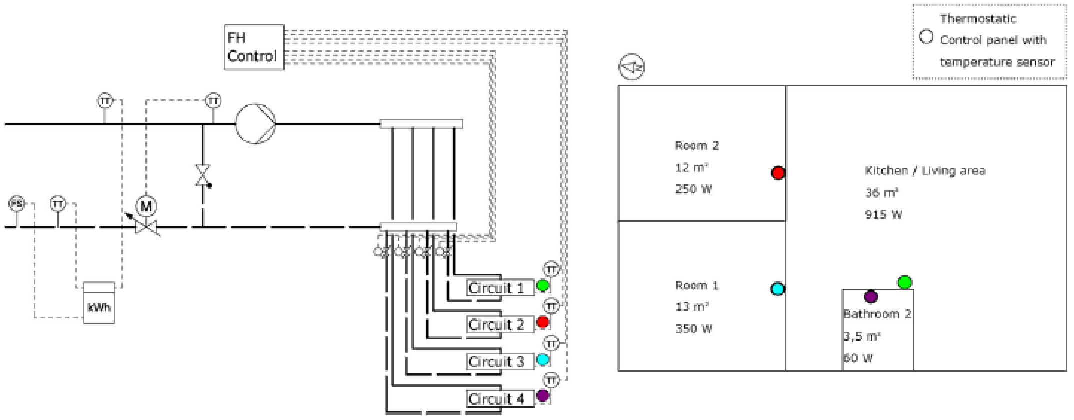

Fig. 3. Example of details of floor heating systems: Principal drawing and corresponding heating loop distribution.

Figure 20: Top: Local control system of the Smart homes controlling the indoor temperature (top); Bottom: Example of details of floor heating systems: Principal drawing and corresponding heating loop distribution [6]

Location of Storage: Underfloor ☒ Facade ☐ DHC Substation ☐ Radiator/AHU ☐ Other

Storage Properties	
Melting Temperature	
Latent Heat Capacity	
Thermal Conductivity	
Density	

Test Results:

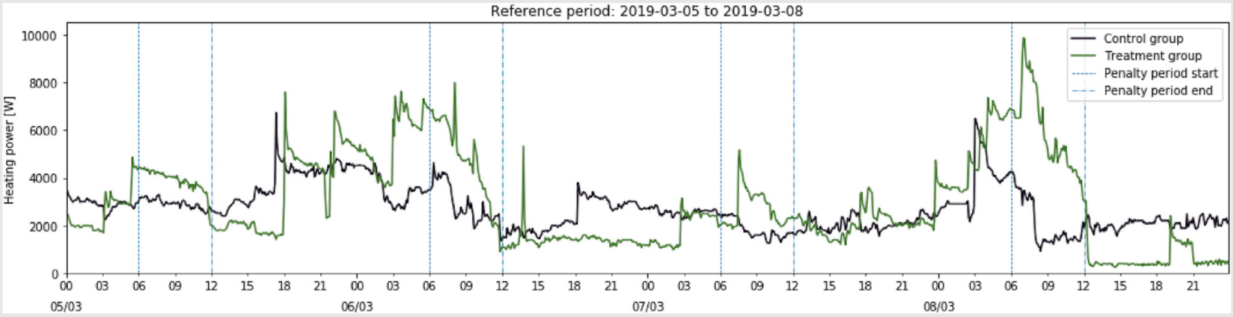

Figure 21: Aggregated heating power in apartments in control and treatment groups during the reference period. [6]

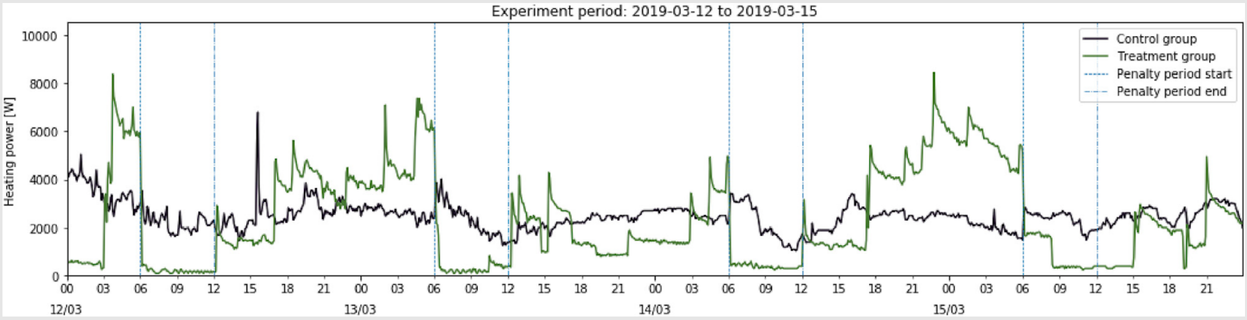

Figure 22: Aggregated heating power in apartments in control and treatment groups during the experiment period. [6]

The results thus confirm that the penalty aware controller can activate the flexibility potential. When we calculate the total energy consumption for the two groups during all hours, we find that for the control group the experiment period had a total energy consumption that was 7% less than the reference period. For the treatment group the result was a 20% reduction. From our result we thus do not see an increase in energy consumption as a result of the experiment. Upon closer inspection we see that the main part of the reduction is dominated by significant reduction in two apartments, B14 and B15 while a single apartment B19 had a large increase in total energy consumption. The result agrees with the intuition that, as we did not pre-heat the apartments the temperatures would be expected to be slightly lower on average and thus the total energy consumption would be expected to be slightly lower as well.

Performance indicators measured	
Reduction in energy use	control group 7%; treatment group (20%)
Reduction in total heat load	~12%

Limitations of Study:

The effect of the flexibility demonstration on the indoor temperatures would be expected to have a lower indoor temperature as a result of the peak shaving without preheating. It is noted that it is not the case that all apartments have lower temperatures from the box plots in Figure 21 and Figure 22. Besides heating supply, there are several other factors influence the indoor temperatures, e.g. solar irradiation, internal heat gains from appliances and people, mechanical ventilation and heat transfers between adjacent apartments. These dynamics are too complicated to fully account for within the scope of this study.

4. References

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