ANNEX 84

EBC
Energy in Building and
Communities Programme

International Energy Agency

Demand Management of Buildings in Thermal Networks (Annex 84) - Deliverable WI B.4 Role of Monitoring, Sensoring and Control Technology

Energy in Buildings and Communities Technology Collaboration Programme

March 2025

Technology Collaboration Programme
by iea

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Authors

Basak Falay, AEE INTEC, AT (b.falay@aee.at)
Ingo Leusbrock, AEE INTEC, AT (i.leusbrock@aee.at)

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www.iea-ebc.org
essu@iea-ebc.org

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 CO2 Emissions Optimization in Building Renovation (*)
Annex 57: Evaluation of Embodied Energy and CO2 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
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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.4 of Subtask B in IEA EBC Annex 84 explores how monitoring, sensing, and control technologies can enable demand response (DR) and improve the performance of district heating and cooling (DHC) systems. As DHC networks evolve toward low-temperature operation for decarbonization, accurate and real-time data from buildings and substations becomes essential to unlock flexibility and system optimization.

The report begins by examining the current status of sensors and monitoring systems within DHC networks. While production and distribution systems are typically well-monitored, building-level substations often lack sufficient instrumentation. This deficiency hampers proactive fault detection and contributes to inefficiencies such as high return temperatures. Incorporating standardized sensor sets—including temperature, pressure, flow, and energy meters—enables smarter control and better system diagnostics.

The study highlights the challenges and opportunities presented by digitalization. Key opportunities include the integration of IoT devices, smart meters, and AI/ML algorithms to enable predictive maintenance, dynamic heat control, and user feedback. However, challenges remain in managing large volumes of data, ensuring interoperability across devices and platforms, and maintaining data privacy and cybersecurity. Regulatory hurdles and varying technical standards also add complexity across different regions.

A major focus is the required sensor technologies for effective DR at the building level. Examples include heat cost allocators, electronic radiator thermostats with return temperature control, and smart IoT-enabled devices such as room temperature collectors and balance valves. These technologies not only support real-time monitoring but also allow decentralized control strategies that enhance energy efficiency and user comfort.

The report also maps the architecture of IoT systems, breaking them into five functional layers (perception, network, middleware, application, and business) and discussing the key communication protocols (e.g., MQTT, CoAP, LoRaWAN, OPC UA). It emphasizes that IoT-enabled smart control infrastructure allows for dynamic energy management, remote diagnostics, and the scaling of DR strategies across diverse building types.

In conclusion, Work Item B.4 presents a compelling case for modernizing DHC networks through smart sensing and control. It offers insights into current technologies, identifies gaps and limitations, and outlines pathways for future integration—ultimately paving the way for more flexible, efficient, and user-centric district heating systems.

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Abbreviations

Abbreviations	Meaning
AI	Artificial intelligence
AMQP	Advance message queuing protocol
BMS	Building management system
CAT.1	Category 1
CoAP	Constrained application Protocol
DHC	District heating and cooling
DHN	District heating network
DHW	Domestic hot water
DDS	Data distribution service
EMS	Energy management system
FBD	Function block diagram
HMI	Human-machine interface
IAQ	Indoor air quality
IIoT	Industrial internet of things
IoT	Internet of Things
LTE	Long term evolution (4G)
LTE-M	Long term evolution machine type communication
ML	Machine Learning
SH	Space heating

1. Scope and Objectives

1.1 Overview of Subtask B and Work Item B.4

The objective of Subtask B is to

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

Subtask B is organized into 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 at the building level for demand response and flexibility option
- B.3 – Role of DHC substations as an element in demand response at the building scale
- B.4 – Role of monitoring, sensoring, and control technology
- B.5 – Evaluation and Summary

Work Item B.4 aims to provide an overview and evaluation of the role Monitoring, Sensoring and Control technology may play as demand response option in combination with a DHC system and highlight their potential and limitations.

The work in Work Item B.4 focussed on the following activities:

- **Activity 1: Status of the sensor's technologies and data collection in district heating networks**
- **Activity 2: Analysis and evaluation** of **challenges and opportunities for Digitalisation of District Heating)**
- **Activity 3: Analysis and evaluation required sensor technologies and data collection for the demand side management in district heating network**

2. Content

2.1 Current Status of sensor technologies and applications

District Heating and Cooling (DHC) networks play a pivotal role in the drive to decarbonize the energy system, offering the potential for substantial cost reductions by transitioning to low-temperature district heating. Comprising heat and cooling generation facilities, distribution networks, and substations/end-users, DHC systems are integral components of this transition. Operators of DHC networks prioritize efficiency enhancements in heat and cooling generation and distribution, with the capability to supervise and regulate heating/cooling supply plants and networks, optimizing supply temperature and pressure. Established protocols enable the identification of operational inefficiencies and prompt resolution of faults to ensure the fulfillment of end-users' energy needs. However, attention to substations and thermal distribution systems for space heating, space cooling, and domestic hot water demands has been insufficient, despite their significant impact on return temperature in networks. Historically, buildings have lacked sufficient monitoring and control, resulting in reactive fault detection only after customer complaints, which in turn compromised system efficiency by maintaining unnecessarily high heating temperatures and low cooling temperatures. Addressing this issue poses a challenge in transitioning toward more efficient systems.

Nevertheless, studies conducted across various periods and locations confirm the feasibility of achieving low-temperature heating without the need for significant renovations. However, poorly performing substations and heating systems contribute to elevated return temperatures in large DHC networks, leading to increased operational costs and environmental impacts. Digitalization emerges as a viable solution, with advanced analytics and automated monitoring enhancing system control and operation. The shift toward smart meters and sensors enables more precise insights into heating system performance, laying the groundwork for further advancements in artificial intelligence and digital twin technologies.

To ensure continuous improvement in the economic and ecological performance of the local heating networks built and operated in **Austria**, corresponding requirements must be placed on the measurement equipment. The measurement equipment of the heating plant, distribution network and heat transfer stations, as well as the type of data recording and data evaluation, are standardized. Minimum requirements for the DHN, the following data must be recorded [1]:

1. Outdoor temperature at the heating centers
2. At all heat suppliers, at the outlet of the non-pressurized distributor, at the outlet from the heat generation centres into the main network line, as well as at all consumers: heat quantities, the required temperatures of supply and return, the volume flows [m^3/h]
3. Recording of electricity consumption (monthly; for larger installations, in consultation with the Quality Manager) from: each heat generator separately, all electrical auxiliary energy required for the operation of the heat generator, electrostatic precipitators, network pump(s)
4. Data on the operation of the heat generators for biomass: activity of fuel feeding, if necessary activity of ash removal/dust removal, temperature of boiler supply and return [°C], temperature of boiler return immediately before the boiler (raised) [°C], setpoint of the power controller on the boiler [kW], boiler power output [kW], flue gas temperature [°C], measurement of the lambda probe (Vol-% O_2), speed settings of the boiler air blowers [%], speed settings of the boiler flue gas blowers [%], boiler negative pressure (control variable for flue gas blowers) [mbar], automatic fault log (with fault reporting for fuel feeding, auxiliary blowers, grate, and ash removal, boiler level monitoring devices, lambda probe, and other emission monitoring devices, safety devices).
5. Hydraulic/Network Data (for optimization purposes): network supply and return temperature [°C], pressure drop of the network at rated load and at summer load, for variable-speed network pumps, critical

system operating/differential pressure, position of the return temperature lift actuators or network mixing device at rated load and at summer load.

2.2 Challenges and opportunities

Digitalization facilitates the incorporation of both new and existing sensors into the district heating infrastructure, including secondary systems such as substations, facilitating the real-time monitoring of critical parameters like temperature, flow rates, and pressure. These sensors collect abundant data, providing valuable insights into system performance and bolstering the implementation of **predictive maintenance strategies** and **demand-side management**. Furthermore, advanced data analytics techniques optimize heat production and distribution, ensuring efficient resource utilization.

In parallel, the Internet of Things (IoT) assumes a crucial role in advancing the digitalization of district heating systems. By interconnecting various devices and sensors, IoT facilitates the seamless exchange of data, thereby enhancing communication and control. IoT-based solutions can monitor and regulate individual building energy consumption, enable demand-response mechanisms, and enhance the overall flexibility and reliability of district heating networks.

The incorporation of advanced sensors and IoT systems enable the potential of artificial intelligence (AI) and machine learning (ML) algorithms to revolutionize the operation and optimization of district heating systems. Through the analysis of extensive datasets, these technologies can identify patterns and generate intelligent forecasts. AI and ML algorithms can optimize heat production schedules, predicting energy demand, and dynamically adjusting heat distribution based on real-time conditions. Consequently, this leads to improved energy efficiency, reduced operational costs, and heightened system reliability.

Challenges

Digitalization involves collecting and analyzing large amounts of data from sensors, meters, and other devices within the heating network. Managing this data effectively, ensuring its quality, and protecting it from **cybersecurity** threats are significant challenges. Implementing robust data management and security measures is crucial to safeguarding sensitive information and maintaining network integrity.

Integrating various digital components and systems within a district heating network, such as sensors, meters, control systems, and data analytics platforms, requires **interoperability** between different vendors and protocols. Achieving seamless communication and data exchange among these diverse components can be complex.

District heating networks often serve diverse customer bases with varying heating demands and infrastructure requirements. Digital solutions need to be **scalable** and **flexible** enough to accommodate different network configurations, customer needs, and future expansion plans. Adapting digital technologies to meet evolving demands and changing circumstances can pose challenges.

Regulatory requirements and **policy frameworks** governing district heating networks may vary across jurisdictions and regions. Ensuring compliance with relevant regulations, standards, and environmental mandates while implementing digitalization initiatives is essential. Navigating regulatory complexities and aligning digitalization efforts with regulatory objectives can be challenging.

Opportunities

The adoption of digital technologies enables the implementation of digital twins for the DHC systems. By integrating optimal control strategies on the demand side based on digital twin modeling, the overall energy efficiency of the entire system can be effectively increased. Additionally, providing consumers with real-time information and feedback encourages energy-efficient behaviours and facilitates the introduction of dynamic pricing mechanisms. This empowers consumers to actively engage in energy conservation and load balancing, ultimately fostering a more sustainable and resilient energy system.

2.3 Required sensor technology for demand side management

Temperature, pressure, and flow sensors are typically installed in each heat source, substation, and customer building in DHC systems. Most district heating companies adopted distributed SCADA systems at that time, utilizing public telephone lines for dial-up internet or radio stations for remote monitoring of heat stations due to the inadequacies of wireless communication. Annex TS4 „Digitalisation of district heating" [2] highlights that integration data from energy meters, heat cost allocators installed in each radiator, and temperature sensors offers the potential to enhance the control and operation of space heating systems without major retrofitting. This integration enables the comfortable heating of existing buildings with supply temperatures ranging from 42 to 58°C throughout the heating season, without the need for extensive energy renovation. Additionally, minimizing supply temperatures can result in energy savings that offset the increased pumping power required for larger mass flow rates.

2.3.1 Sensors

Heat cost allocators are devices used to measure the heat consumption of individual radiators in multi-apartment buildings or other types of shared heating systems. These allocators are typically attached to each radiator and measure the amount of heat emitted by that specific radiator. This data is then used to allocate heating costs among the residents or tenants based on their individual usage.

Tunzi et al provided an innovative methodology for utilizing existing data from heat cost allocators, energy meters, and temperature sensors installed on the supply/return pipes of the secondary side of the space heating heat exchanger to improve the operation of residential multi-apartment buildings [3]. Heat cost allocators are used to estimate the distribution of total energy consumption, as recorded by the central energy meter, thereby pinpointing apartments and radiators exhibiting the highest energy usage. Analysis focuses on data from December and January to mitigate the influence of solar gains within the buildings. Assuming a standard indoor temperature of 22°C and employing a distribution of heating degree days, it becomes feasible to approximate the heat loss coefficient for the critical room, thereby estimating the heat demand based on outdoor temperature fluctuations. Temperature sensor data delineate the actual operating temperature variance within the space heating systems, with the lowest measurement serving as a constraint to compute the minimum required supply temperature for the critical radiator. Implementing this methodology presents a practical approach to enhance the existing operation of residential space heating systems. It underscores the observation that heat distribution among flats is not uniform, often due to end-users opting to keep some or all their radiators inactive, differing apartment locations and temperature set-points, and occasional malfunctions in settings or components. Achieving a uniform heat distribution across flats would facilitate further reductions in operating temperatures, representing a future objective in building servicing. Integration of current data with indoor temperature sensors are envisioned to enable ongoing system monitoring, empowering building service personnel to swiftly identify and rectify faults and user-related issues as they arise.

Electronic radiator thermostat is a device used to control the temperature of individual radiators in a heating system. It is typically installed on the radiator itself and allows users to set and adjust the desired temperature for each room independently. These thermostats are often programmable, offering features such as scheduling and temperature presets to help optimize energy usage and maintain comfort levels. Electronic radiator thermostats work by regulating the flow of hot water through the radiator based on the temperature settings input by the user. When the room temperature falls below the desired level, the thermostat opens to allow hot water to flow into the radiator, heating the room. Once the desired temperature is reached, the thermostat closes to reduce or stop the flow of hot water, maintaining the set temperature. These thermostats can be controlled manually through buttons or dials on the device itself, or remotely via a smartphone app or central control system. They are often considered more energy-efficient and convenient compared to traditional manual radiator valves, as they allow for precise temperature control and automation based on user preferences and schedules. Additionally, electronic radiator thermostats can help reduce heating costs by preventing overheating and optimizing energy usage.

Tunzi et al has recently been developed electronic radiator thermostat and tested in two Danish multi-family buildings [4]. The distinguishing feature of the electronic thermostat lies in its incorporation of an extra return temperature sensor and a specialized algorithm designed to regulate valve operation, ensuring that the return temperature remains at its maximum set point. Additionally, through the regulation of flow within the radiator, the electronic thermostat offers automatic hydronic balancing, further enhancing its functionality and efficiency.

Learnings from Subtask B.4

Decentralized Substation: Most radiator control systems currently do not possess the capability to directly measure the primary supply temperature. Introducing new temperature sensors onto or within the primary supply pipe would entail significant costs and time investments. Currently, 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.

Hydronic Radiators: The most common methods to provide space heating to rooms uses water or other fluids to distribute heat or cold through pipes embedded in floors, walls, or ceilings. Mounting modern thermostats on old radiator valves is a challenge since the thermostat does not fit the thread of the valves on the radiators. However, the connection could be achieved using adaptors, though careful modification of the adaptor pins was needed. When the thermostat has full wireless control the battery Life and stable Internet and Z-wave connection creates challenges. 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.

2.3.2 Internet of Things (IoT)

Particularly in the energy sector, IoT devices offer the capability to integrate diverse network assets into a unified distributed system, yielding substantial benefits such as enhanced energy efficiency, increased utilization of renewable energy sources, cost savings on maintenance, and improved comfort levels.

IoT technology holds significant potential for optimizing district heating systems by enabling remote monitoring, control, and automation of various components and processes. IoT-enabled monitoring systems can detect anomalies and deviations from normal operating conditions, signaling potential faults or inefficiencies in the system. ML algorithms can analyze data patterns to predict equipment failures or performance degradation, allowing for proactive maintenance and troubleshooting. IoT platforms can integrate data from various sources, including weather forecasts, building occupancy patterns, and energy demand profiles, to optimize energy production, distribution, and consumption in district heating systems. This dynamic optimization improves energy efficiency, reduces operating costs, and minimizes environmental impact. IoT-enabled control systems can respond to fluctuations in energy demand by adjusting heating output, flow rates, and distribution patterns in real-time. **Demand response strategies can help balance supply and demand, optimize system utilization, and avoid peak load situations, reducing energy waste and improving overall system reliability.**

By organizing IoT systems into five layers given in Figure 1, stakeholders can better understand the various components, interactions, and dependencies within the architecture, facilitating the design, implementation, and management of IoT solutions.

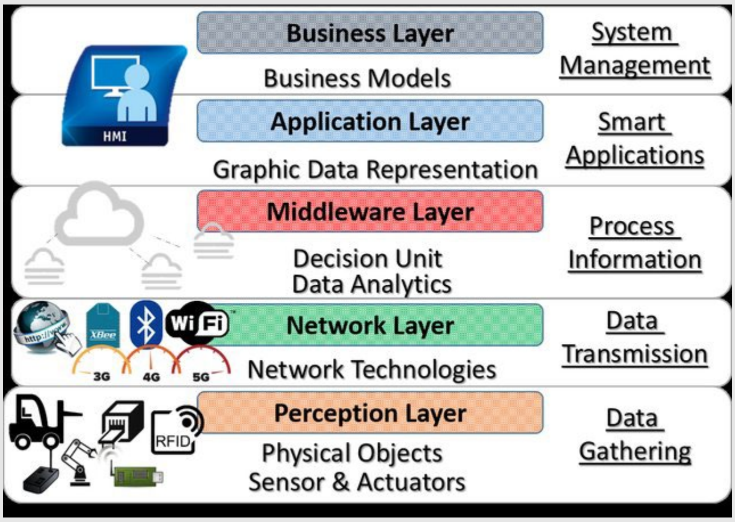

Figure 1: Five layer in IoT Architecture [5]

Middleware layer is a software layer that acts as an intermediary between different applications, services, or systems within a distributed computing environment. It facilitates communication, data exchange, and interaction between heterogeneous components by providing a set of services and abstractions that abstract away the complexities of underlying technologies and protocols. Various protocols are used to provide the communication and services to the application in this layer.

The Hypertext Transfer Protocol (HTTP): used for transmitting hypermedia documents, such as HTML files, over the internet. It defines the rules and conventions for communication between web clients (such as web browsers) and web servers. HTTP is a Transmission Control Protocol (TCP)/Internet Protocol (IP)-based, application-level protocol for distributed, collaborative hypermedia information systems.
The Constrained Application Protocol (CoAP): An upgraded version of HTTP, is a specialized web transfer protocol designed for use in constrained environments, such as low-power, low-bandwidth networks, and IoT devices. CoAP is intended to provide a lightweight and efficient communication protocol that is suitable for resource-constrained devices and networks while maintaining interoperability with the web.
Message Queuing Telemetry Transport (MQTT): is a lightweight, open-standard messaging protocol designed for efficient communication between devices in low-bandwidth, high-latency, or unreliable network environments. Originally developed by IBM, MQTT has gained widespread adoption in IoT applications due to its simplicity, scalability, and flexibility.
OPC Unified Architecture (OPC UA): is a platform-independent, open-standard communication protocol designed for industrial automation and the Industrial Internet of Things (IIoT). Developed by the OPC Foundation, OPC UA aims to provide secure, reliable, and interoperable communication between devices, systems, and applications in industrial environments.
Extensible Messaging and Presence Protocol (XMPP): is an open-source communication protocol based on XML (Extensible Markup Language). Originally known as Jabber, XMPP was developed for real-time communication, including instant messaging, presence information, and multi-party chat. It is widely used in

various applications, including instant messaging services, collaboration tools, IoT, and social networking platforms.

Advanced Message Queuing Protocol (AMQP): is an open-standard messaging protocol designed for reliable, asynchronous communication between applications and services. AMQP enables the exchange of messages between different systems, regardless of the programming language, operating system, or underlying technology stack.

Data Distribution Service (DDS): is a standard for real-time, scalable, and reliable data communication between distributed systems and devices. It is commonly used in complex distributed systems where high performance, low latency, and reliability are critical, such as industrial automation, aerospace, healthcare, and IoT applications.

Network (Transport) Layer is a crucial component of computer networking that facilitates communication between devices across different networks. Its primary function is to route data packets from a source device to a destination device through one or more intermediate network devices, such as routers. The standards and protocols to enable this connection used are:

IP version 6 (IPv6): Internet Protocol version 6, is the most recent version of the Internet Protocol (IP) designed to succeed IPv4. IPv6 was developed to address the limitations of IPv4, particularly to expanded addressing capabilities; header format simplification; improved support for extensions and options; flow labeling capability; authentication and privacy capabilities.

ZigBee: is a wireless communication standard designed for low-power, low-data-rate, and short-range wireless networking applications. It is commonly used in home automation, industrial control, healthcare monitoring, and other Internet of Things (IoT) applications where devices need to communicate wirelessly with each other in a reliable and energy-efficient manner (a low data rate, low-power-consumption, low cost, wireless networking protocol)

Z-Wave: is a wireless communication protocol primarily used for home automation and smart home devices. It operates in the sub-1 GHz frequency range and is designed for low-power, low-data-rate communication between devices within a home or building.

Bluetooth: is a wireless communication technology used for short-range data transmission between electronic devices. It operates in the 2.4 GHz frequency band and is commonly used for connecting devices such as smartphones, tablets, headphones, speakers, keyboards, and smartwatches. In the most widely used mode, transmission power is limited to 2.5 milliwatts, giving it a very short range of up to 10 m (30 feet).

WiFi: short for Wireless Fidelity, is a wireless networking technology that allows electronic devices to connect to a local area network (LAN) wirelessly, typically using the 2.4 GHz or 5 GHz radio frequency bands. It is one of the most used means of accessing the internet in homes, businesses, and public spaces.

4G/Long Term Evolution (LTE): is a mobile telecommunications standard designed to provide high-speed wireless internet access and data transmission for mobile devices. It represents the fourth generation of mobile network technology, succeeding 3G networks.

5G: short for fifth-generation wireless technology, is the latest standard for mobile telecommunications networks. It represents a significant leap forward in wireless technology compared to previous generations like 4G LTE. 5G promises faster data speeds, lower latency, increased capacity, and support for a wide range of connected devices and applications.

LoRAWAN: (Long Range Wide Area Network) is a wireless communication protocol designed for long-range, low-power IoT (Internet of Things) applications. It enables devices to communicate over long distances (several kilometers in urban areas and up to tens of kilometers in rural areas) while consuming minimal power, making it suitable for battery-operated devices with long lifespans.

Low-Power Personal Wireless Area Networks (6LoWPAN): is a networking protocol designed to enable the connection of low-power, low-cost Internet of Things (IoT) devices to the Internet or other IP-based networks. It is specifically optimized for devices with limited resources, such as memory, processing power, and battery life.

Long-term evolution machine (LTE-M): is a low-power, wide-area (LPWA) cellular technology specifically designed for IoT and machine-to-machine (M2M) communication. LTE-M offers a cost-effective and efficient solution for connecting a wide range of IoT devices to cellular networks, providing extended coverage, improved battery life, and support for massive device connectivity.
Narrow Band Iot (NB-IoT): is a LPWA cellular technology designed for efficiently connecting many IoT devices to cellular networks. It operates in licensed spectrum and offers extended coverage, deep penetration, and improved power efficiency compared to traditional cellular technologies.

Qamar et al. conducted a survey involving various experts, including city officials overseeing smart city projects, energy experts from technology companies, and professionals involved in planning or managing buildings and districts utilizing IoT services [6]. According to the findings, survey participants regarded MQTT and HTTP as essential communication protocols for IoT technology. Furthermore, LoRaWAN was identified as the predominant network protocol within IoT middleware by the respondents. **Lastly, experts highlighted demand-side management as the most anticipated application for IoT platforms, indicating a promising trend towards digitalization in energy systems.**

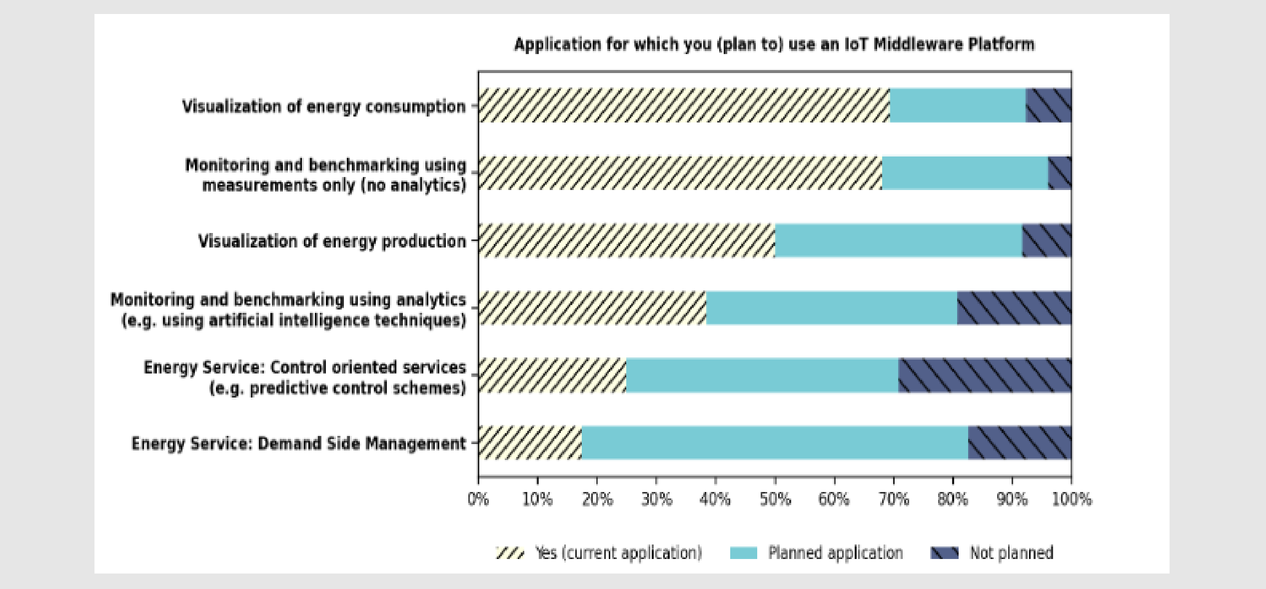

Figure 2: Survey responses detailing applications where IoT middleware is currently utilized or planned for implementation [7].

2.3.3 Smart Devices

An IoT-device or smart devices incorporates digital connectivity and smart capabilities, allowing it to communicate with other devices and systems within an energy infrastructure. Here are some examples of such differences [7]:

“IoT”-enabled smart meters utilize standard Internet protocols like TCP/IP to transmit real-time heating usage data to both utilities and consumers, often equipped with onboard processing capabilities to analyze consumption data locally prior to transmission to utility systems. This functionality enables real-time analytics, anomaly detection, and predictive maintenance, providing insights into energy usage patterns and potential issues. Additionally, they feature advanced security measures to safeguard sensitive consumer data and prevent unauthorized access or tampering. By facilitating coordinated control and automation of energy usage, these meters promote more accurate billing, empower customers to manage their heating consumption effectively, and minimize the necessity for manual meter readings.

“IoT” Balance Valve is a smart valve integrated with IoT technology, designed for balancing and regulating fluid flow in heating, cooling, and plumbing systems. This innovative valve incorporates sensors and connectivity features that allow it to communicate data about flow rates, temperature, pressure, and other relevant parameters to a central control system or cloud-based platform. The valve is equipped with a PT1000 sensor that collect water temperatures of the secondary network and later the data is uploaded to the cloud through NB-IoT, LORA, CAT.1, etc. and receives instructions from the cloud. The cloud-embedded algorithm can perform real-time analysis based on parameters such as water temperatures, flow rates, etc., and send instructions to the valve with more accuracy. IoT balance valves enable remote monitoring and control of fluid flow parameters through web-based or mobile applications. The sensors embedded within IoT balance valves collect valuable data on system performance and operational conditions. This data can be analyzed to identify inefficiencies, predict maintenance needs, optimize energy usage, and improve overall system reliability. Advanced algorithms integrated into these valves can dynamically adjust flow rates and valve settings based on changing environmental conditions, demand fluctuations, or preset optimization goals. This adaptive control capability enhances system efficiency and responsiveness. IoT balance valves can seamlessly integrate with existing BMS platforms, allowing for centralized control and coordination of HVAC (Heating, Ventilation, and Air Conditioning) systems, plumbing networks, and other building infrastructure components.

“IoT” Room temperature collector is a device equipped with IoT technology designed to gather and transmit real-time temperature data from various rooms within a building or facility. This collector typically consists of sensors placed strategically throughout different rooms to monitor and record temperature levels continuously. The collector is equipped with temperature sensors that are strategically placed in different rooms or zones within a building. These sensors may be integrated into the collector device itself or deployed as separate units connected wirelessly. The sensors continuously measure the ambient temperature in their respective locations. The collector aggregates this temperature data from all sensors, creating a comprehensive overview of the temperature distribution throughout the building. Using IoT connectivity protocols such as Wi-Fi, Zigbee, NB-IoT, or Bluetooth, the collector transmits the collected temperature data to a central control system or cloud-based platform. This allows for real-time monitoring and analysis of temperature conditions across multiple rooms simultaneously. Building managers or occupants can remotely access the temperature data collected by the IoT collector using web-based or mobile applications. This enables them to monitor temperature trends, identify deviations from desired setpoints, and take corrective actions if necessary. The IoT temperature collector can integrate seamlessly with existing Building Management Systems (BMS) or Energy Management Systems (EMS). This integration allows for centralized control and coordination of heating, ventilation, and air conditioning (HVAC) systems based on real-time temperature data. The collector can be programmed to send alerts or notifications via email, SMS, or push notifications if temperature levels exceed predefined thresholds or if anomalies are detected. This proactive monitoring helps prevent equipment failures, minimize energy waste, and maintain occupant comfort.

Programmable Logic Controller (PLC) is a specialized computing device used to control industrial processes and machinery in manufacturing, automation, and various other industries. PLCs are designed to withstand harsh industrial environments and operate reliably over extended periods. PLCs interface with sensors, switches, actuators, and other devices through input and output modules. Input modules receive signals from external devices, such as sensors detecting temperature, pressure, or position. Output modules send control signals to actuators, motors, valves, or other equipment to perform specific actions. The CPU is the brain of the PLC, responsible for executing control logic, processing input data, and generating output signals. It performs calculations, executes programmed instructions, and communicates with input/output modules and external devices. PLCs contain various types of memory for storing program instructions, data, and system configuration settings. This includes read-only memory (ROM) for storing the PLC's operating system and user program, random-access memory (RAM) for temporary data storage, and non-volatile memory for retaining data even when power is disconnected. PLCs are programmed using specialized software tools provided by the PLC manufacturer. Programmers use these tools to create, edit, debug, and download control logic programs to the PLC. Programming languages commonly used for PLCs include ladder logic, function block diagrams (FBD), structured text, and instruction list. PLCs feature communication ports or interfaces for connecting to external devices, networks, or supervisory control systems. This allows PLCs to exchange data with human-machine interfaces (HMIs), other PLCs, programmable automation controllers (PACs), supervisory control and data acquisition (SCADA) systems, or enterprise-level systems for data logging, monitoring, and control. PLCs support various operating modes, including run mode for normal operation, program mode for editing or debugging programs, and remote mode for communication with external devices. Some PLCs also feature simulation models for testing control logic without affecting the actual process. PLCs are designed for high reliability and safety in industrial environments. They often incorporate redundant hardware configurations, watchdog timers, error-checking mechanisms, and fail-safe programming techniques to prevent system failures, ensure fault tolerance, and protect personnel and equipment.

3. References

[1] Working Group QM for Biomass DH Plants, *QM Planning Handbook*, 3rd completely revised edition. Straubing: C.A.R.M.E.N. e.V, 2022.

[2] D. Schmidt and International Energy Agency, Eds., *Guidebook for the digitalisation of district heating: transforming heat networks for a sustainable future: final report*. Frankfurt am Main, Germany: AGFW-Project Company, 2023.

[3] M. Tunzi, T. Benakopoulos, Q. Yang, and S. Svendsen, 'Demand side digitalisation: A methodology using heat cost allocators and energy meters to secure low-temperature operations in existing buildings connected to district heating networks', *Energy*, vol. 264, p. 126272, Feb. 2023, doi: 10.1016/j.energy.2022.126272.

[4] M. Tunzi, D. Skaarup Østergaard, and S. Svendsen, 'Development and Test of a Novel Electronic Radiator Thermostat with a Return Temperature Limiting Function', *Energies*, vol. 15, no. 1, p. 367, Jan. 2022, doi: 10.3390/en15010367.

[5] L. Antao, R. Pinto, J. Reis, and G. Goncalves, 'Requirements for Testing and Validating the Industrial Internet of Things', in *2018 IEEE International Conference on Software Testing, Verification and Validation Workshops (ICSTW)*, IEA DHC, Ed., Vasteras: IEEE, Apr. 2018, pp. 110–115. doi: 10.1109/ICSTW.2018.00036.

[6] Q. Alfalouji *et al.*, 'IoT Middleware Platforms for Smart Energy Systems: An Empirical Expert Survey', *Buildings*, vol. 12, no. 5, p. 526, Apr. 2022, doi: 10.3390/buildings12050526.

[7] He Le and Du Yanhui, 'Application and Energy analysis of AI-based digitalization of district heating system', in *The 18th International Symposium on District Heating and Cooling (DHC2023). Conference Proceedings*, Beijing, China, Sep. 2023, pp. 200–207. [Online]. Available: https://www.iea-dhc.org/fileadmin/public_documents/DHC2023_Conference_proceedings_CDHA.pdf