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TÜRKİYE SUSTAINABLE BUILDINGS NETWORK

THE SUSTAINABLE BUILDINGS E-LEARNING PROGRAM

Module **5**

DISTRICT HEATING AND COOLING SYSTEMS

This module was co-funded by the European Union. Its contents are the sole responsibility of WRI Türkiye and do not necessarily reflect the views of the European Union.

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SIFIR ENERJİ ve PASİF EV DERNEĞİ
ZERO ENERGY and PASSIVE HOUSE ASSOCIATION

Danish Green Growth Network

TÜRKİYE SUSTAINABLE BUILDINGS NETWORK

The Türkiye Sustainable Buildings Network was established as part of the "Türkiye Sustainable Buildings Network Project," which is co-funded by the European Union under the Civil Society Action towards European Green Deal Grant Scheme. The project is coordinated by WRI Türkiye, in partnership with the Zero Energy and Passive House Association (SEPEV) and with the support of the Danish Green Growth Network (DGGN).

The network operates with the aim of supporting climate action in the building and construction sector, promoting green transformation, enhancing the technical knowledge and skills of sector stakeholders, and mainstreaming the concept of sustainable buildings.

As part of this effort, the Sustainable Buildings E-Learning Program has been developed to serve as a comprehensive knowledge resource for all stakeholders in the building sector. The program consists of 10 training modules designed to contribute to the sector's sustainability, energy efficiency, and low-carbon transition goals.

Module 1: **Overview of Sustainable Buildings**

Module 2: **Decarbonization in the Building Sector and the Whole Life-Cycle Approach**

Module 3: **Sustainable Building Materials**

Module 4: **Sustainable Construction and Demolition Practices**

Module 5: **District Heating and Cooling Systems**

Module 6: **Innovative Building Technologies**

Module 7: **Financing Instruments for Sustainable Buildings**

Module 8: **Emissions Trading Systems and the Building Sector**

Module 9: **Energy-Efficient and Passive Building Design**

Module 10: **The European Green Deal and the Building Sector**

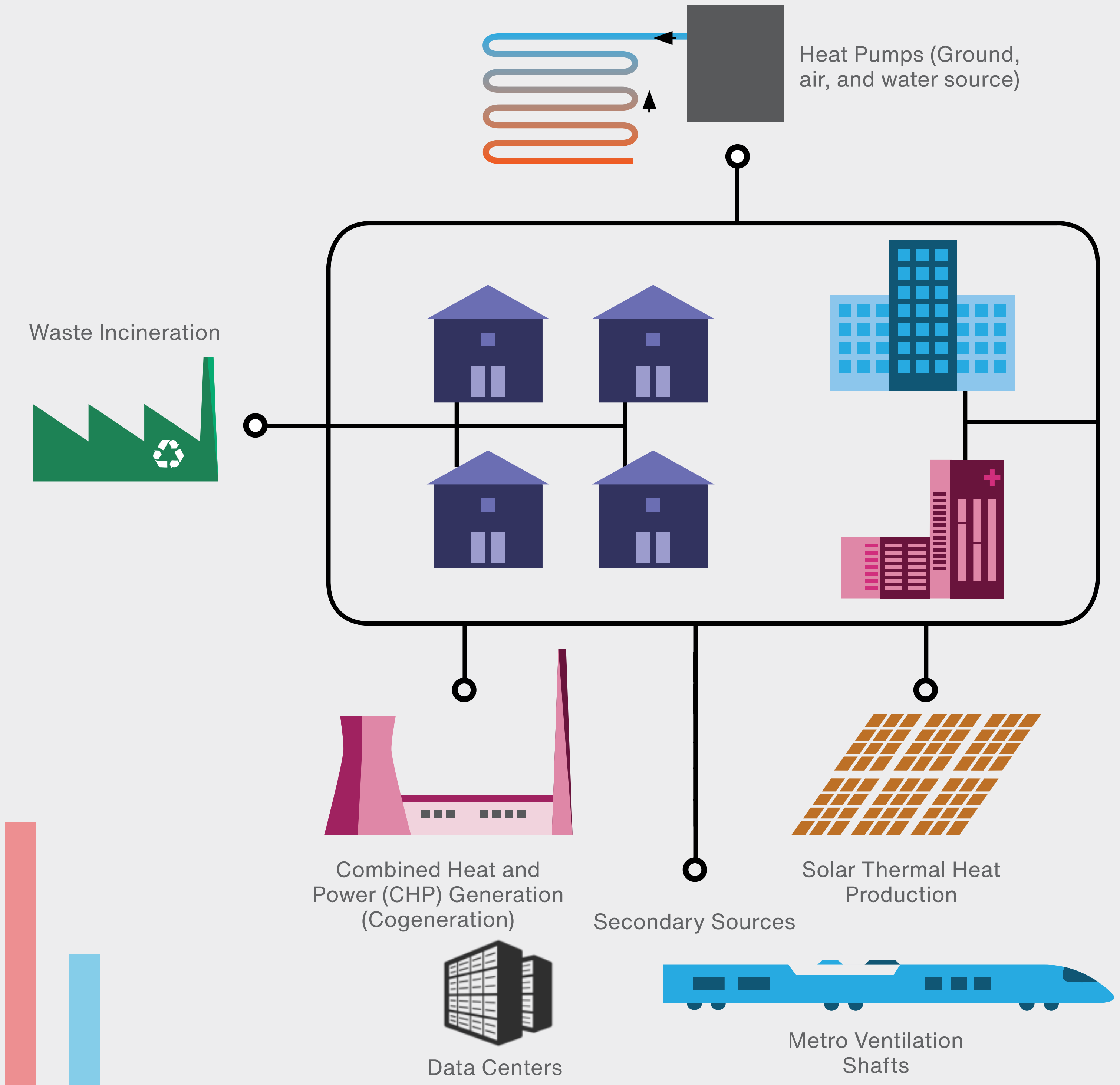
For more information about the Türkiye Sustainable Buildings Network and to access other modules, please visit **the link**.

MODULE OBJECTIVES

The expansion of electric vehicles, the decarbonization of the electricity grid, and adaptation to climate change are driving fundamental changes in the way we produce, distribute, and consume energy. The scale and speed of this transformation necessitate a comprehensive shift in urban energy infrastructure while also creating new economic, social, and environmental opportunities.

This module aims to provide fundamental knowledge on the design, implementation, and management of district heating and cooling systems, which can contribute to the sustainability of urban-scale energy systems. The objectives of the module are as follows:

- Assessing urban-scale district energy system applications by understanding the advantages and limitations of district energy systems.
- Understanding the importance of heat demand management in district energy systems and analyzing the economic, environmental, and technical aspects of planning.
- Identifying the roles of stakeholders such as municipalities, the private sector, and other public institutions and effectively managing collaborations.
- Recognizing innovative technologies used in district energy systems, including thermal energy storage and digitalization, and analyzing their functions.
- Understanding decarbonization strategies for district heating and cooling systems and exploring their implementation areas.
- Learning about investment models, regulatory frameworks, and return-on-investment calculation methods for district energy systems.



Adapted from the ***Five minute guide to Energy in Cities*** *document [1][1]*

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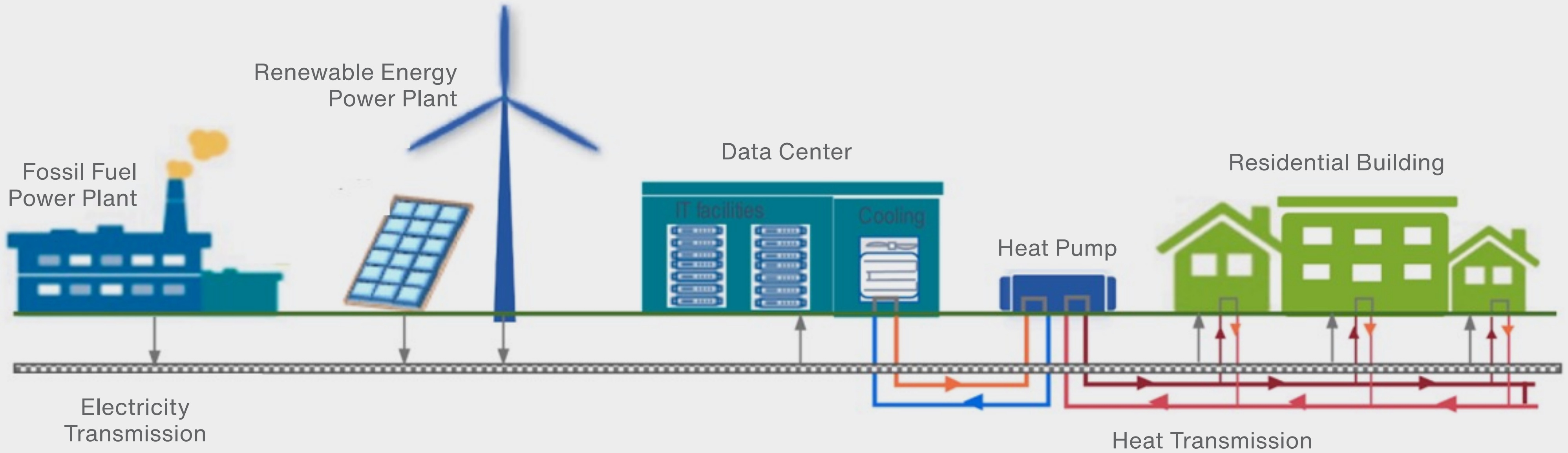
Section **1**

WHAT IS A DISTRICT HEATING AND COOLING SYSTEM?

1.1. Introduction

A district heating and cooling system is an integrated energy distribution system that supplies heating and cooling to multiple buildings or facilities from a centralized energy source. In such a system, hot or cold water or steam is generated at a central production facility and transported to consumers through insulated underground pipelines.

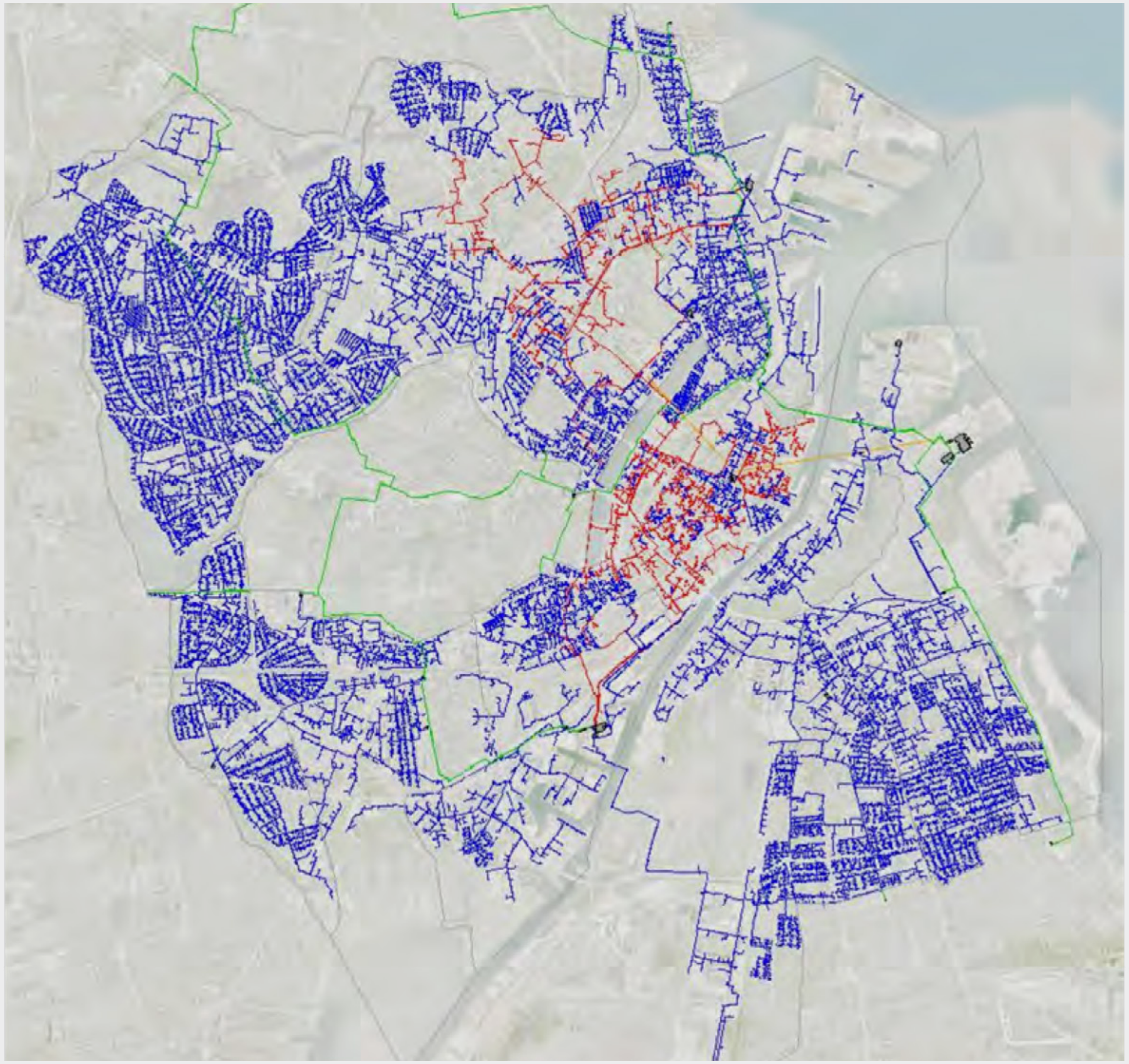
- *District heating and cooling is one of the key solutions for reducing carbon emissions from urban heating and cooling demand by enabling the integrated management of various energy sources through optimized operational strategies.*
- *It creates a strong leverage effect in achieving decarbonization goals by integrating large-scale renewable energy sources such as biomass, geothermal, and solar energy, as well as various waste heat sources, into a centralized distribution network.*



Integration of Data Center Waste Heat into the District Heating System [2]

1.1. Introduction

- *Additionally, it enhances flexibility in electricity markets by balancing fluctuations in renewable electricity generation through solutions like direct electric heating and large-scale heat pumps.*
- *District heating and cooling networks enable integration with national energy grids by connecting heat, electricity, and gas systems through solutions that support energy storage and waste heat utilization strategies.*
- *Urban transformation planning that incorporates a multi-source energy system, considering heating and cooling demand, provides local governments with new opportunities to achieve energy efficiency and decarbonization goals.*
- *In addition to renewable energy sources, various low-grade waste heat sources, such as data centers, can also be integrated into district heating systems*



Copenhagen District Heating Network [3]

1.2. Social Impacts and Benefits

District heating and cooling systems play a key role in the transition to a low-carbon energy system and the development of resilient cities. With their ability to enhance energy security, increase crisis resilience, reduce carbon emissions, and support social benefits, these systems have become a fundamental component of sustainable urban infrastructure. By strengthening cities' ability to withstand current climate change threats, district energy systems also help them become more resilient to future challenges.

Environmental Benefits

- **Reduction of carbon emissions:** Significant reductions in carbon emissions are achieved through the integration of renewable energy sources and the recovery of waste heat. This supports cities in meeting their climate change targets.
- **Energy efficiency and lower primary energy consumption:** By utilizing cogeneration systems and low-temperature heating approaches, primary energy consumption is reduced. The efficient use of waste heat helps prevent energy loss.
- **Improved air quality:** District solutions replace individual building boilers, controlling emissions. This leads to reduced air pollution in urban centers and has positive health impacts.

1.2. Social Impacts and Benefits

Resilient Cities and Energy Security

- **Enhanced energy security:** The use of multiple energy sources ensures diversity in energy supply. Local energy production reduces risks associated with global energy crises.
- **Withstanding harsh weather events:** District energy systems enhance infrastructure reliability by providing uninterrupted energy services even during extreme heatwaves or cold spells.
- **Reliable energy infrastructure during crises:** During natural disasters, critical facilities such as hospitals and water treatment plants receive continuous energy supply. The redundant structure of centralized energy systems ensures resilience against power outages.

Long-Term Planning and Flexibility

- **Flexible and scalable infrastructure:** District systems can easily adapt to innovative technologies and evolving energy demands. This facilitates cities' ability to respond to future energy and climate challenges.

Social Benefits

- **Reducing energy poverty:** Bulk energy purchasing and high efficiency lower heating costs, improving access to energy for low-income households.
- **Community-centered planning:** Local energy cooperatives and community participation are encouraged. This approach enables communities to take a more active role in energy management.
- **Urban space optimization:** Centralized energy production facilities eliminate the need for boilers and chimney systems within buildings, optimizing space usage. This provides greater flexibility in urban planning.

1.3. District Heating and Cooling at the Urban Scale

The global phenomenon of urbanization is driving a dramatic increase in energy demand for heating and cooling. To address this challenge, next-generation district heating and cooling systems, combined with energy-focused urban transformation plans, offer solutions that enhance sustainability and urban resilience. The scale of these systems also allows for the cost-effective implementation of innovative technologies such as thermal energy storage and the Internet of Things (IoT). However, the design of these systems must be carefully considered with the urban context they are intended to serve.

Benefits of energy-focused planning at the urban scale

- **Energy Efficiency and Emission Reduction:** District heating, cogeneration systems, waste heat sources, and the use of renewable energy reduce carbon emissions and improve energy efficiency.
- **Fuel Flexibility for Long-Term Security:** District energy systems can be designed to easily switch between energy sources. This flexibility enhances energy security and provides protection against fluctuations in fuel prices.
- **Change in Planning Approach:** By making citywide planning energy-focused and using methods such as heat demand mapping, it becomes easier to determine which areas would benefit more from district systems and which would be better served by individual solutions.
- **Safe and Easy Maintenance:** Centralized systems, managed with continuous professional oversight, carry less risk compared to individual boilers and offer simpler maintenance processes.
- **Compatibility with Urban Transformation:** In urban transformation projects, if earthquake safety and energy efficiency are considered together, existing building stock can be improved to align with district energy systems.
- **Cost Advantages:** Managing heating demand from a single central point reduces operational, maintenance, and capital costs compared to individual systems.

CopenHill Waste-to-Energy Facility with Ski Slopes and Climbing Walls[4]

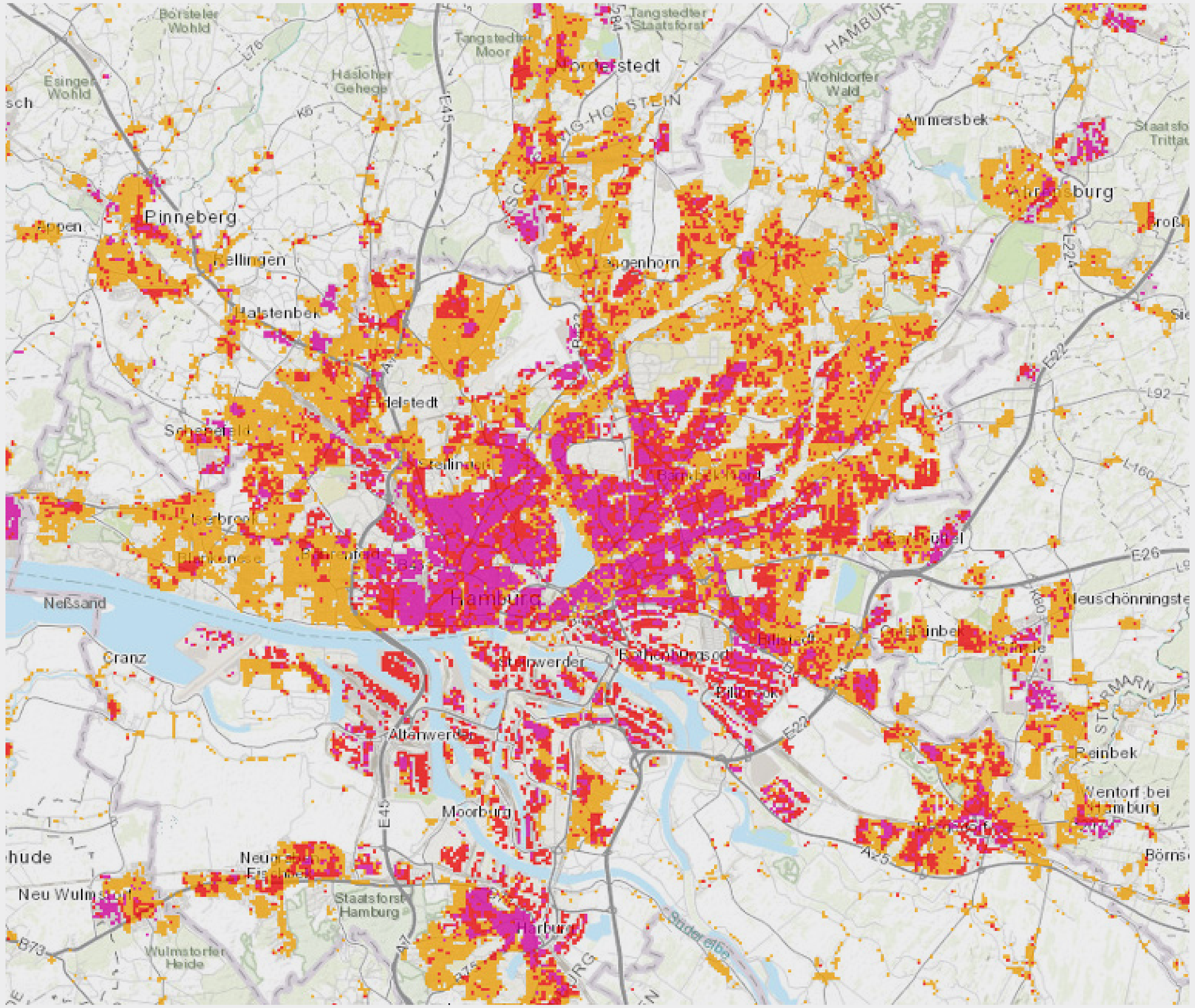
CopenHill, as a waste-to-energy facility, provides energy to 150,000 homes annually through Copenhagen's district heating system, while aiming to reduce carbon emissions, making it a sustainability marvel. Representing an innovative approach to urban planning, the project also inspires an eco-friendly lifestyle by combining recreational activities with industrial infrastructure, featuring a ski slope, walking paths, and climbing walls on its roof.

1.4. Heat Demand-Focused Planning

Heat demand-focused planning, along with tools such as heat demand maps, enables cities to strategically utilize local renewable resources and waste heat, contributing to the development of sustainable and climate-resilient urban areas.

- **Importance for Municipalities and Local Planning:** Municipalities can use heat maps as a planning tool in decision-making processes for the design and implementation of district heating and cooling networks. In several EU countries, heat maps and associated planning are mandatory, and they guide the transition strategies for many cities towards clean energy.
- **Evaluation of Energy Sources and Heat Demand:** By mapping locally available renewable energy and waste heat sources, along with urban heat demand, an initial evaluation can be made regarding the need for district heating or cooling networks. This also includes the selection of technologies to be used. Detailed analyses of local energy sources and demand are essential for conducting an accurate feasibility study. Heat demand maps provide insights into the feasibility of district heating and/or cooling in any area, serving as a starting point for engineering studies..
- ***Pan-European Thermal Atlası (PETA):*** PETA contains details on heating and cooling demand in EU cities, district heating distribution costs, geothermal and biomass potential, waste heat sources, and the feasibility of district heating. Developed by the *Heat Roadmap Europe* project, PETA provides scientific evidence to reduce heating- and cooling-related carbon emissions. According to the project's findings, CO_2 emissions could be reduced by 4.340 million tons, or 86%, compared to 1990 levels using existing technologies.

Heat Demand Density
Residential and services sector (Peta 5.0.1.)



Hamburg Heat Demand Density [5]

1.5. Stakeholder Management

The development of district heating and cooling systems presents significant challenges, especially in regions where individual systems are prevalent, as seen in our country. Such a transformation may face social resistance because it requires individuals to change their daily habits and community-level actions. However, participatory approaches and well-structured stakeholder engagement processes play a critical role in overcoming these challenges.

Effective Stakeholder Engagement

- **Identifying Stakeholders and Setting Priorities:** The planning of district energy systems requires the involvement of a wide range of stakeholder groups, such as local governments, energy providers, building owners, end users, equipment suppliers, planners, designers, construction contractors, financing investors, and regulatory ministries. Stakeholder engagement is not just about communication; this process should be shaped through a two-way dialogue by listening to the stakeholders' views and integrating them into the project. For example, understanding the needs and concerns of target groups when starting a project significantly increases the acceptance rate of the project.
- **Planning and Vision Setting:** Setting a vision for district energy systems can increase communities' commitment to long-term goals. This vision, being both inspiring and feasible, can serve as a source of motivation in challenging processes. Additionally, during technical and economic feasibility studies, stakeholders' concerns regarding energy demand and environmental impacts can be addressed through a participatory energy vision.

Community Engagement

Community engagement plays a critical role in the following areas:

- Ensuring the social acceptance of projects,
- Stimulating local demand for action on climate change,
- Directly involving consumers in low-carbon energy production,
- Ensuring that projects are transparent and accountable,
- Capturing social and economic benefits that may arise at the local level.

Evidence from countries that have implemented district energy system solutions shows that projects are more successful when they go beyond being merely “profit-driven” and adopt a long-term investment perspective. They are also more effective when they develop beneficial relationships with stakeholders who create value for society. In this context, local governments and social enterprises play a natural role in such projects due to their commitment to multiple objectives, such as ensuring energy efficiency, reducing carbon emissions, creating economic benefits, ensuring social participation and justice, and supporting local development.

1.5. Stakeholder Management

DETERMINING COMMUNICATION STRATEGIES

At every stage of the project development process, the right messages must be created, and these messages should be updated throughout the process to align with the goals. The desired outcomes should be the focus at each stage. For example, messages used when energy consumption data is being collected should differ from those used when a contract is being established between parties or stakeholders. To determine the most effective messages, stakeholder feedback should be considered, and messages should be shaped accordingly, taking into account their concerns and motivations.

When determining the project's communication strategy, the following questions should be considered:

- Do stakeholders prefer an innovative approach, or do they want to adopt a proven technology?
- Are stakeholders more sensitive to short-term gains (such as cost advantages), or to long-term sustainability goals?
- Do stakeholders place more importance on viewing district energy systems as a community-based solution or on controlling their own heating systems?
- Is the project more effectively presented as a local initiative or as part of a national strategy?
- Would an approach that highlights a striking structure, such as an energy facility, be more effective, or would communication that presents it as a technical component of a reliable infrastructure be more effective?
- The right individuals should be chosen to deliver messages to the target audience. Messages delivered by trusted and familiar individuals are generally more effective than those communicated by the project manager or sponsor. Therefore, care should be taken to select the right people for effectively conveying the messages. [7]

Continuity and Balance in Stakeholder Communication

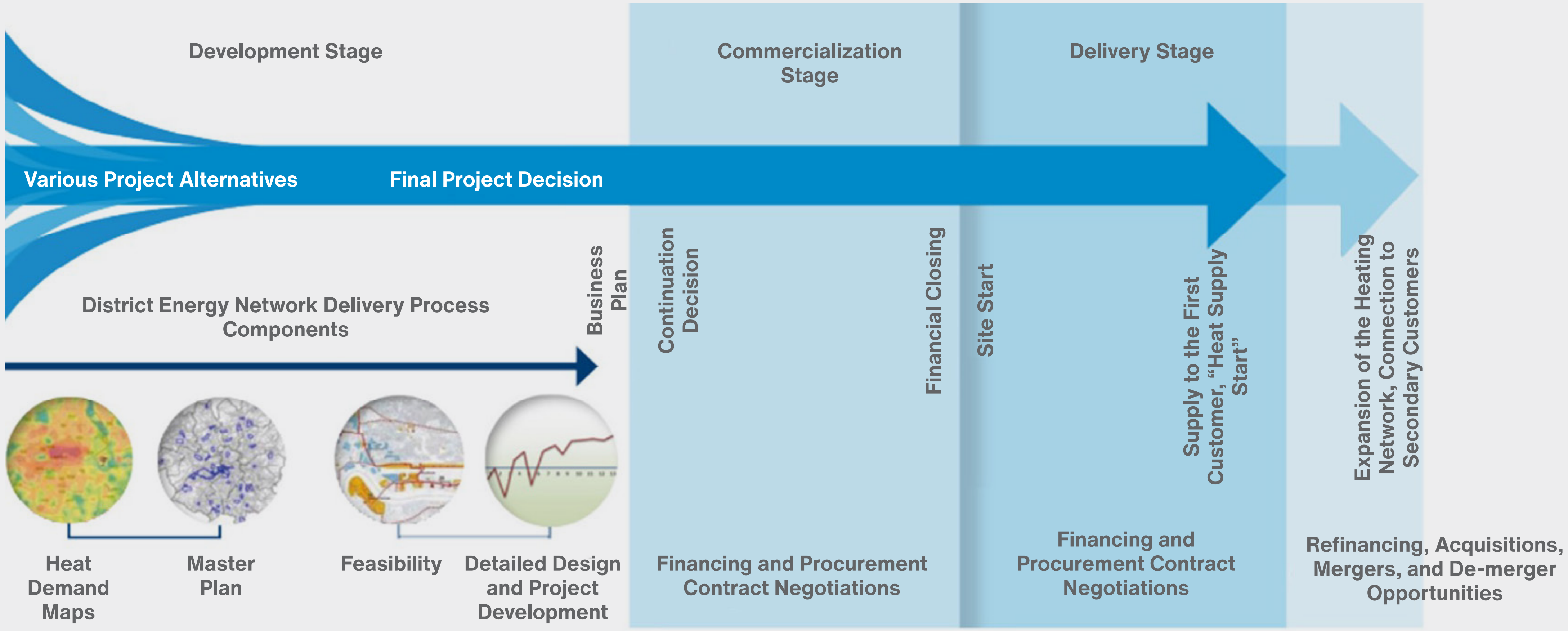
The communication plan should ensure regular and purposeful communication, addressing or balancing long periods of communication gaps (for example, during technical feasibility studies). The plan should aim to prevent stakeholder fatigue caused by excessive communication and the loss of motivation due to prolonged periods of silence. A consistent plan should be developed, and the level of participation, timing, and nature of each stakeholder's involvement should be clearly defined. This information should be communicated to stakeholders, and feedback should be collected regarding the suitability of the proposed activities and timeline.

1.5. Stakeholder Management

STAGES

- **Heat Demand Mapping and Master Plan:** Involving stakeholders in the initial stage is important to minimize potential resistance in the future. In this stage, tools such as heat demand maps should be used to analyze which buildings will be connected to the energy network.
- **Commercialization and Implementation:** To ensure long-term success, appropriate financing mechanisms and business models should be developed. For example, large energy consumers can be involved in the early stages to ensure economic feasibility.

The successful implementation of district energy systems requires the development of an effective strategy in both planning and execution processes. Heat demand mapping provides a clear roadmap for identifying which buildings will be connected to energy networks, establishing the technical foundation of projects. The commercialization and implementation phase, on the other hand, supports long-term success by ensuring economic feasibility through appropriate financing models and partnerships.



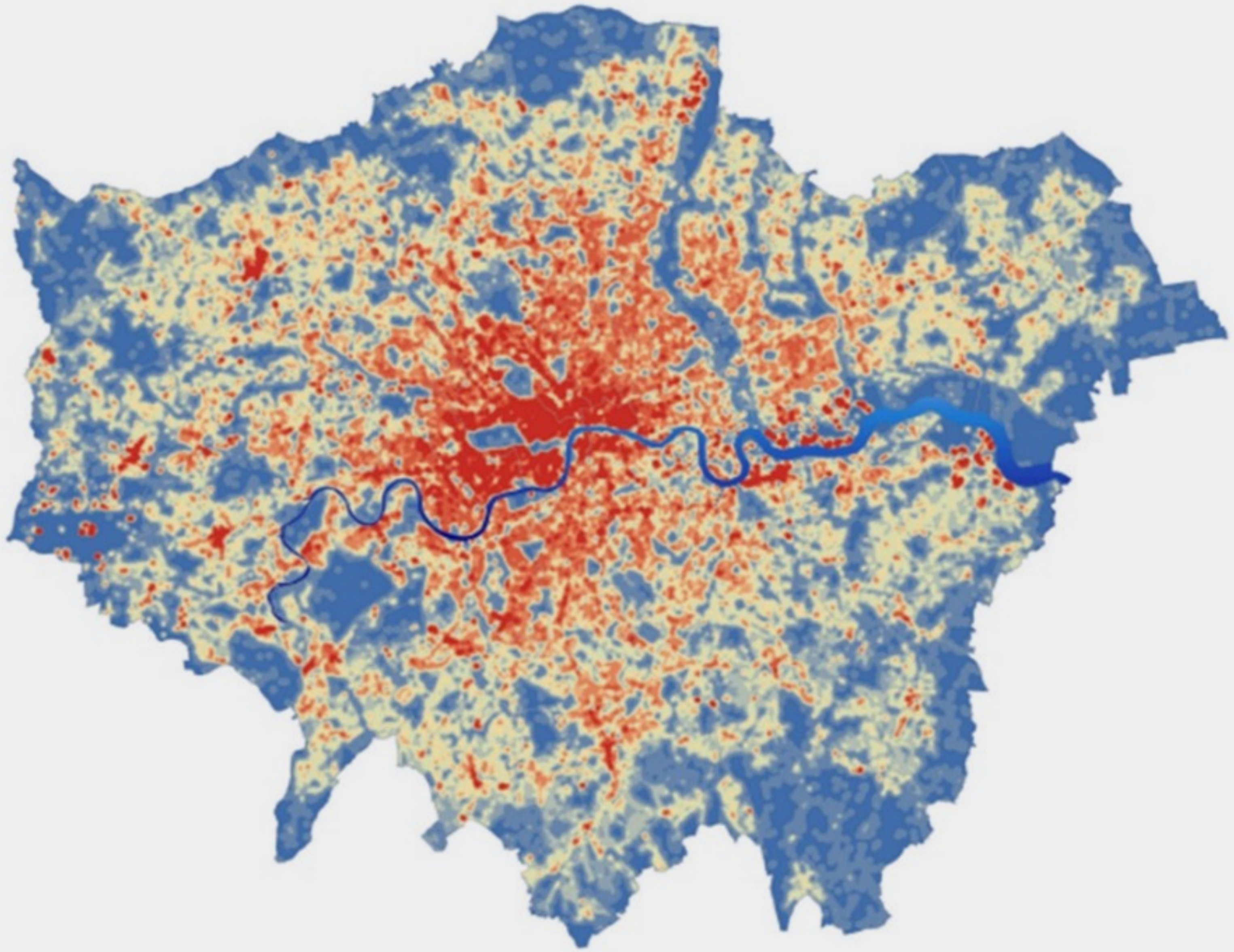
Stages of District Energy Network Development [7]

1.5. Stakeholder Management

BEST PRACTICES AND STRATEGIES

District energy systems are a key tool for reducing the carbon footprint of cities and enhancing energy security. However, the successful implementation of these systems requires addressing both technical and social dimensions simultaneously. The active involvement of stakeholders in the process and the clear communication of the tangible benefits of the projects will increase their sustainability and acceptability.

- **London Plan:** London has emerged as a city that champions a decentralization approach in its energy systems. Ambitious strategies have been developed to reduce the city's carbon emissions and achieve sustainable energy goals. Among these strategies, the role of a dedicated *agency* established to tackle climate change stands out. This agency collaborates with both local authorities and the private sector to support energy projects. In London, significant importance has been placed on communication strategies to ensure active public participation in projects and to raise awareness. Open data policies have been effective not only in informing the public but also in increasing trust in local projects. Furthermore, London's investment in innovative technologies for low-carbon energy solutions and its close cooperation with local communities have reinforced the success of this approach. [8



London District Energy Master Plan Heat Demand Intensity Map [6]

1.5. Stakeholder Management

BEST PRACTICES AND STRATEGIES

- **Denmark Model:** Denmark has achieved significant success in district heating systems by increasing the use of renewable energy. Collaboration with local authorities has both enhanced the effectiveness of planning and encouraged public participation. The use of cooperative models, in particular, has allowed the public to have a say in energy projects and has strengthened the trust environment. In this model, investments in wind energy have not only diversified energy supply but also created an exemplary approach supporting sustainable development. Denmark's success has been driven by transparent communication, the benefits provided to local economies, and policies aligned with environmental goals. For example, through cooperative structures, local people can become shareholders in wind energy projects, thus reducing potential resistance to these projects. [8]

Section **2**

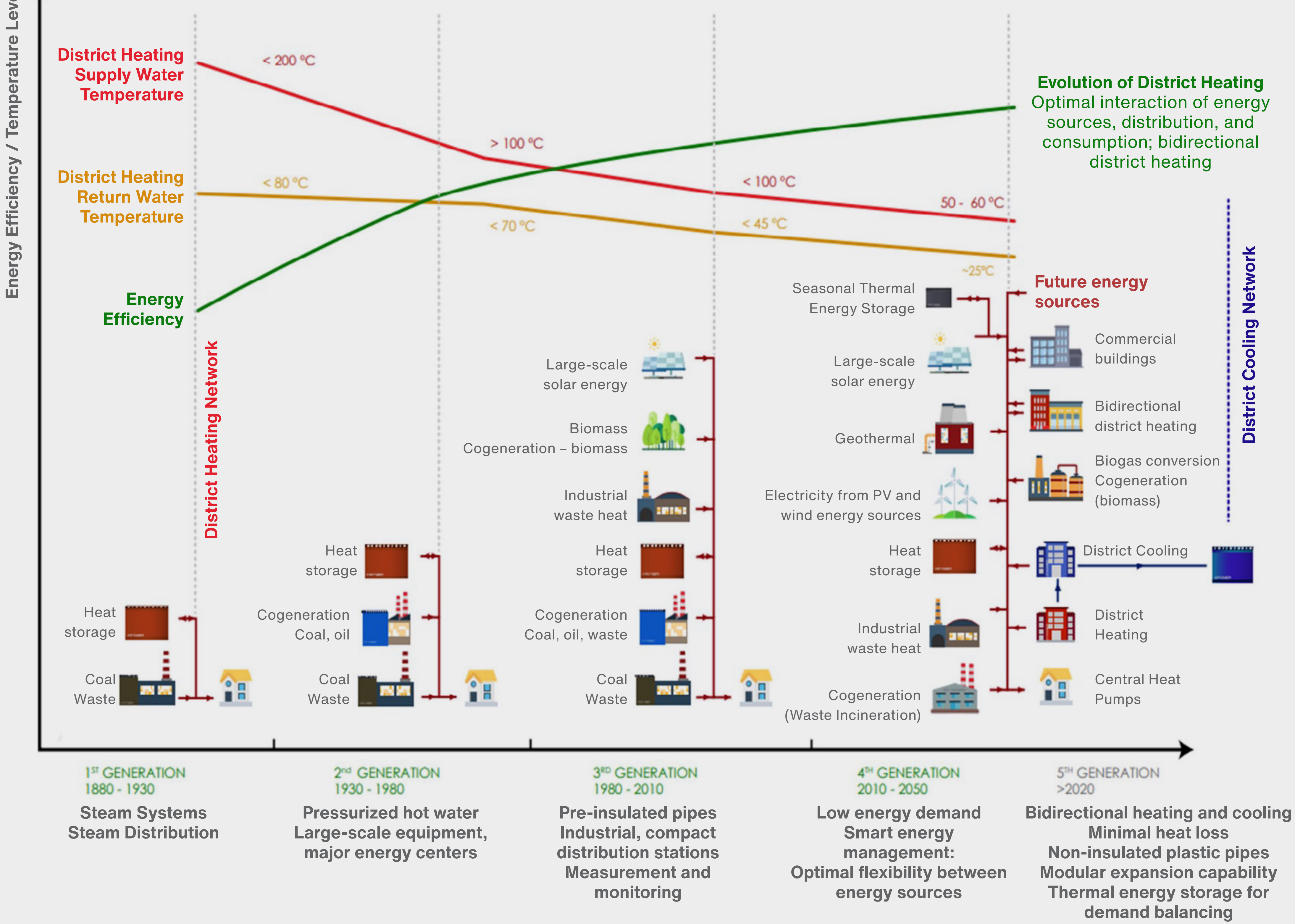
DISTRICT ENERGY SYSTEM TECHNOLOGIES

2.1. Development of Technology

Since their introduction more than a century ago, district heating systems have undergone significant transformation through technological advancements and innovative processes.

- Today, these systems ensure high energy efficiency while incorporating features such as stronger integration with the electricity grid. At the core of these advancements are technologies that enable low-temperature heating and high-temperature cooling.
- Fifth-generation district heating and cooling systems represent the most advanced stage of this transformation. These systems operate at low temperatures, minimizing energy losses, while facilitating the integration of various energy sources—such as waste heat, geothermal energy, and renewable energy—into the network, thereby enhancing energy security.
- By contributing to low-carbon heating and cooling targets, fifth-generation systems not only integrate electricity and thermal networks but also provide greater flexibility to the overall energy system.

Historical Development of District Heating Systems [9,10,11]



2.1. Development of Technology

TYPES OF DISTRICT HEATING NETWORKS

- **Third-Generation Systems:** In third-generation district heating systems, heat is produced at a centrally located energy center and distributed to buildings through a piping network and pumps. The supply water temperature is typically 90–60°C, while the return temperature ranges between 50–40°C. These systems consist of a standard or pre-insulated pipe network and high-capacity thermal energy storage systems. Third-generation networks can also directly supply domestic hot water; however, there is no interaction between buildings, nor is it possible to integrate cooling into the system. [12]

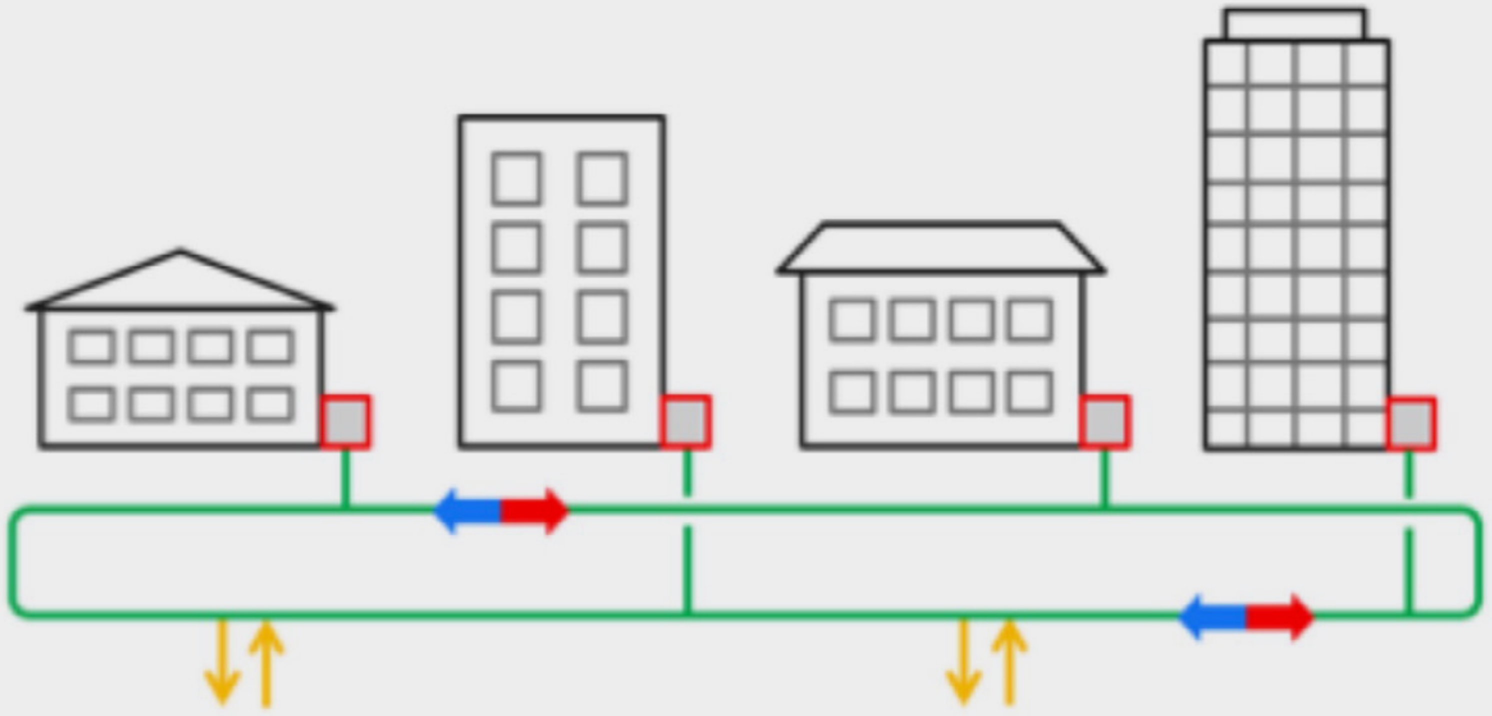
- **Fourth-Generation Systems:** Fourth-generation district heating networks distribute heat from a centralized energy center using a piping network and pumps. These systems are designed to operate with a wider temperature differential (ΔT). The supply water temperature is typically 55–45°C, while the return temperature is around 25–15°C. The pipes used in these systems are mostly made of plastic and are either pre-insulated or insulated on-site. These systems typically include large-capacity thermal energy storage units. To meet the higher temperature demand of domestic hot water systems, an auxiliary heating system is required. If cooling is needed, it is provided by a separate system, and heat exchange between buildings is not possible. [12]

4th Generation District Heating System [12]

Heating and cooling are carried out independently.

2.1. Development of Technology

- **Fifth-Generation Systems:** These systems are built on a non-traditional structure. Heat production is typically carried out in a decentralized manner at various centers, and heating demand is met through a distribution network that operates at very low temperatures (for small-scale systems, a pipe network operating at ambient temperature may also be possible). The supply water temperature in the district heating network is below 45°C, and the ΔT (temperature difference) is less significant, with return temperatures generally ranging between 25–15°C.Fifth-generation systems typically consist of non-insulated plastic pipes. Since the system operates near ambient temperature, heat losses are very low, allowing for longer pipe networks. These solutions may also include seasonal and sometimes short-term thermal energy storage systems to balance the main network's temperature. Due to their low operating temperature, fifth-generation systems always require additional support systems to meet domestic hot water demands. These systems include an integrated cooling system, and heat exchange between buildings is possible. [12]



5th Generation District Heating System [12]

Heating and cooling are carried out together.

5TH GENERATION DISTRICT HEATING AND COOLING SYSTEMS

Fifth-generation district heating and cooling systems maximize energy efficiency while minimizing carbon emissions through low-temperature operation, cyclical energy flow, and the integration of heat pumps. Waste heat from energy-intensive sources such as data centers, industrial facilities, and commercial buildings is recovered through heat pumps and shared with other components of the system. This cyclical structure minimizes energy losses, enabling future energy demand to be met in a sustainable, flexible, and efficient manner.

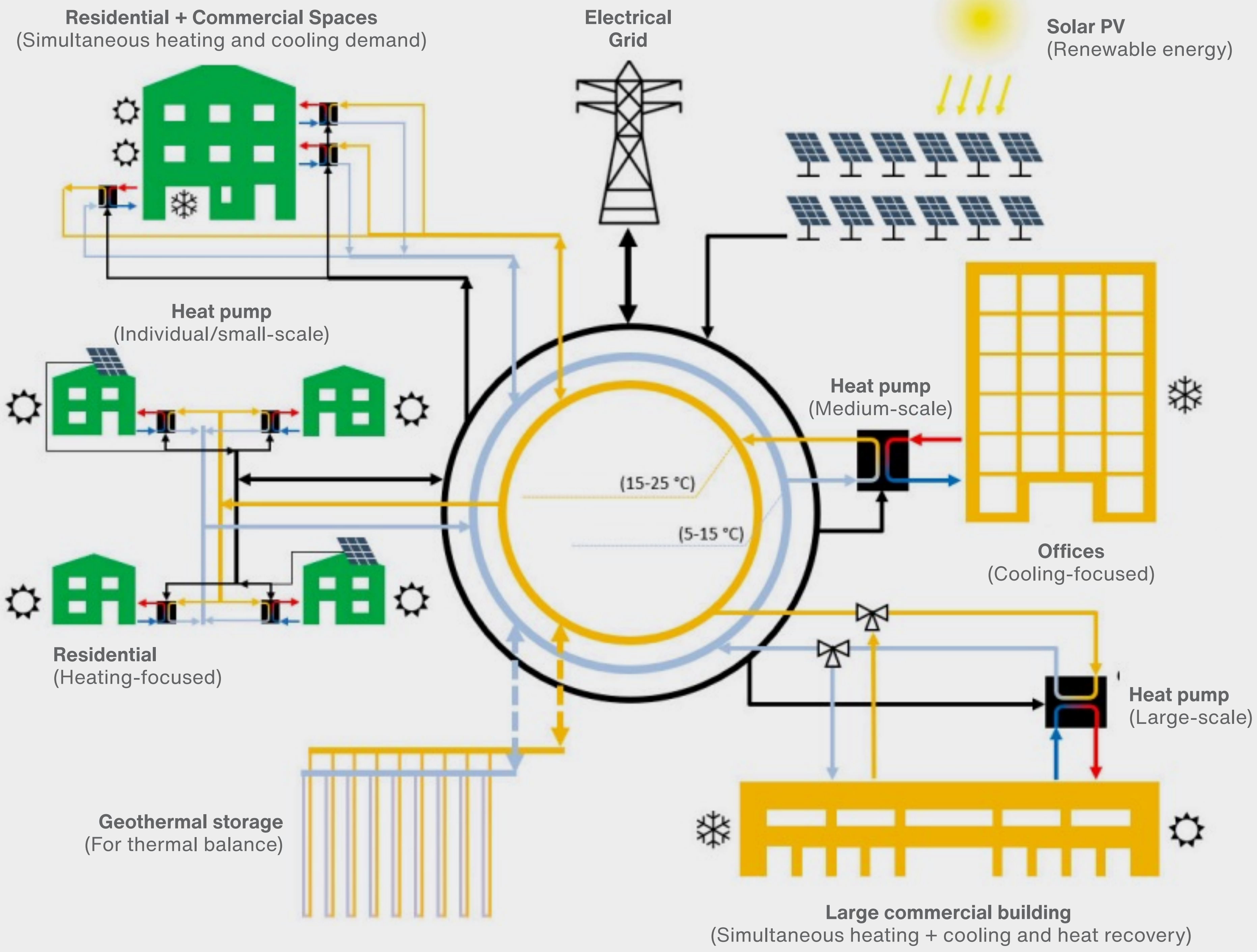
Circularity: The Core Dynamics of 5th Generation Systems

- Fifth-generation district heating and cooling systems are based on the principle of cyclical energy flow and the use of local energy resources. Circularity refers to the dynamic, two-way transfer of energy, rather than its one-way movement. This allows waste heat to be reused within the system to meet the needs of other buildings or processes. This structure is especially important for integrating waste heat sources and optimizing energy demand.

2.1. Development of Technology

Key examples of the system's operation include:

- **Data centers:** They produce significant amounts of low-temperature waste heat due to high energy consumption. In fifth-generation systems, this energy can be used for heating homes or providing hot water.
- **Industrial facilities:** Waste heat generated from production processes is integrated into the system to provide energy for local residences and commercial buildings.
- **Shops and offices:** Balanced heating and cooling needs throughout the year enhance the system's efficiency by maintaining thermal equilibrium in energy sharing.
- **Storage systems:** To balance seasonal and instantaneous energy fluctuations, hot and cold water tanks are used to store energy, which can be reintroduced into the system when needed.

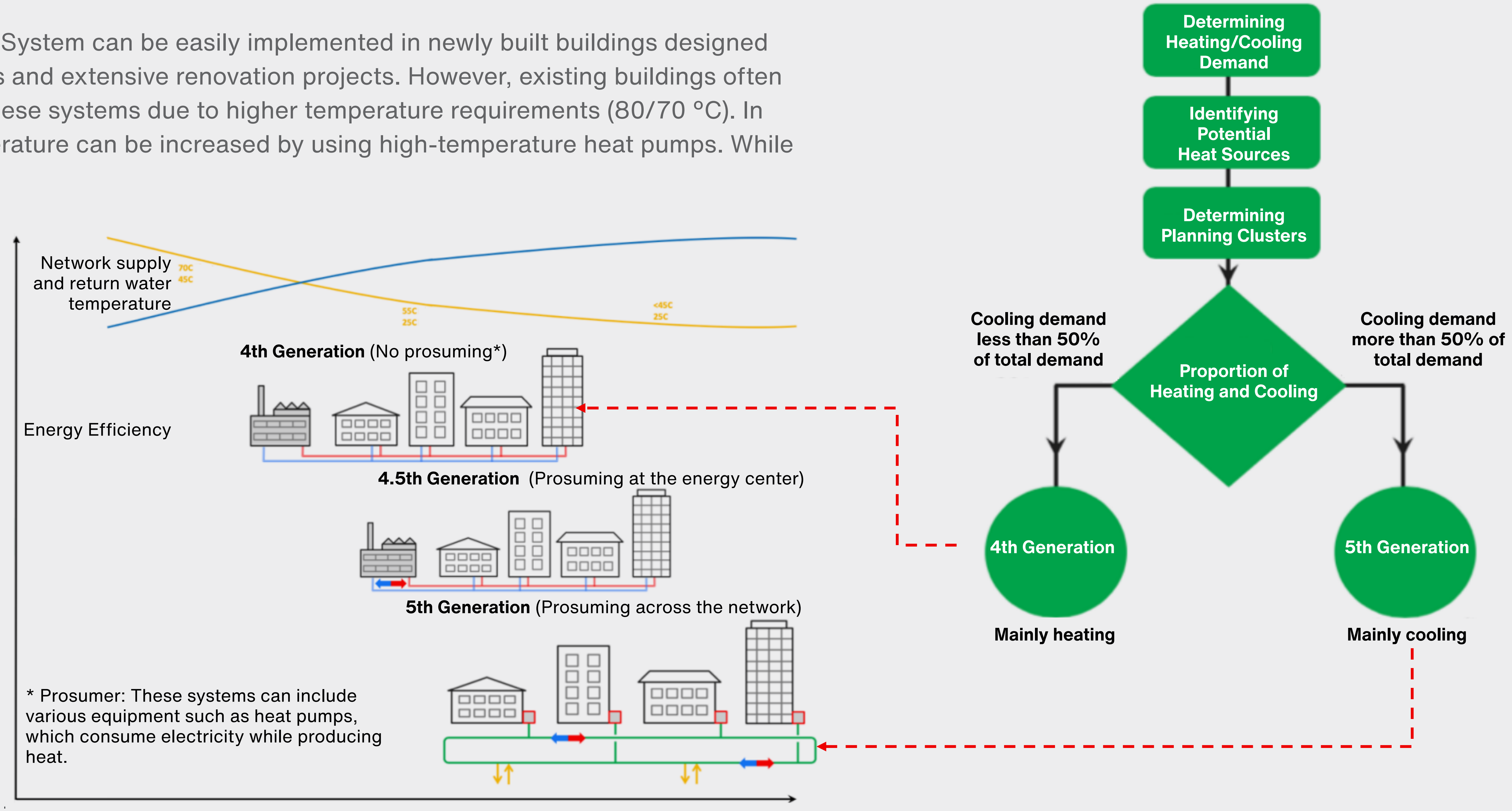


Cyclical Representation of the Fifth-Generation System[13,14]

2.1. Development of Technology

DETERMINING THE NETWORK TYPE

The 4th Generation District Heating System can be easily implemented in newly built buildings designed for low-temperature heating systems and extensive renovation projects. However, existing buildings often pose challenges for implementing these systems due to higher temperature requirements (80/70 °C). In such buildings, the feedwater temperature can be increased by using high-temperature heat pumps. While 4th Generation systems offer a suitable solution mainly for areas with heating needs, 5th Generation systems can simultaneously meet both heating and cooling demands. This allows for the use of low-temperature waste heat sources over a wide range, creating various heat recovery opportunities. 5th Generation systems require different approaches in heat mapping and feasibility studies.



Network Type Selection Diagram [12]

2.1. Development of Technology

LOW-TEMPERATURE HEATING AND HIGH-TEMPERATURE COOLING

Traditional district heating systems were designed based on the principle of meeting heating demand by carrying hot water or steam at temperatures of 100°C or higher. However, these systems have high energy losses and low efficiency. Today, these systems are being designed based on the principle of low-temperature heating.

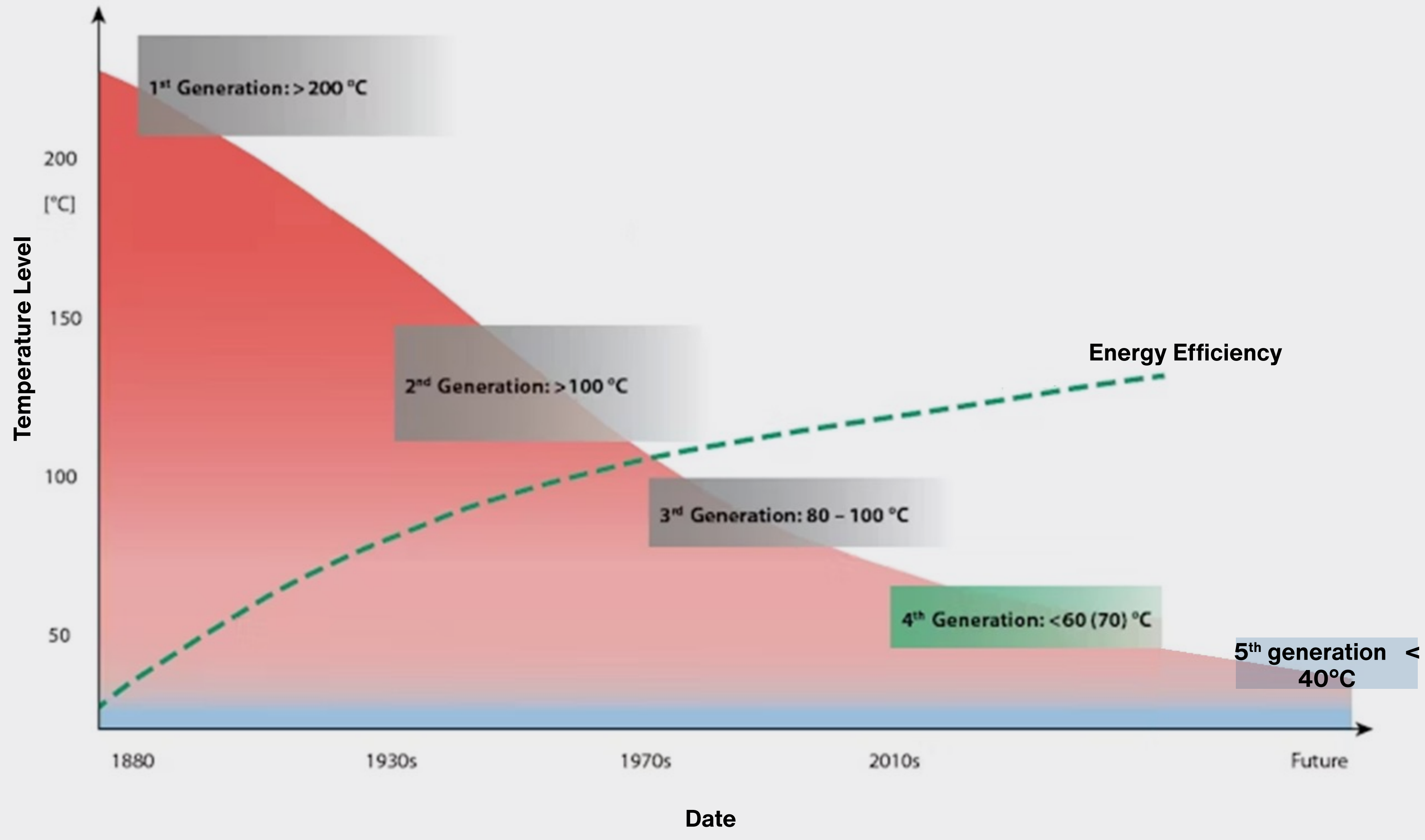
Low-Temperature Heating Systems

Low-temperature heating systems provide solutions where water is transported at temperatures between 30°C and 55°C, minimizing energy losses and meeting comfort standards for well-insulated buildings. This principle is a central component of fifth-generation district heating and cooling systems, and even next-generation systems aim to implement district heating solutions that operate close to the ambient temperature.

Role of Heat Pumps

Heat pumps play a critical role in ensuring the cyclical flow of energy in fifth-generation district heating and cooling systems. They elevate energy from low-temperature sources to higher temperatures, making it usable, while simultaneously meeting cooling needs and providing a bidirectional energy flow.

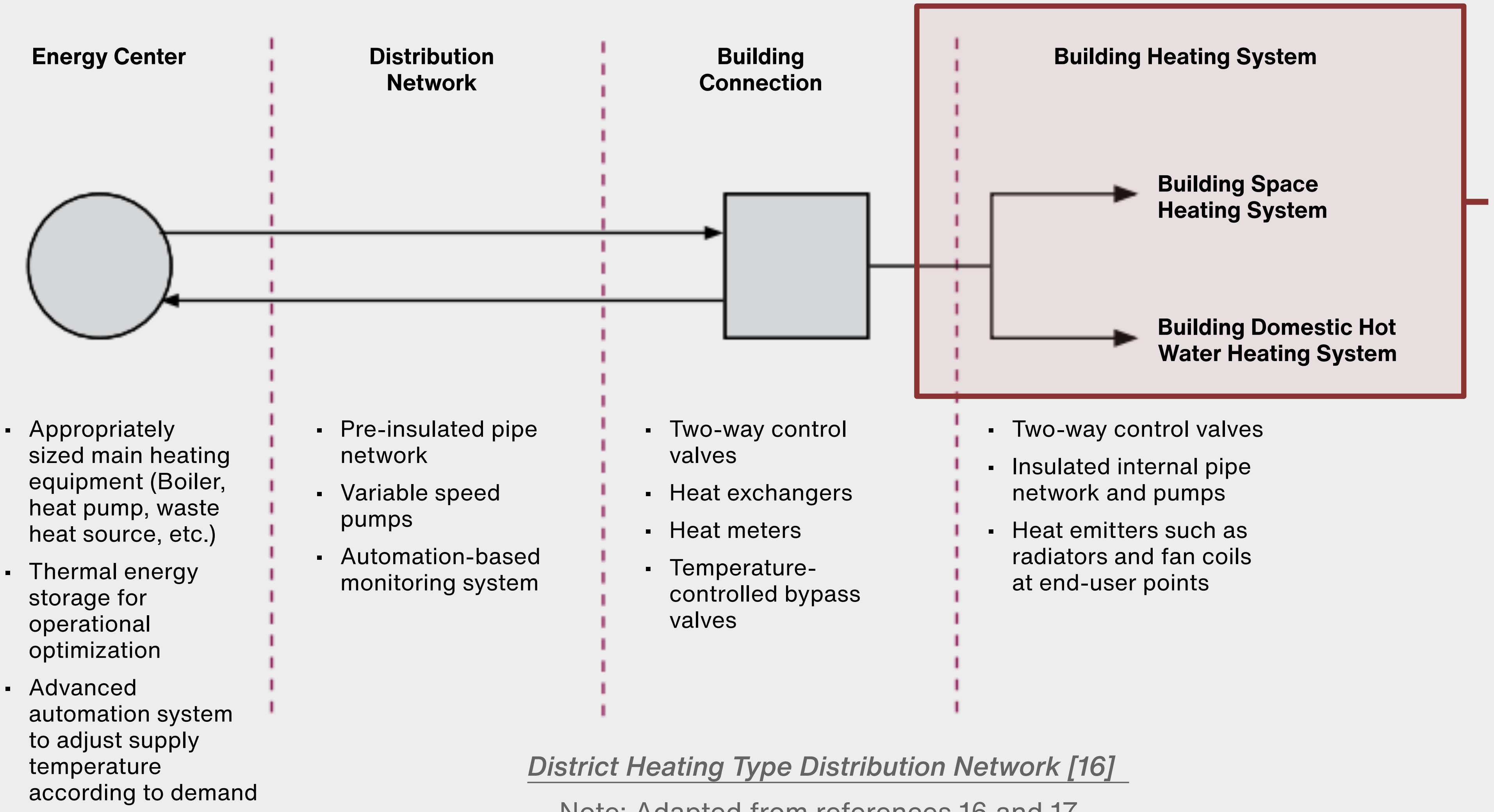
- **Waste Heat Recovery:** Low-temperature waste heat from data centers, industrial facilities, or commercial buildings can be raised to higher temperatures with the help of heat pumps and used to meet the heating demand of residential or office buildings.
- **Bidirectional Operation:** Heat pumps provide cooling during the summer months while recovering excess heat generated during the cooling process and reintegrating it into the system. This energy can be used for hot water needs or other heating requirements.



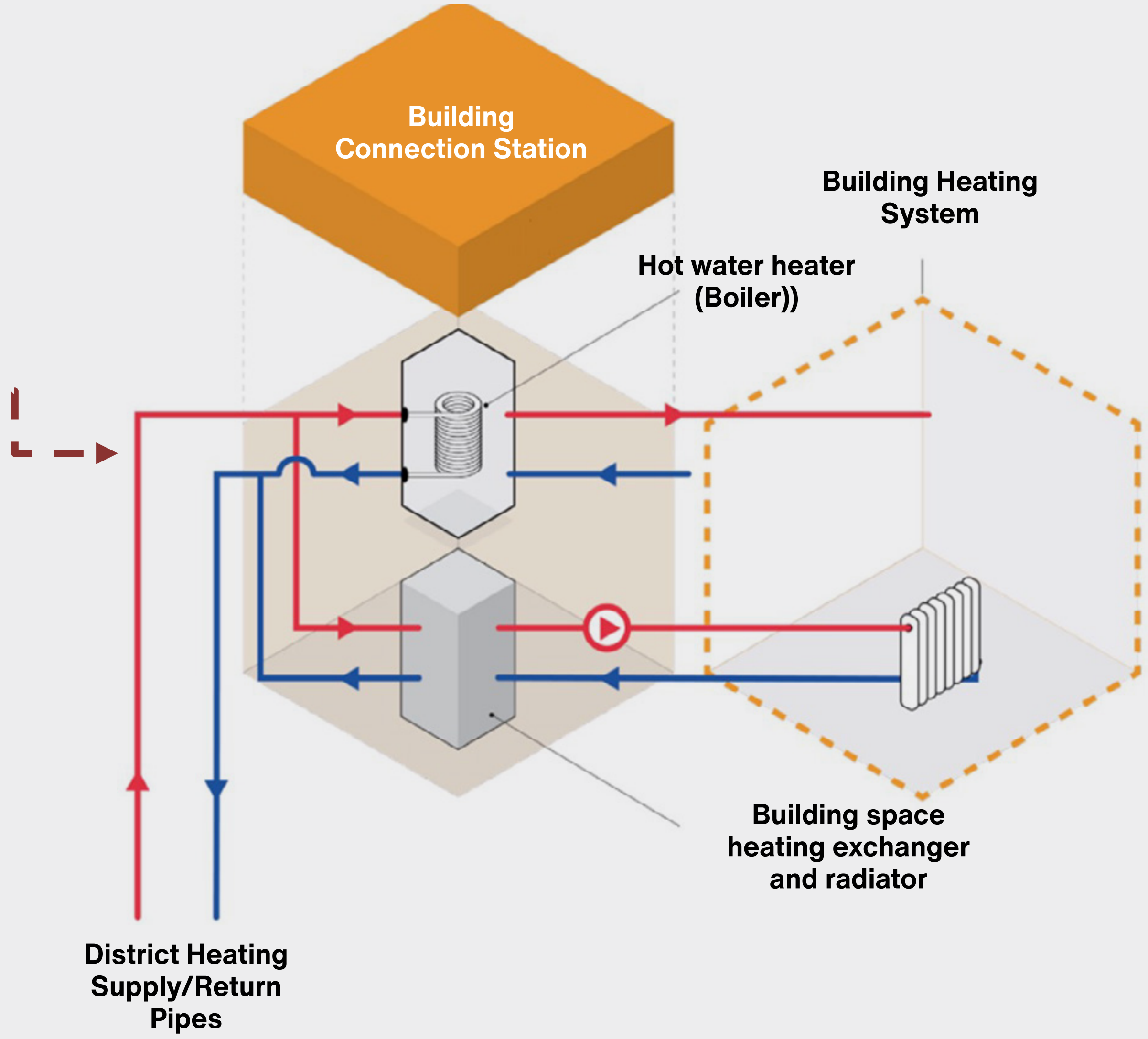
Temperature Variation in District Heating Systems [15]

2.2. System Components

Considering their basic functions, a district heating and cooling system consists of four main parts: the energy center where heating or cooling takes place, the pre-insulated pipe network through which energy is distributed to end-users, pumps, thermal energy storage volumes, and the end-use points.



District Heating Type Distribution Network [16]



Typical Building Connection Interface [17]

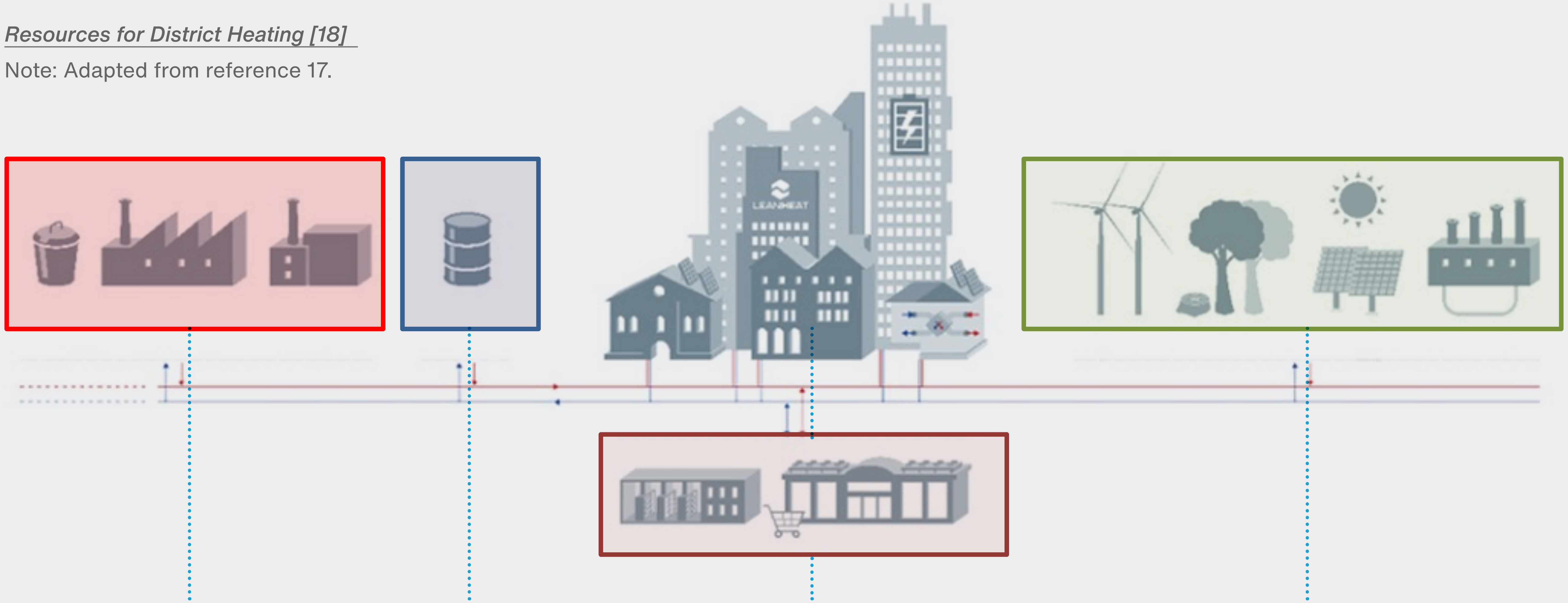
Note: Adapted from references 16 and 17.

2.3. Resources for District Heating

New generation district heating systems are designed to utilize low-temperature heating principles, incorporating a variety of low-temperature waste heat sources such as traditional heating systems, data centers, metro ventilation shafts, and more.

Resources for District Heating [18]

Note: Adapted from reference 17.



High-Grade Heat Sources

- Waste incineration technologies
- Industrial waste heat
- Cogeneration technologies

Thermal Energy Storage

- Storing energy for later use
- Applicable in various scales, from residential use to entire districts

Low-Grade Waste Heat Sources

- Data centers
- Supermarkets
- Metro ventilation shafts
- Sewage systems

Renewable Energy

- Wind
- Biomass
- Solar energy
- Geothermal

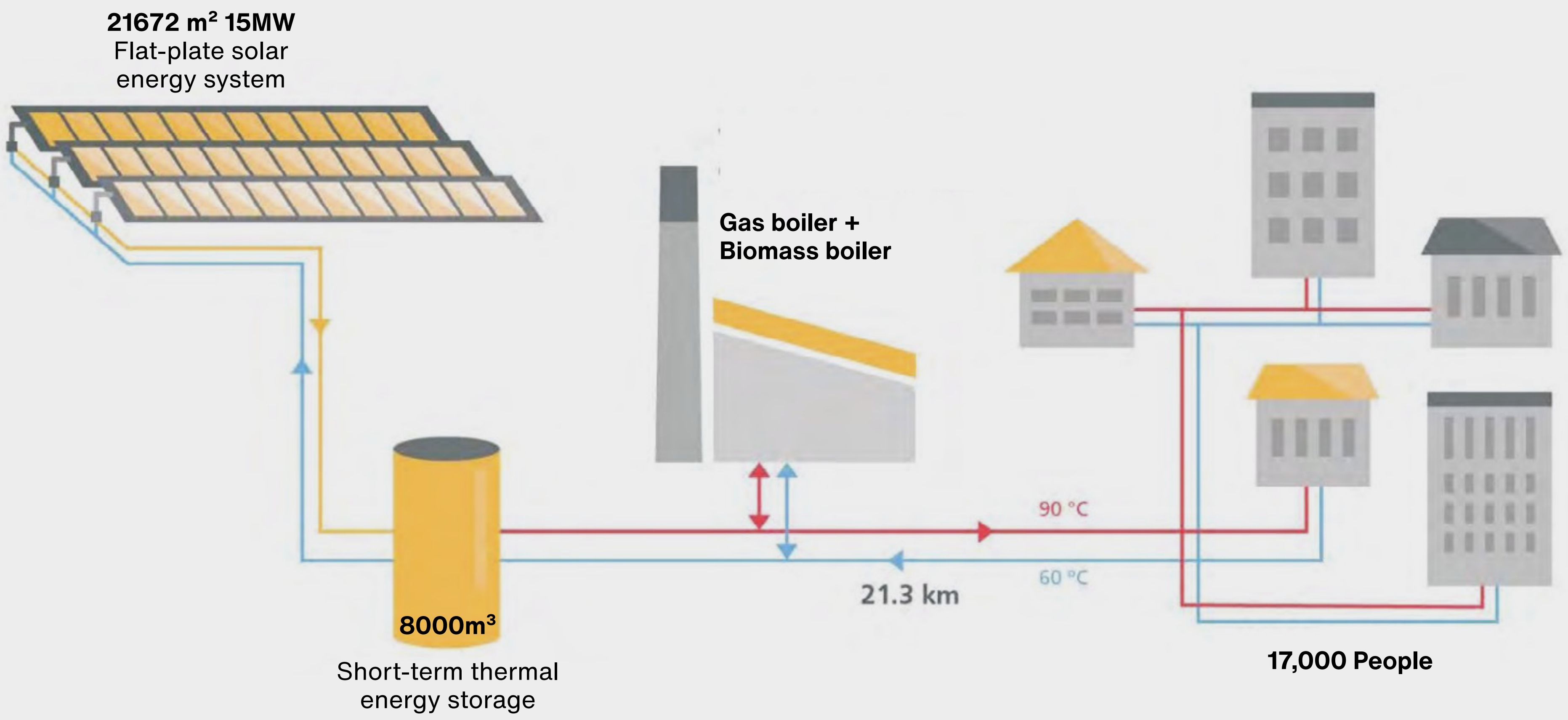
2.4. District Heating Technologies

Biomass/Biogas:

Biomass and biogas systems generate energy from renewable organic materials. Bioenergy can be produced from four main categories of raw materials: energy crops, agricultural residues, forest products, and other organic waste. The most commonly used biomass type for heat production is wood in the form of chips or pellets. To ensure sustainable energy production, biomass must primarily be sourced from waste processes or obtained locally through sustainable production methods. The use of non-waste biomass sources requires the guarantee of a carbon-neutral supply chain and a detailed environmental impact assessment.

Geothermal

Geothermal energy sources can be classified based on the drilling depth into shallow (<400 m) and deep geothermal (>400 m). Shallow geothermal systems are generally a good source for heat pumps. The main advantage of deep geothermal systems is the direct use of heat from a high-temperature aquifer. High-temperature systems are typically used for electricity generation, while low-temperature systems are used for heating, either directly or with the support of heat pumps. Geothermal energy-related emissions are very low or negligible compared to any fossil fuel technology. Most of these emissions result from the release of gases, such as methane, naturally found in geothermal fluids or trapped in rocks, during operation. Although geothermal energy usage carries a risk of gas leakage, many modern facilities today operate with closed-loop systems, well casing protections, and processes that minimize discharges.



Salapis 90% Renewable Energy District Heating System [19]

2.4. District Heating Technologies

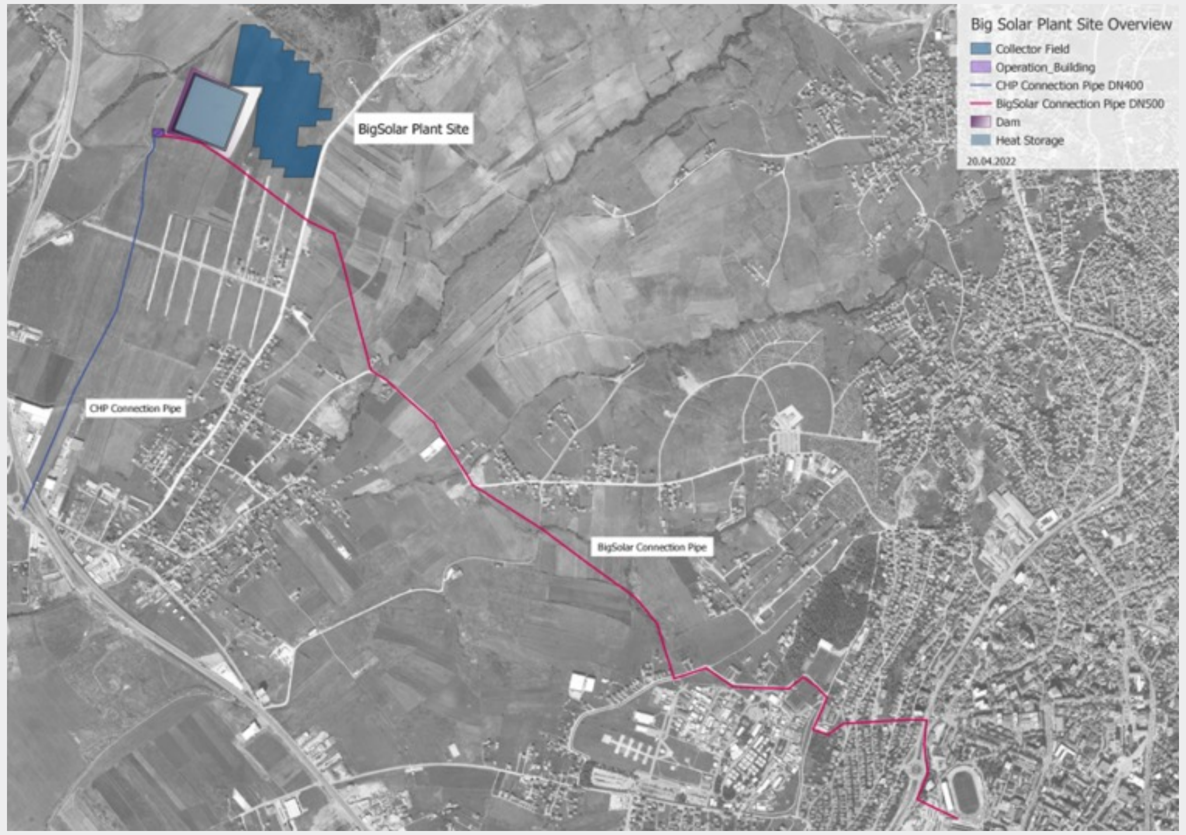
Solar Energy

Solar energy technologies can be scaled from decentralized micro-solutions to large-scale systems for heating applications. Depending on the operating temperature, different solar collector technologies are available, such as flat plate, vacuum tube, double-coated, and vacuum flat plate collectors. Since the seasonal output of these systems is variable, district heating networks involving solar energy are often integrated with other energy sources or seasonal storage systems. Storage technologies enable the heat generated by solar energy to be transferred from the summer months, when heating demand is low, to the winter season. Architecturally integrated solar energy solutions allow production points to be distributed within the system to where demand exists. Photovoltaic systems can also be operated integrated with district heating systems through direct electric heating or heat pumps.

Salapis District Heating Plant

Heat Pumps

Heat pumps are machines that extract energy from a low-temperature heat source (ambient air, water, soil, waste heat, etc.) to provide heating. This technology requires energy input to raise renewable thermal energy to usable temperature levels. Although heat pumps can reach high temperatures, their efficiency is higher when operated at lower temperatures. Heat pumps typically use an electrically driven compressor cycle to extract heat from a low-temperature energy source. These devices, when integrated with renewable energy sources, offer significant potential for decarbonizing heating systems.



Pristina District Heating Rehabilitation Project [19]

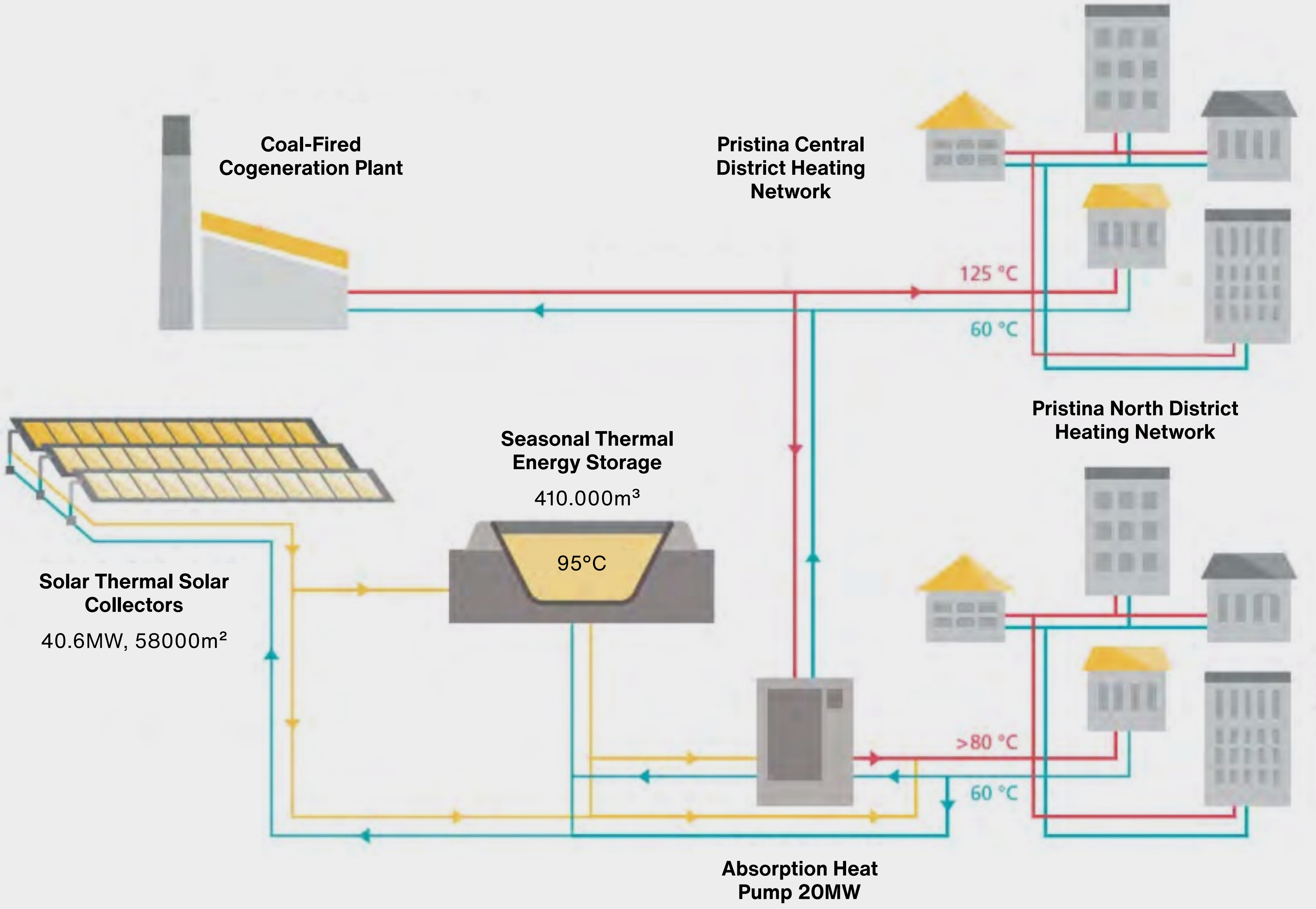
2.4. District Heating Technologies

District Heating Boilers

Traditional high-capacity boilers are one of the key technologies used since the first-generation district heating systems. In new-generation systems, boilers can still be used to meet the base load with locally sourced biomass-derived fuels. Traditional boilers are still operated with fossil fuels as part of some existing systems, but integrated solutions, such as the addition of heat pumps, renewable energy-supported thermal storage, or biomass boilers, are being implemented to reduce the total emissions of these systems.

Cogeneration

Combined heat and power (CHP) or cogeneration refers to the simultaneous production of electricity and heat. Conventional electricity generators (e.g., gas turbines or internal combustion engines) can produce electricity with an efficiency of 30-40%, but when waste heat from the engine or turbine is directly utilized, the primary energy input can be evaluated at an efficiency rate of 70-90%. The waste heat generated in these systems can be directed to a nearby district heating network, where it can be used to meet heating and electricity demands, often in combination with thermal energy storage or renewable energy sources.



2.5. Decarbonization of Heating

Heat Pumps and Electrification of Heating

Although heat pump technology is an old and long-established technology, its importance has increased in parallel with the rising share of renewable energy in the electricity grid. A heat pump is a thermal machine that extracts heat from a low-temperature environment and transfers it to a higher-temperature environment. To facilitate this thermodynamic cycle, a heat pump must consume energy, usually in the form of electricity. Operating heat pumps with electricity generated from renewable sources enables the decarbonization of heating processes.

The efficiency of heat pumps depends on the temperature difference between the low-temperature heat source and the target temperature. Since many heat pumps can operate in reverse, they can also provide cooling. When integrated with city-scale thermal energy storage and the electricity grid, heat pumps can absorb fluctuations in renewable energy production, offering an alternative storage strategy to electric batteries. In this way, heat pumps contribute to grid balancing, providing flexibility on a weekly or even seasonal scale.

Heat Pump Configurations

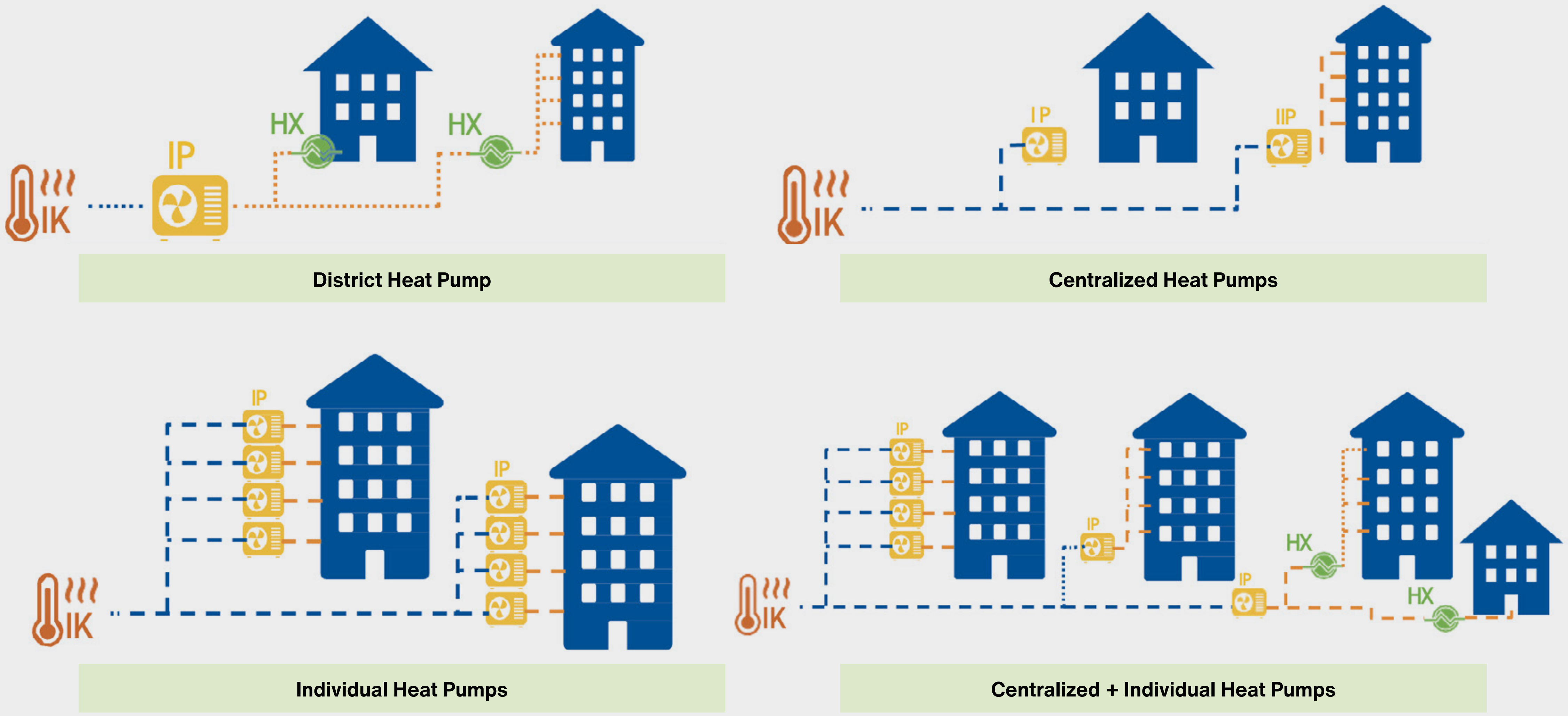
Since the temperature levels of district heating networks and the heating requirements of buildings vary, various configurations have been developed for heat pump-supported heating networks.

- **District Heat Pumps:** The simplest configuration follows a conventional approach, consisting of a central heat pump and heat exchangers in different buildings.
- **Centralized Heat Pumps:** Another approach involves distributing heat at a low temperature within the district network while increasing the supply water temperature in buildings that require higher temperatures through building-specific heat pumps. The advantages of this method include allowing different buildings to operate within a wider temperature range and reducing heat losses in the pipe network. However, compared to fully centralized district heating systems, the investment costs of decentralized (building-specific) systems are higher. On the other hand, this configuration enables cooling within the same system.
- **Individual Heat Pumps:** In this solution, water circulates at a low temperature within the district heating network, while individual users have their own heat pumps to increase the supply water temperature. This configuration further reduces thermal losses within the building; however, it comes with higher investment costs and reduces the operational advantages of centralized management. Nonetheless, cooling is a standard feature of this system.

2.5. Decarbonization of Heating

Advantages of district heating systems powered by heat pumps

- Reduction of heat losses through low-temperature heating.
- Provision of alternative strategies for utilizing waste heat.
- Decarbonization of heating and reduction of fossil fuel consumption in parallel with the increasing share of renewable energy in the electricity grid.
- Improvement of local air quality.
- Enhancement of renewable energy utilization by offering alternative solutions to electric batteries.

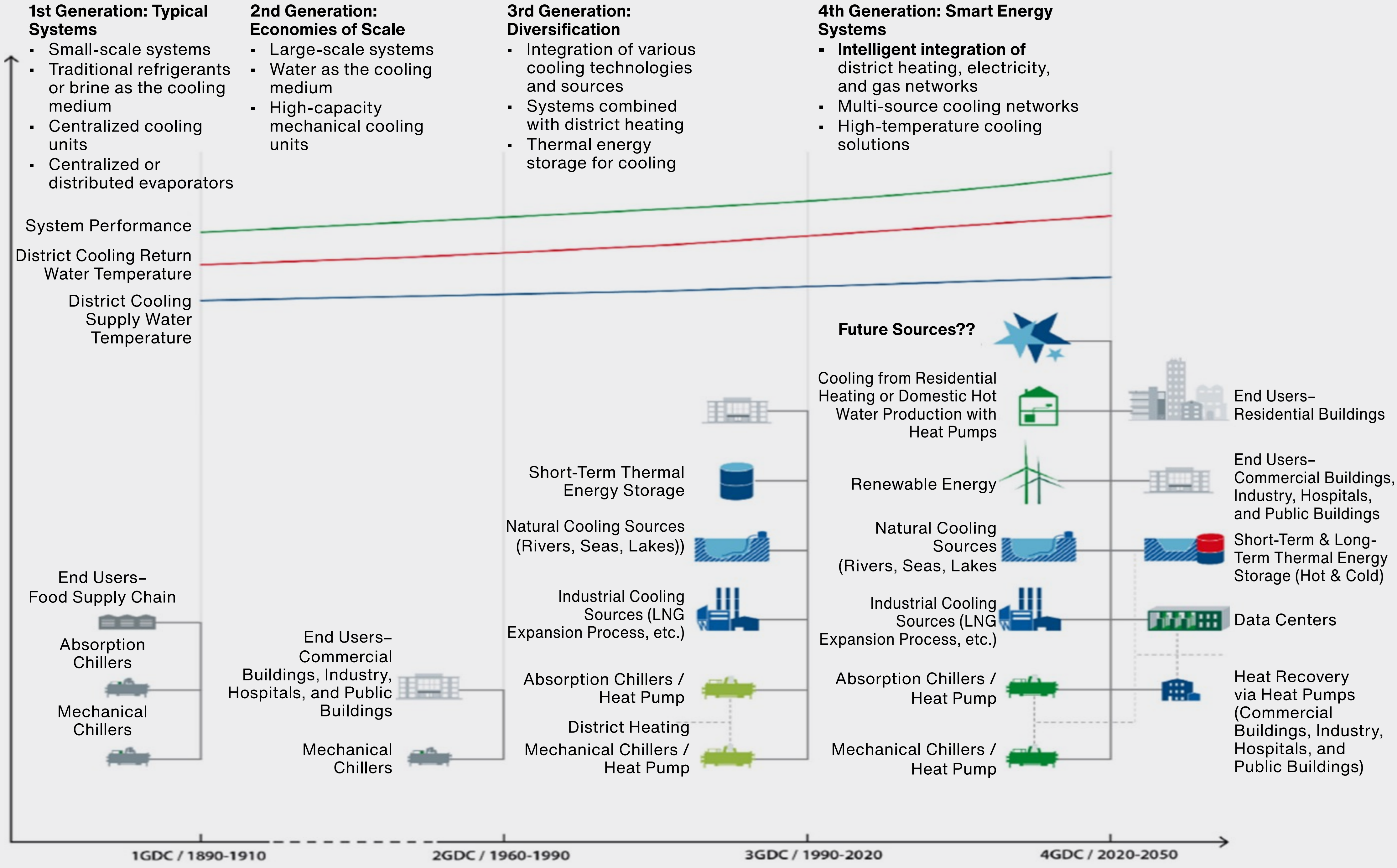


Heat Pump-Based District Heating [20]

2.6. District Cooling Technologies

District cooling systems can achieve up to twice the efficiency of traditional individual air conditioning systems. These systems reduce peak energy consumption, especially during periods of high cooling demand, by integrating thermal energy storage. Cooling sources can include electric chillers, reversible heat pumps, solar energy, geothermal energy or waste heat-driven absorption chillers, and natural cooling technologies.

- **Energy Efficiency:** Cooling is provided through centralized, high-efficiency, large-scale equipment.
- **Low Carbon Emissions:** By utilizing renewable energy sources, waste heat, and more efficient cooling technologies, the carbon footprint can be significantly reduced.
- **Economic Savings:** Compared to individual cooling solutions, district cooling reduces maintenance, operational, and energy costs, making it a more cost-effective option.
- **Space Efficiency:** As individual cooling units are no longer needed, more usable space is created within buildings. Roofs, basements, or other technical rooms can be freed from equipment, enabling alternative uses such as green roof applications.
- **Flexibility and Scalability:** District cooling systems can be easily expanded to meet growing demand or to accommodate new users.



Historical Development of District Cooling Systems[[21]

2.7. Distribution & Storage Technologies

Distribution

The distribution network of district heating and cooling (DHC) systems consists of pre-insulated pipe networks, pumps, control valves, heat exchangers, meters, and measurement points, as well as building connection stations. The design of the distribution network may vary depending on local requirements. The distribution network, or pre-insulated pipe system, represents the most costly component of district heating and cooling systems. *The initial investment in the transmission and distribution system typically accounts for 50% to 75% of the total cost of a district heating or cooling system.* Due to the high initial costs of distribution systems, optimizing pipeline design and usage is of great importance. The increasing adoption of low-temperature heating and high-temperature cooling, the wider use of pre-insulated pipes, and the implementation of leak detection technologies have significantly reduced heat losses and improved efficiency in heat distribution.

Factory-assembled pre-insulated pipes
© Logstor

District heating building connection station
© Danfoss

Storage

Thermal energy storage technologies play a critical role in modern district heating and cooling (DHC) systems. These technologies help bridge the gap between heat demand and production, particularly due to the intermittency of heat generation sources (e.g., solar energy) and fluctuations in thermal energy costs throughout the day. In general, thermal energy storage systems contribute to a more stable and efficient heat production process while also facilitating the integration of variable renewable energy sources into the energy system. These technologies can be classified based on storage duration as either short-term (daily) or long-term (seasonal) storage. Short-term storage (e.g., water tanks) is used to meet daily energy demands. Seasonal storage is designed for long-term needs and includes applications such as earth probes, tank/pit storage, and aquifer storage.

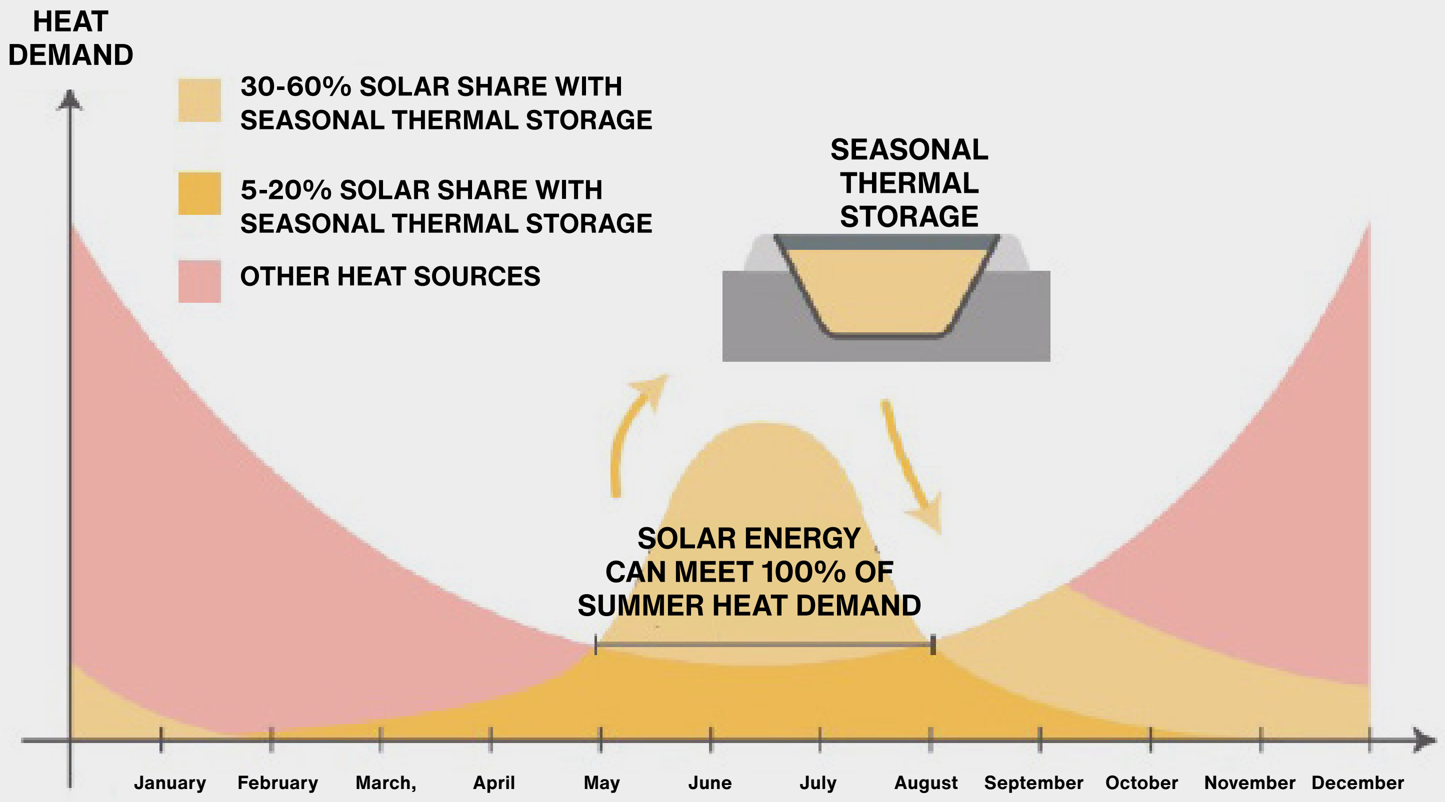
Seasonal thermal energy storage pit
© Solmax

Seasonal storage fit construction
© Arcon-Sunmark

2.7. Distribution & Storage Technologies

How Seasonal Storage Works?

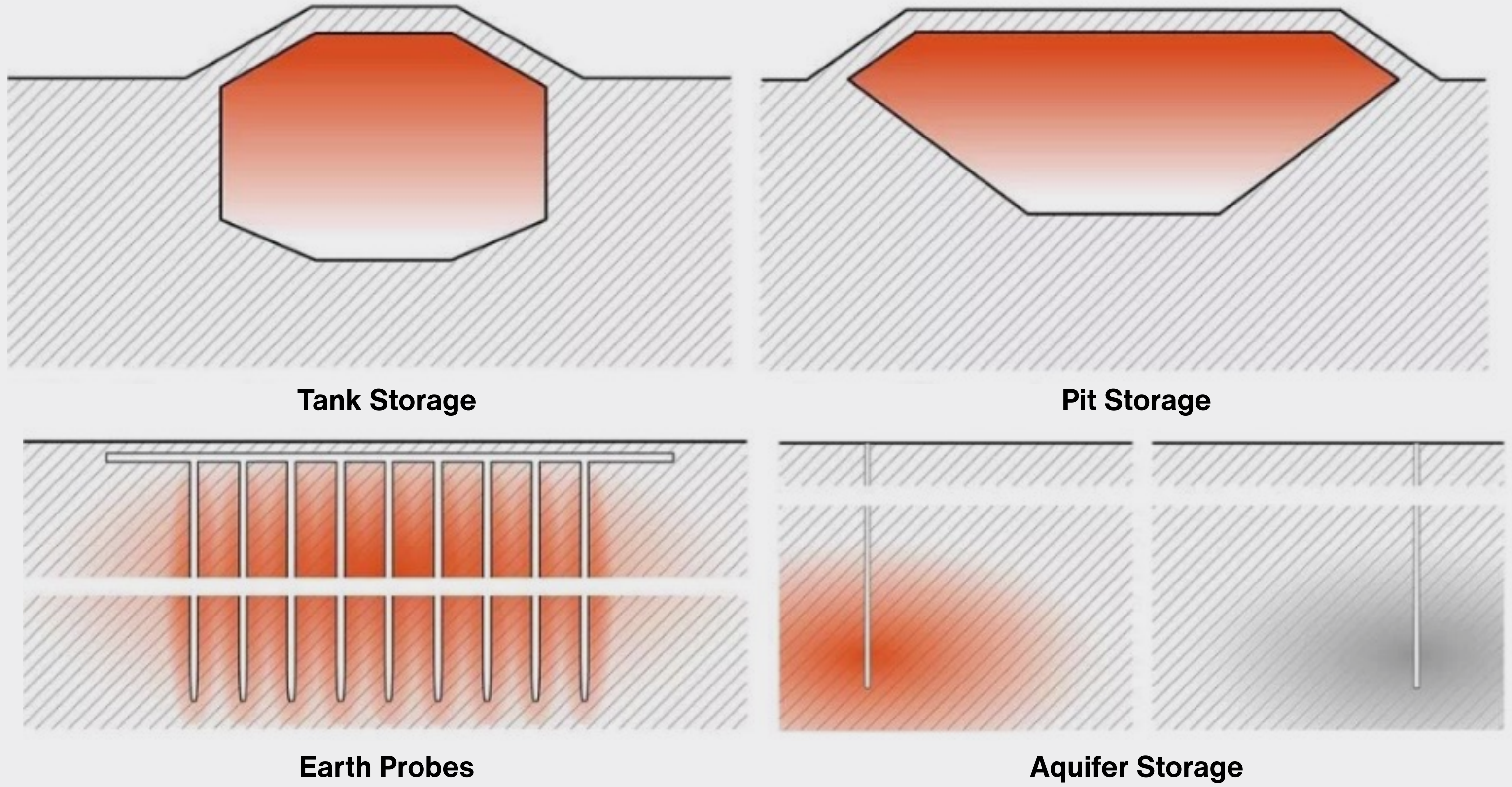
Seasonal thermal energy storage enables the excess heat produced by solar energy during the summer months to be stored for use in the winter. The graph demonstrates that the increased heat demand in winter can be significantly met by the solar energy stored in the summer. During June, July, and August, solar energy production can fully meet heating needs, with any excess being stored in seasonal storage systems. This energy is then used in the winter, reducing dependence on fossil fuels and providing a more environmentally friendly heating method. As a result, energy costs decrease, and carbon emissions are significantly reduced.



Seasonal Storage Capacity Distribution

Seasonal Storage Options

The methods used for storing thermal energy vary depending on design and application needs. Tank-type storage typically involves storing heat energy in a closed tank, either above or below ground, with a highly insulated structure. Pit-type storage has a more expansive open design and is often implemented by digging into the ground. Earth probe is a method that uses numerous deep drilling wells to store energy and preserves heat within underground geological layers. Aquifer type storage, on the other hand, aims to store energy using underground water-bearing layers, offering a large-scale energy storage capacity. These methods provide flexible solutions tailored to energy storage needs.



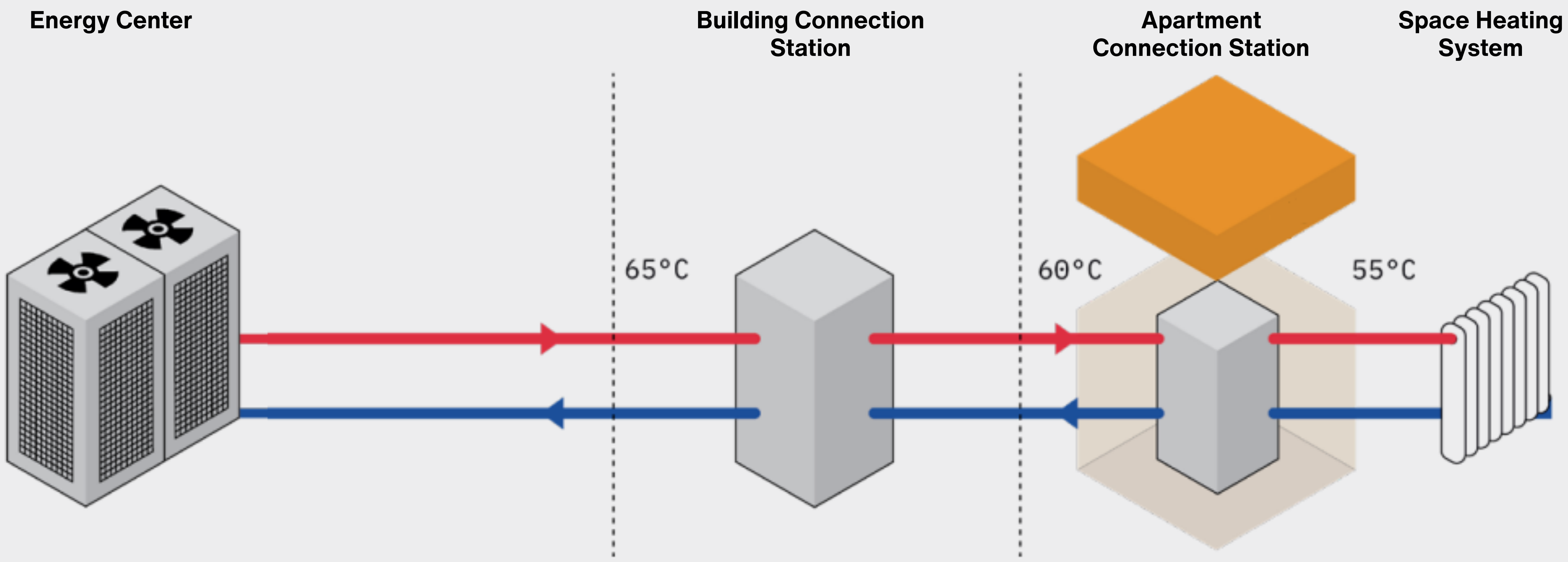
Seasonal Storage Options © gigaTES

2.8. End-User Technologies

Final Consumption Points

In district heating systems, end-user technologies are as critical as heat production, distribution, and storage. These technologies enable the efficient management of district heating systems, ensure the equitable distribution of heat to users, and allow precise measurement of consumption levels.

- **In-Building Heat Distribution System:** This system consists of components such as radiators, underfloor heating installations, pipes, and hot water distribution systems. It may vary based on the specific needs of each building.
- **Apartment or Building Distribution Station:** This station connects the main distribution network to the in-building heat distribution system. A heat exchanger transfers heat from the distribution network to the building's heating system. A distribution station may include components such as a hot water storage tank, measurement equipment, and a control interface. In fifth-generation systems, where distribution occurs at lower temperatures, heat pumps can also be integrated into the distribution station to meet high-temperature demands, such as domestic hot water.



© Danfoss

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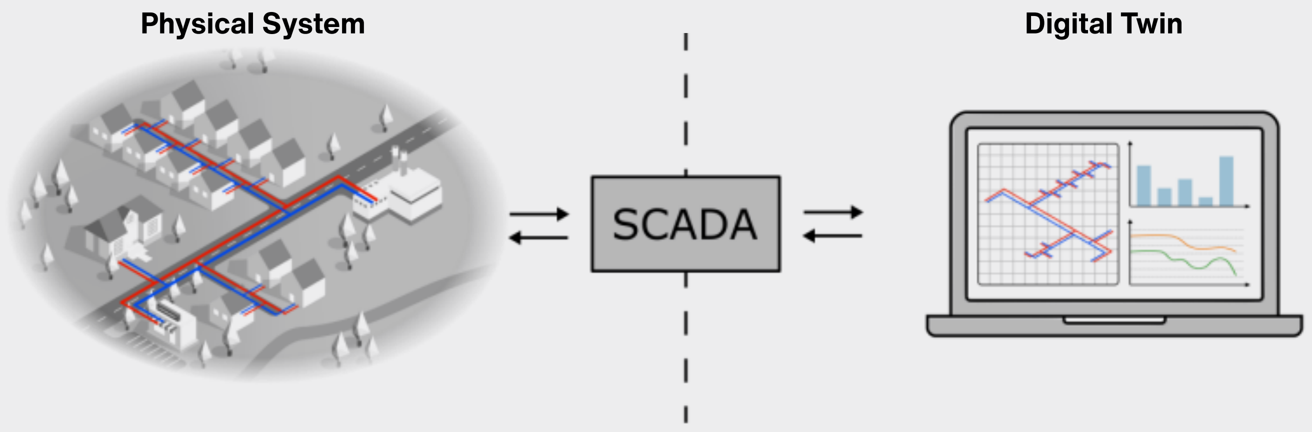
2.9. Digitalization in District Energy Systems

Digitalization enhances the integration of renewable energy sources into district heating and cooling systems while strengthening the connection with the electricity grid. In the future, smart management systems will enable district heating and cooling networks to fully optimize facility and network operations. These interconnected infrastructures will help maximize the utilization of renewable and waste heat energy sources by scheduling heat supply according to predicted demand.



District Heating System Digital Twin [22]

Digitalization at the Production Level

- ÜSimultaneous integration between production and consumption control systems ensures that energy production is optimized in line with demand.
- Infrastructure is provided to allow consumers to select tariffs and participate in demand-side management.
- Operators are granted flexibility to manage the demand side, enhancing system-level efficiency.
- By leveraging machine learning approaches and data-driven, real-time models, grid flexibility can be increased, and more effective forecasting models can be developed

Digitalization at the Distribution Level

- DAutomated fault detection systems are used in distribution networks to identify anomalies in building connection stations. This accelerates maintenance and repair processes, reducing inefficiencies.
- Advanced, self-learning digital twins based on artificial neural networks continuously monitor and control the grid in real time, enabling the assessment of different operational scenarios in advance.
- Digital twin-based operations allow the testing and evaluation of new operational algorithms before their physical implementation, ensuring optimal performance..

Digitalization at the Building Level

- TIt supports the development of solutions and operational scenarios that include demand-side management. By optimizing demand timing and usage, cost and energy savings can be achieved.
- Apartment and building stations can be remotely monitored, and consumption data can be measured and analyzed remotely.
- It enables the implementation of integrated control systems that allow the efficient operation of hybrid solutions, such as district heating and cooling systems combined with individual heat pumps. These solutions optimize different heating systems, ensuring more efficient use of energy resources.

Section **3**

FINANCING OF DISTRICT ENERGY SYSTEMS

3.1. Business Model Framework for District Energy Systems

The business model for district energy systems is project-specific and depends on various factors such as the region of investment, the type of energy sources, and the profile of investors. The selected model should establish a meaningful economic framework for all stakeholders, including investors, operators, service providers/suppliers, end-users, and municipalities. Any investment in a district energy system must ensure both environmental and financial sustainability. Due to the high initial investment costs and the involvement of multiple stakeholders to guarantee societal benefits, district heating and cooling networks require the participation of public decision-makers. Public authorities can engage in a district energy system investment in the following roles:

- Local policymaker
- Planner
- Regulator or consumer
- Partial or full project owner

The involvement of the public sector is critical for coordinating different projects within a broader city vision. Even projects with significant private sector control are often facilitated or supported by the public sector.

Factors Determining Public and Private Sector Involvement:

- **Rate of Return for Investors:** The financial benefits the project offers to investors.
- **Public Sector Control and Risk Tolerance:** The extent of control and risk-taking capacity of the public sector in the project.
- **Regulatory Framework:** The legal and regulatory conditions affecting the project.

These factors serve as a fundamental guide in determining the appropriate business model structure for each city.

3.1. Business Model Framework for District Energy Systems

Calculating Return on Investment

The decision of public or private sector entities to invest in district energy systems primarily depends on two factors: the ***Return on Investment*** (ROI) and the public sector's risk appetite, which in turn determines the level of control over the project. ROI is a financial metric influenced by a project's ***Internal Rate of Return*** (IRR) and ***Weighted Average Cost of Capital*** (WACC).

IRR is a project-specific metric determined by the financial structure resulting from public, private, or joint investments. It depends on the project's costs and revenues, while WACC is shaped by the project's risk profile, current and future investors, and the debt-to-equity ratio in its financial structuring. Generally, private sector investors focus on a project's financial internal rate of return, whereas the public sector also considers additional socioeconomic and environmental costs and benefits beyond standard project financing.

What is IRR?

The Internal Rate of Return (IRR) is a financial indicator used to assess the profitability of an investment. Technically, it is the discount rate that equates the net present value (NPV) of an investment to zero. In other words, it is the interest rate at which the total present value of a project's cash flows equals the present value of the initial investment. IRR helps determine whether a project is profitable. If the IRR is higher than the project's Weighted Average Cost of Capital (WACC), the investment is generally considered viable, as it indicates a positive return for investors.

$$\text{NPV} = \sum \frac{\text{Cash flow}}{(1 + \text{IRR})} - \text{Initial Investment} = 0$$

What is WACC?

The Weighted Average Cost of Capital (WACC) is the average rate of return that a company is expected to pay to all its investors. The WACC is calculated by weighting the cost of each financing source (debt, equity, preferred shares, etc.) according to its proportion in the company's target capital structure. These weights represent the share of each financing source in the total capital of the company.

3.1. Business Model Framework for District Energy Systems

Public Sector Control Level and Risk Tolerance

Unlike private sector investors, the public sector has the opportunity to use district heating and cooling projects as a strategic tool to achieve various social and economic objectives. These objectives may include:

- **Providing affordable energy:** The public sector can offer lower-cost energy to residential and commercial customers.
- **Local economic development:** Creating local jobs and preserving regional economic values.
- **Environmental sustainability:** Promoting low-carbon energy production, integrating renewable energy sources, and reducing air pollution.

Quantifying these objectives through economic modeling can yield additional returns beyond standard financial analyses. These returns, known as secondary benefits, offer public authorities the opportunity to create social value, going beyond mere financial gain. This can increase the public sector's risk tolerance, allowing for a broader acceptance of risks compared to private sector-driven investments.

The public sector can assume different levels of control in the planning and implementation of district heating and cooling projects:

- **Full control:** Developing, owning, and operating the project.
- **Partial control:** Coordinating the project, local planning, and policy-making.
- **Exemplary projects:** Developing demonstration projects that showcase the business models of district energy projects.

The role of the public authority ensures that district energy projects are directed in line with their objectives. While some cities prefer to deliver energy services through public utilities, others may be more open to private sector involvement. However, in all cases, the public sector can ensure that projects are designed to deliver not only financial but also social and environmental benefits by adopting a strategic approach.

This approach enables the public sector to take on greater responsibility and ensures that projects achieve long-term sustainability goals.

3.1. Business Model Framework for District Energy Systems

Legal Framework

The success of district energy system investments is highly dependent on the legal regulations in place. These regulations can directly impact the business model design and financing mechanisms of the project.

- **Balancing initial investment costs and returns:** District energy system projects require significant initial investments (high capital expenditures) in exchange for long-term returns. Existing legal frameworks should ensure that these initial investments are justified by predictable returns.
- **Risk management for municipalities/companies:** Various project risks affect municipalities and public companies implementing district heating and cooling systems. Strong regulations and public support mechanisms can help mitigate these risks and increase the project's credibility with financial institutions.
- **Incentive mechanisms:** Regulations that promote cost reduction enable district energy system operators to maximize infrastructure investments while minimizing the financial burden on end users.
- **Sharing efficiency gains with consumers:** Regulations on efficiency gains ensure that savings from energy efficiency are not solely retained as profit by operators but are also passed on to end consumers in the form of lower energy prices or higher service quality. This allows consumers to benefit from more affordable services and supports the overall acceptance of the system.

Why is public contribution important?

In many countries, existing legal frameworks may not align with the fast investment timelines required for district energy projects. Restrictions on equity financing, borrowing limits, and pressure to reduce operating costs can hinder critical investments. In this context, public-backed financial instruments can play a crucial role in overcoming these barriers.

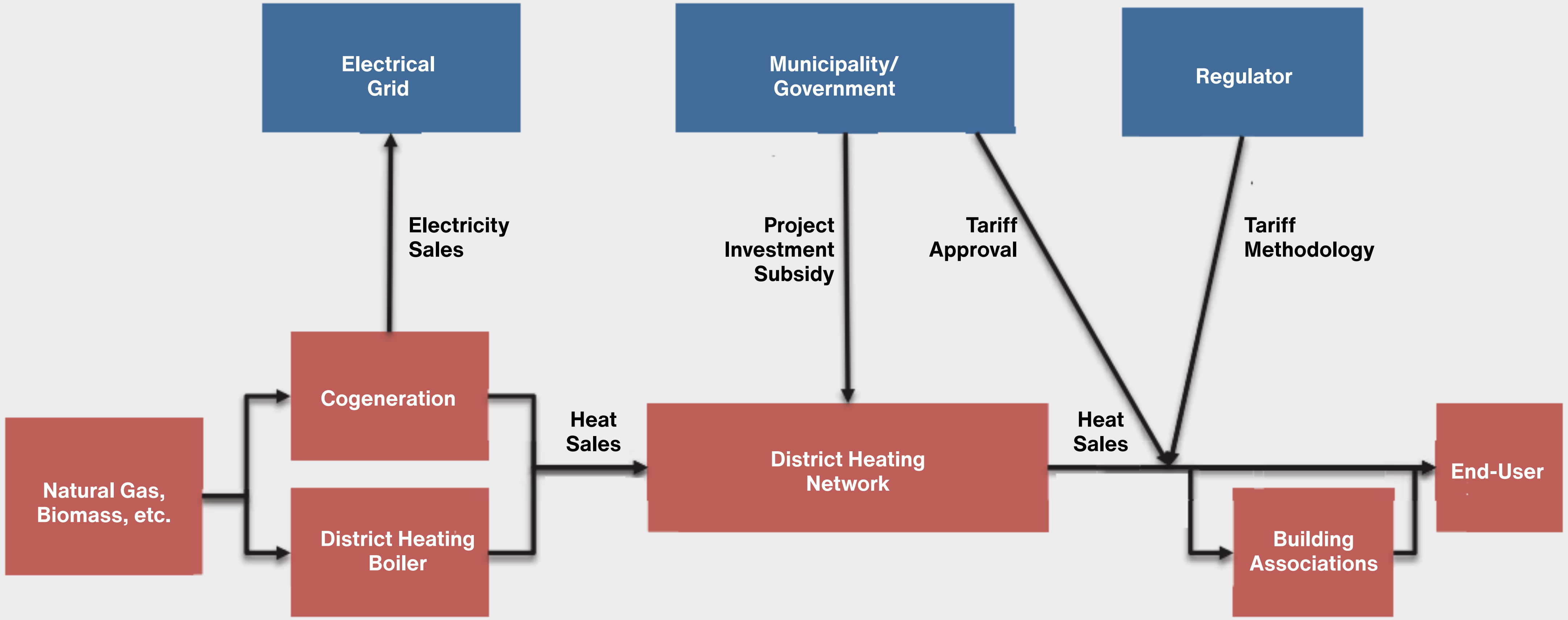
3.2. Investment Models

Public Investments

The most common district energy system investment model is public investments. In this model, institutions or municipalities investing on behalf of the public become the owners of the district energy system investment, taking on the role of the local authority or public service provider. This allows for full control of the project and helps achieve broader social objectives, such as meeting environmental targets and reducing energy poverty through tariff control. In this model, a significant portion of the investment risk is borne by the city. In densely urbanized areas, such projects are usually developed through a public utility, and the low return rate is balanced by spreading it across other projects with higher returns. Projects in new urban areas are typically developed by establishing a new government/municipal partnership to alleviate the administrative burden of the local authority. This type of spin-off can provide additional benefits, such as limiting the city's financial responsibility, speeding up decision-making processes, and increasing flexibility. Furthermore, the local authority can reduce its own risks related to the project by outsourcing technical design and construction (and sometimes operations) processes.

Why is the contribution of the public sector or municipalities important?

District heating and cooling systems are seen as an attractive infrastructure investment opportunity that can be funded by city resources as long as they contribute to a city's strategic goals, such as reducing carbon emissions, increasing energy security, improving resilience, or providing affordable heat supply. The low interest rates on public debt are the main reason why many advocates of district heating and cooling systems argue that municipalities can (and should) make these types of investments. Therefore, local governments are leading many district energy system investments.

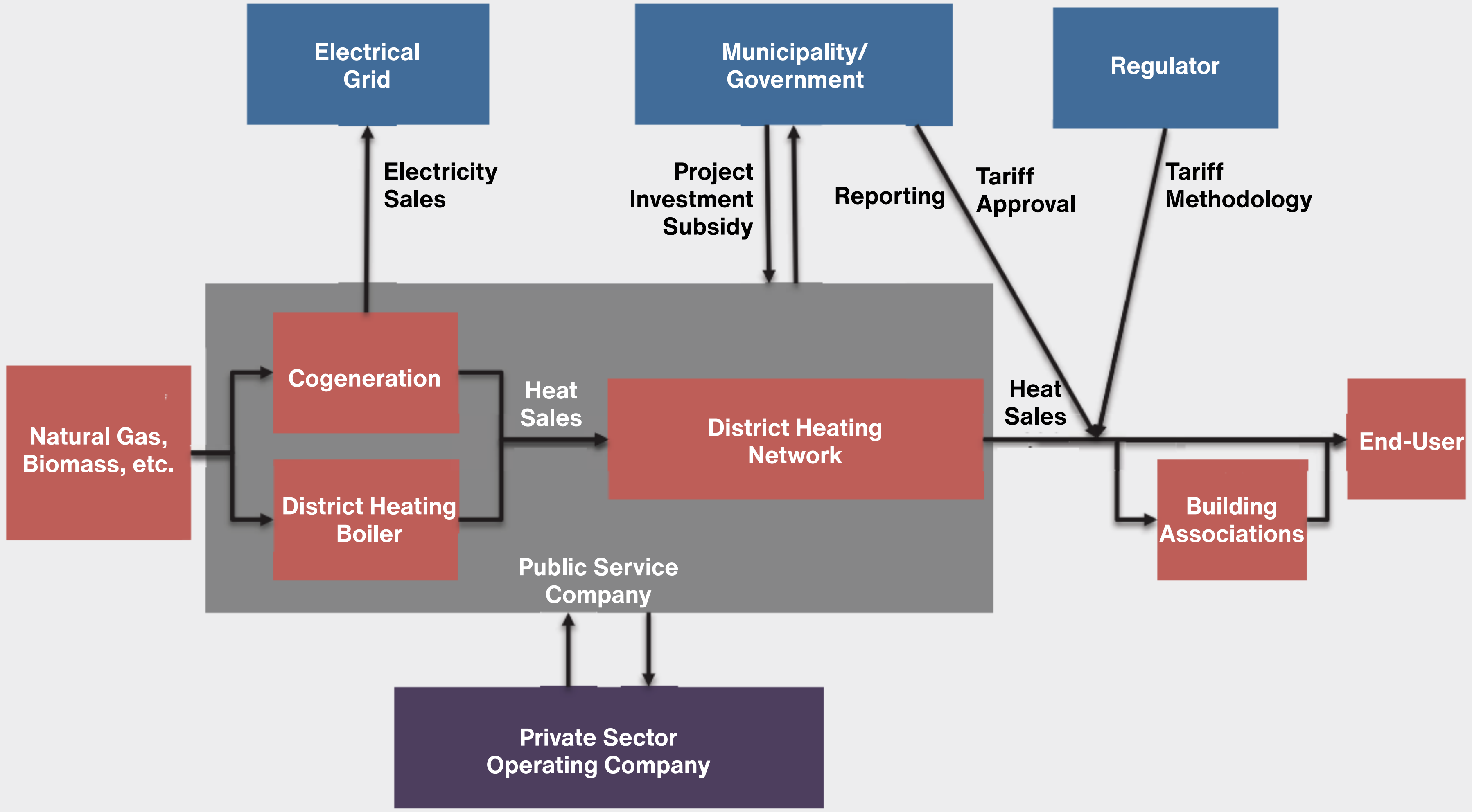


Traditional Public Investments [23]

3.2. Investment Models

Public/Private Sector Investments – Operating Model

When the return on investment for a district heating and cooling system is attractive enough to attract the private sector, a “public/private sector” partnership model may be adopted. In this model, the local authority is willing to take on certain risks and maintain a level of control over the project, while seeking the participation of the private sector to provide expertise and/or private capital. However, the biggest challenge in such projects is ensuring that all parties have a clear and aligned vision regarding the project goals and how to achieve them.



Private Sector Operating Model for District Heating [23]

What is an operating agreement?

An operating agreement involves the delegation of a public utility operation to the private sector through outsourcing, while ownership and investment decisions remain with the public sector. Operating agreements are typically short-term (2-5 years) and do not involve the transfer of employees to the operator. The private operator is generally paid a fixed fee to cover personnel and expenses. Additionally, a performance-based fee may be paid, depending on the quality of service, and penalties may apply if performance parameters are not met. Under the operating agreement, the operator is responsible for billing and collections on behalf of the public utility and may assume a certain collection risk depending on the performance standards.

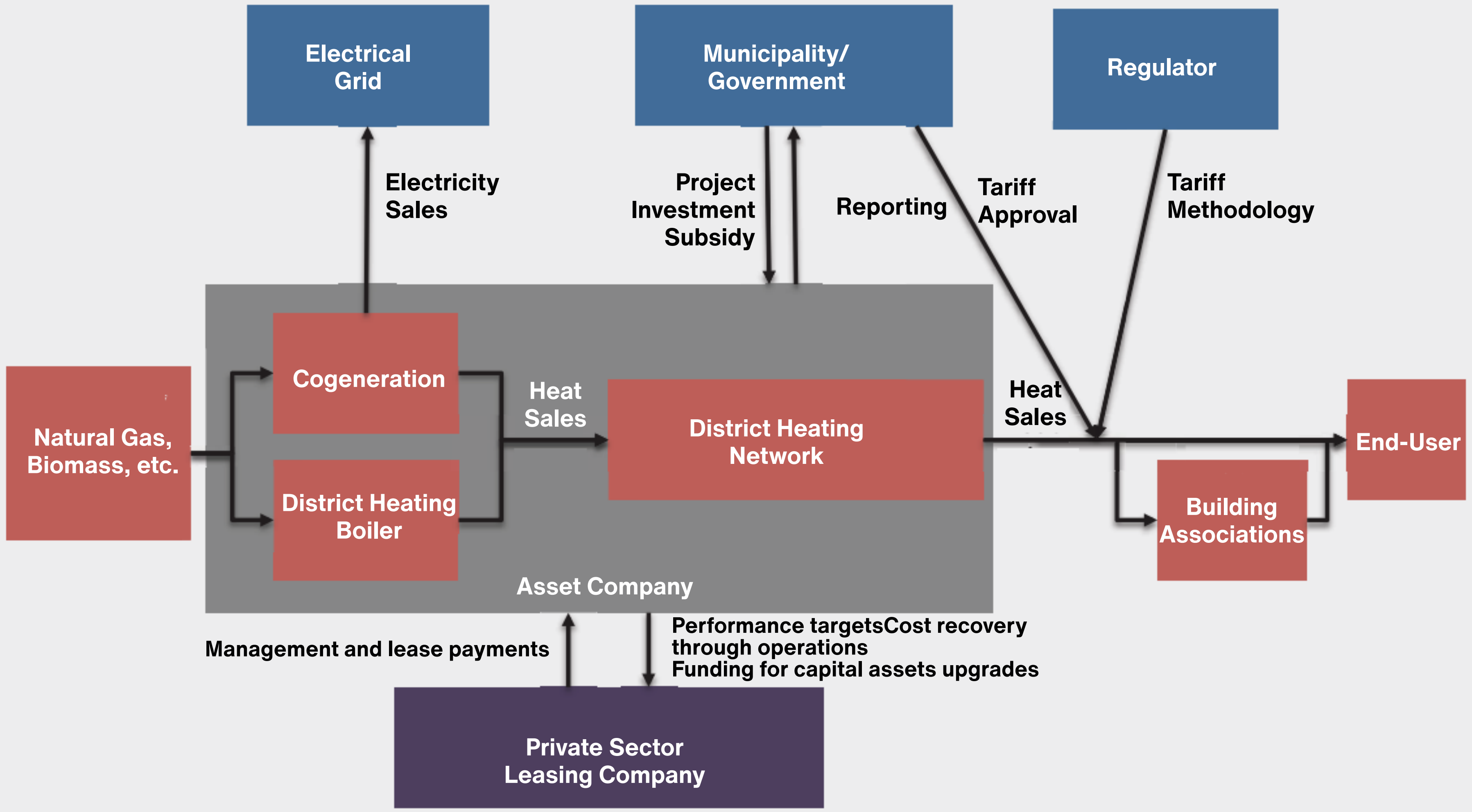
3.2. Investment Models

What is a lease agreement?

In the lease model, a private party (the lessee) undertakes the operation, management, and implementation of facility improvements of a District Heating and Cooling system under a contract with the public party (the lessor). The public party (the lessor) receives lease payments from the lessee, and these payments are reinvested into operational improvements as required by the lease agreement. Lease contracts are typically of medium to long-term duration (usually 8 to 15 years), and often involve temporarily assigning or transferring employees to the operator company. The private party (the lessee) covers the lease costs through operations, and the revenue collection risk is transferred to the lessee. Therefore, the lessee requests assurances regarding tariff levels and increases throughout the lease period. Additionally, a compensation/review mechanism must be established in cases where tariff projections are not met. Maintenance costs and certain renewal expenses are transferred to the lessee, and the lessee assumes a certain asset risk in terms of asset performance. Furthermore, the lessee may be tasked with overseeing the capital investment program or specific capital projects.

Public/Private Sector Investments – Leasing Model

Under the leasing model, operation and management, revenue collection, and investments are carried out by the private sector; however, ownership remains with the public sector. In addition to the benefits provided by the operating agreement, the lease contract offers stronger incentives for operational efficiency and improved asset management. However, the lease agreement limits the authority's right to intervene and carries the risk of asset quality deteriorating at the end of the lease term. This could lead to issues if not properly regulated within the lease contract.

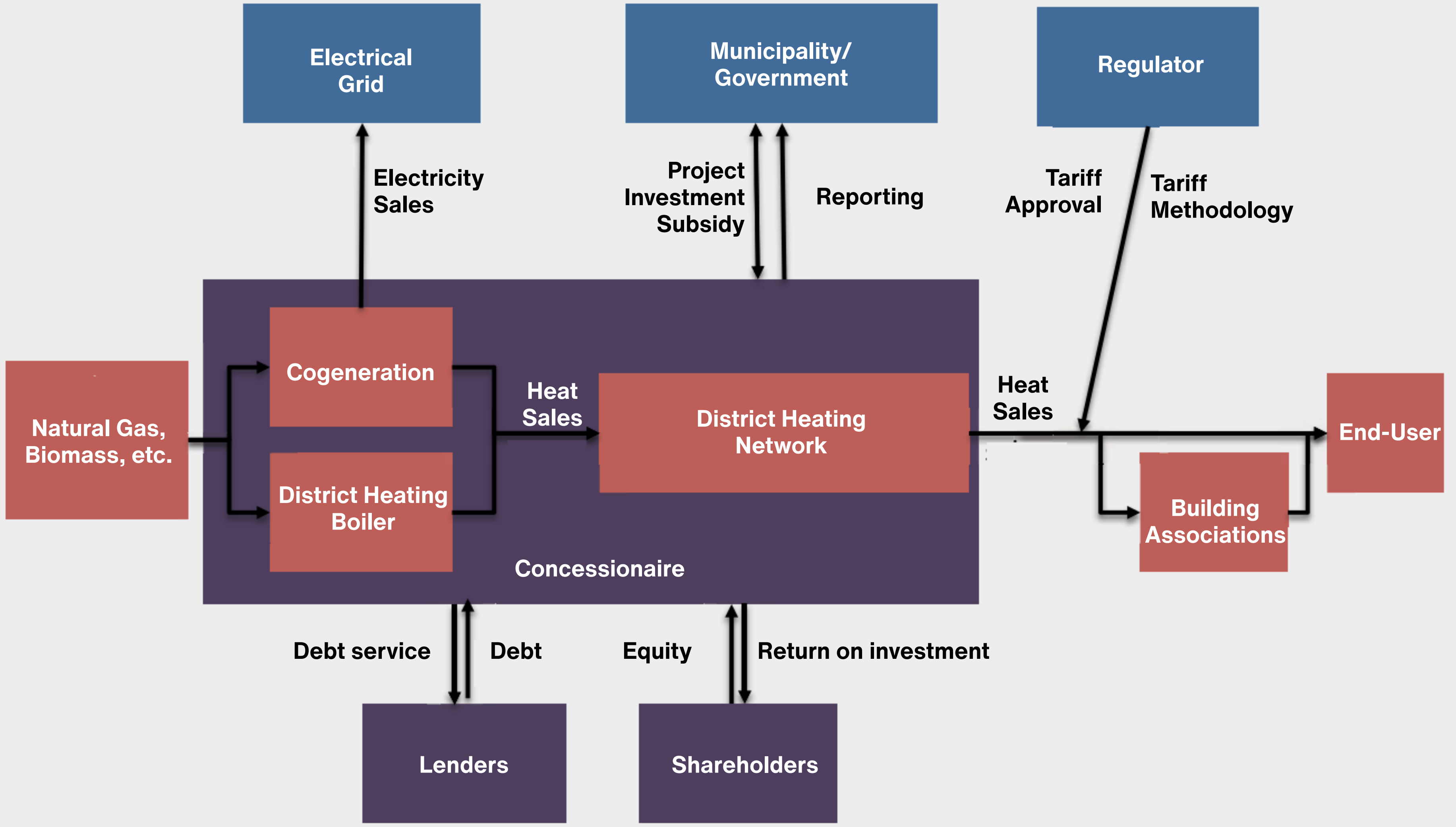


Private Sector Leasing Model for District Heating [23]

3.2. Investment Models

Public/Private Sector Investments – Concession Model

Under a concession agreement, the public authority grants a private party (the concessionaire) the right to renew, finance, and operate an existing infrastructure asset or, in the case of a Build-Own-Operate-Transfer (BOOT) model, to design, construct, finance, and operate a new infrastructure asset. Ownership of the assets remains with the public sector, but concession agreements are typically long-term (25-30 years), allowing the concessionaire to recover their investments. At the end of this period, the operational responsibility returns to the public authority.



Private Sector Leasing Model for District Heating [23]

What is a concession agreement?

In this model, the public authority typically initiates the first steps of district heating and cooling projects and then tenders the project to the private sector. The concessionaire recoups its investment, covers operating and financing costs, and generates profit by selling services directly to end-users. Additionally, the concessionaire often pays a concession fee to the awarding authority. The concessionaire assumes risks related to insufficient demand for the use of the asset, as well as risks associated with design, financing, construction, and operation. However, the public authority may share the demand risk by agreeing to a minimum level of usage. User fees may be defined in the contract or set by the concessionaire under the oversight of the sector regulator. The benefits of concession agreements include those of management and leasing contracts. Furthermore, concession agreements provide stronger incentives for optimizing operational efficiency and lifecycle costs. More importantly, well-structured concession agreements can help mobilize additional financial resources.

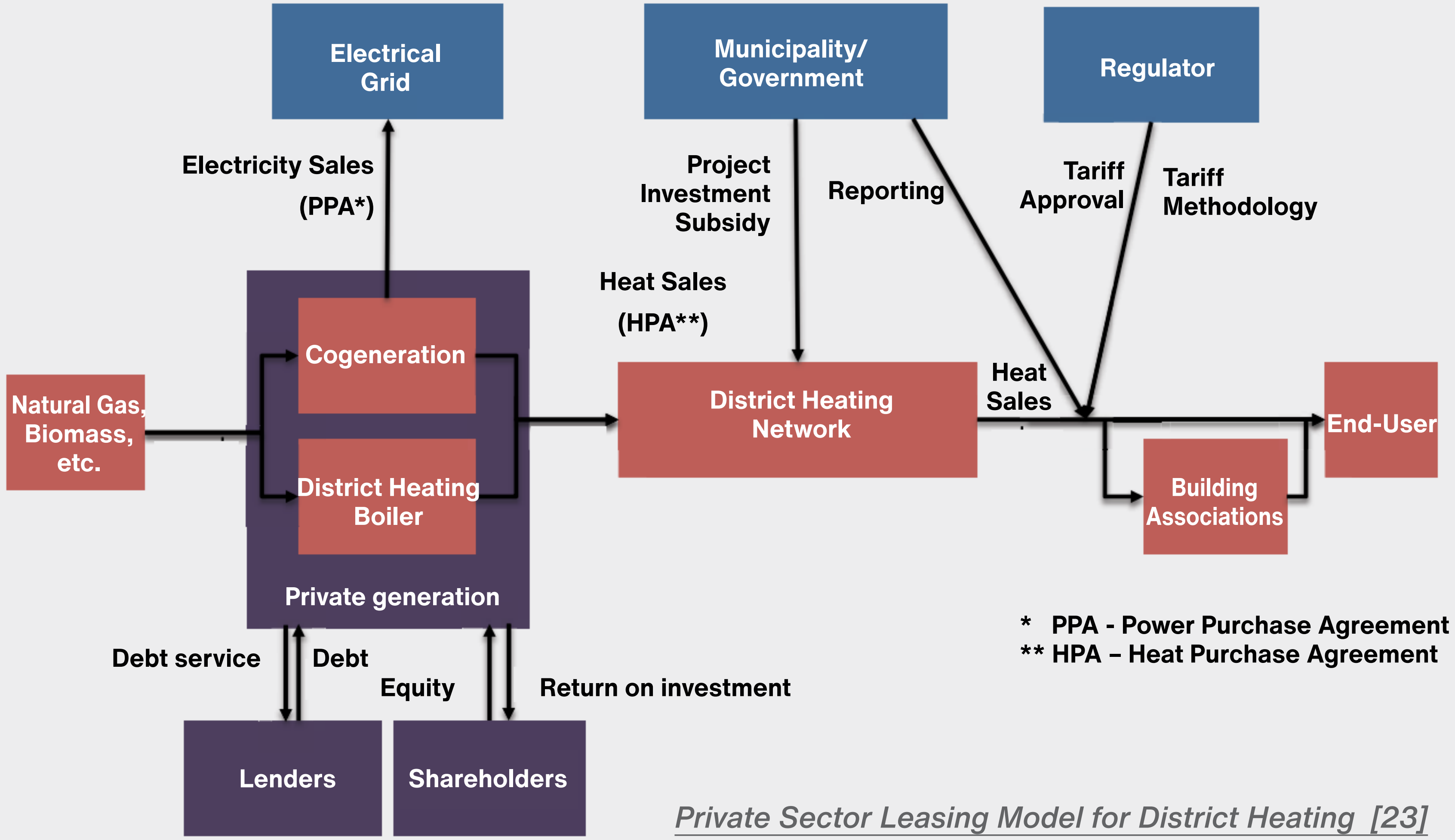
3.2. Investment Models

Private Sector Investments

When a local government presents a district energy project proposal with a high return rate but also has a low risk tolerance and a relatively low desire for control, it can attract the interest of private sector companies. However, this does not mean the local government will completely disengage from the project; many successful, privately owned district energy systems still involve indirect participation from local governments. For example, the local government may be the project's initial supporter and/or provide financing and grants for the project. In any case, planning and regulatory support are required, and the local government can assist in connections that may be seen as too risky for the private sector but are considered socially optimal. Additionally, it can develop initiatives that encourage social or environmental goals, such as mechanisms supporting low-carbon production.

What is private sector investment?

In cases where the investment is fully made by the private sector, the risk is borne by the private company. However, the company may enter into a Joint Venture Agreement with the local government to reduce risks during the planning or expansion processes or to encourage network connection requests through planning policies. This is commonly referred to as the Strategic Partnership Model. In return, the local government can benefit from other social or environmental advantages arising from the regional energy system investment, such as lower tariffs and profit sharing. Financing is provided by the private sector company. The private sector company may request a capital contribution in the form of a connection fee for public buildings connected to the district heating network. Local or national authorities may have the opportunity to attract international credits or grants for the project.



Private Sector Leasing Model for District Heating [23]

Different investment models

The flowchart provided on the left visually presents the privatization or provision of the heating system by the private sector to meet the heating demand. This model is a structure that combines electricity sales under an electricity supply agreement and heat sales to a public district heating company under a heat supply agreement. Private sector investments can occur in various forms, not limited to this model.

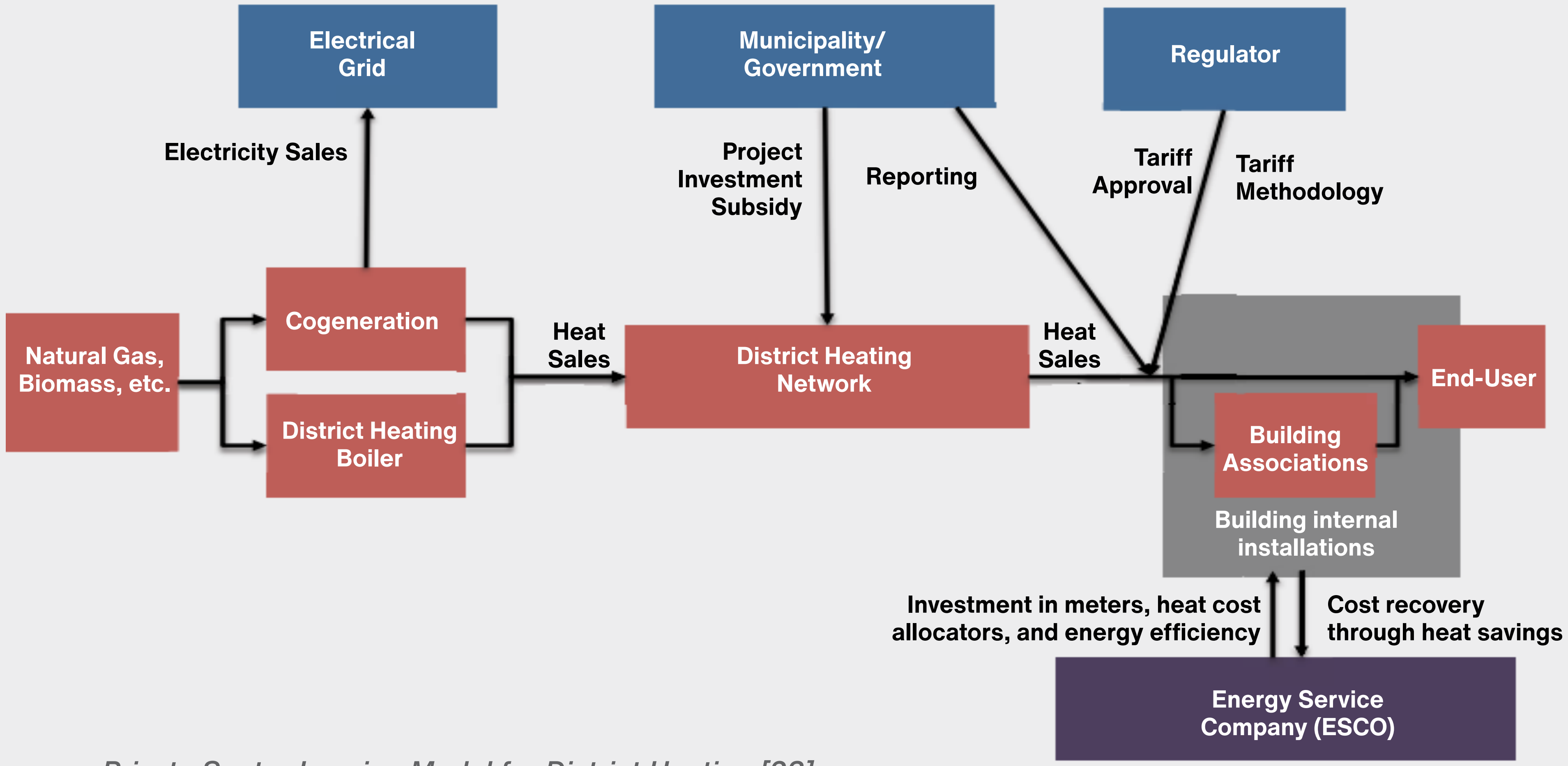
3.2. Investment Models

Heat pumps and energy performance contracts

The integration of heat pumps into district energy networks offers significant benefits in terms of cost and emissions reduction. This integration can enhance the security and flexibility of heat supply while contributing to the stabilization of the energy market. However, there are various challenges that hinder the adoption of these systems. Particularly, information gaps, economic issues, and process complexities make it difficult to use heat pumps in conjunction with district heating systems, especially for residential users. The Energy Performance Model is an ideal approach, especially for central heat pump solutions. In this model, the ESCO has full control over the heat pump. For the model to be profitable, the heating cost provided by the heat pump must be lower than the fee paid by customers. To ensure this cost-effectiveness, the ESCO must also include the building's internal infrastructure (such as radiators, underfloor heating systems, etc.) in the performance contract.

Private Sector Investments – Energy Efficiency Performance Model

An energy service company (ESCO) provides energy efficiency services to end energy users (e.g., households). These services include the supply and installation of energy-efficient equipment and building renovations. The ESCO may share the savings it generates or enter into a performance guarantee agreement. ***"Shared Savings"*** model: In this model, the ESCO takes on the investments and receives a share of the energy savings generated. ***"Performance Guarantee"*** model: In this model, the ESCO provides a savings guarantee, and the investment is covered by the asset owner. The ESCO guarantees energy savings or the provision of the same level of energy services at a lower cost. The ESCO's fee is directly tied to the energy savings achieved. Therefore, the ESCO takes on a certain level of risk regarding improvements in energy efficiency. In some countries, the ESCO market is facilitated by third-party insurance of energy savings. These risk mitigation tools are typically supported by development banks.

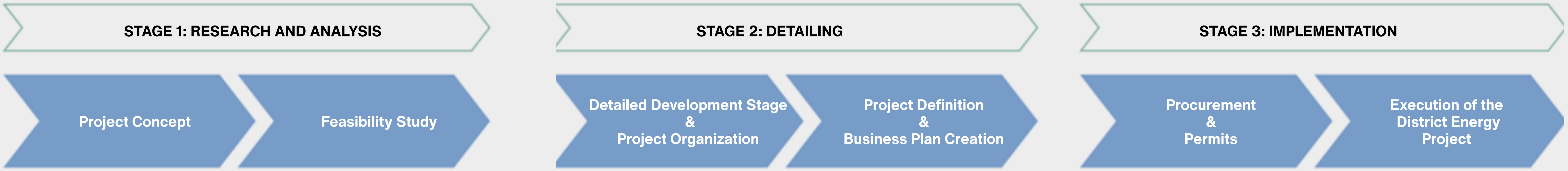


Private Sector Leasing Model for District Heating [23]

Section **4**

PLANNING A DISTRICT ENERGY SYSTEM

4.1. Planning Stages



What is the local renewable energy potential?

District energy system planning primarily requires mapping renewable and conventional energy sources across the city. In each project area, some resources may have higher priority or greater potential than others. This planning process, which maps heating/cooling demand and energy sources, helps to understand the relationship between demand and available resources, facilitating informed engineering decisions. For instance, heat pumps may be needed to raise the temperature of low-temperature sources to the desired operating level. Since renewable energy sources often require large open spaces for production, it is recommended to consider regional energy potential rather than just urban energy generation capacity. This approach enables optimal energy exchange between the city and its surroundings. Similarly, the recovery of waste heat or valuable waste streams from adjacent industrial and agricultural complexes should also be taken into account. Additionally, key factors such as urban density and building usage types in the service area should be considered in the early decision-making process.

Is a district heating and cooling system technically feasible?

The first step in establishing a new district heating or cooling network is to include all major consumers (e.g., swimming pools, hospitals, offices, supermarkets, large residential complexes) in the planning process. Large consumers can significantly facilitate system implementation. Involving these stakeholders in a working group provides a meaningful planning approach by allowing the system's benefits and customer needs to be shared effectively. To maximize the opportunities created by a district energy system, establishing a structure coordinated by the municipality can play a supportive role in the project. Since such approaches are closely linked to urban planning procedures, the role and approach of municipalities are particularly crucial.

Is a district heating and cooling system financially viable?

For a district energy system project to be successful, it must provide financial returns for all stakeholders. These returns depend on certain technical and economic conditions. In any planning process, the following questions are critical:

- What is the distance between the energy source and consumers?
- What type of distribution method will be used?
- Are urban density, heat demand intensity, and relevant urban renewal strategies suitable for district energy system investment?

Due to high initial investment costs and long-term commitments, district energy system investments require detailed financial analysis approaches.

4.2. Role of Municipalities in Planning Processes

Municipalities play a crucial role for stakeholders involved in implementing any district energy system project, starting from the planning phase. Therefore, it is essential for municipalities to envision the future energy system of their cities, including the state of the building stock and its interaction with the electrical grid. This approach allows planners, suppliers, financiers, and end users to have a general framework for the effective implementation of such systems and the mitigation of associated risks.

The roles that municipalities can take in a district heating and cooling system project may vary depending on the technical and financial capacity of the respective municipality. In the planning phase, municipalities may either hire external expertise for technical specialties or take full responsibility for the entire process from planning to operation.

- **Environment and Climate Change:** The municipality monitors local climate change and energy efficiency goals. Responsible units may lead the district heating system project or contribute to it as project stakeholders.
- **Planning:** Municipality departments responsible for planning oversee the development of the district heating network and its integration with other planning elements. They create heat demand maps and contribute to investment or expansion decisions for the district heating network based on these.
- **Building Permits:** The municipality follows and facilitates the permit processes necessary for district energy system projects.
- **Infrastructure and Engineering:** The municipality coordinates the installation of district heating network pipes and their integration with other infrastructure lines. Relevant technical departments track energy consumption in municipal buildings and develop pilot projects by connecting these buildings to the district energy network.
- **Administrative Affairs and Legal:** The municipality prepares cooperation agreements with various stakeholders at the start of the district heating and cooling system investment process and coordinates the stakeholders.
- **Finance:** The municipality manages various grant supports for project investment and handles the financial processes related to the project.
- **Communication:** The municipality carries out communication activities about the district heating system and raises public awareness to ensure that connection requests are secured.

Section **5**

APPLICATION EXAMPLES AND DISTRICT ENERGY STRATEGIES

5.1. The Bunhill District Heating System

Location: England

Metro Shaft Heat Recovery + Heat Pump

Bunhill Phase 2, constructed in 2019, is an innovative district heating and heat pump application that utilizes low-grade waste heat from the metro ventilation shafts. A 1 MW ammonia heat pump draws heat from the London Underground ventilation shafts (with temperatures ranging from 18°C to 28°C) to meet the heating and hot water demands of residences connected to the district heating network. The heat pump extracts heat or provides cooling from the ventilation shaft based on summer and winter operating conditions. The energy center also includes two 237 kWe combined heat and power (CHP) units and thermal energy storage tanks.

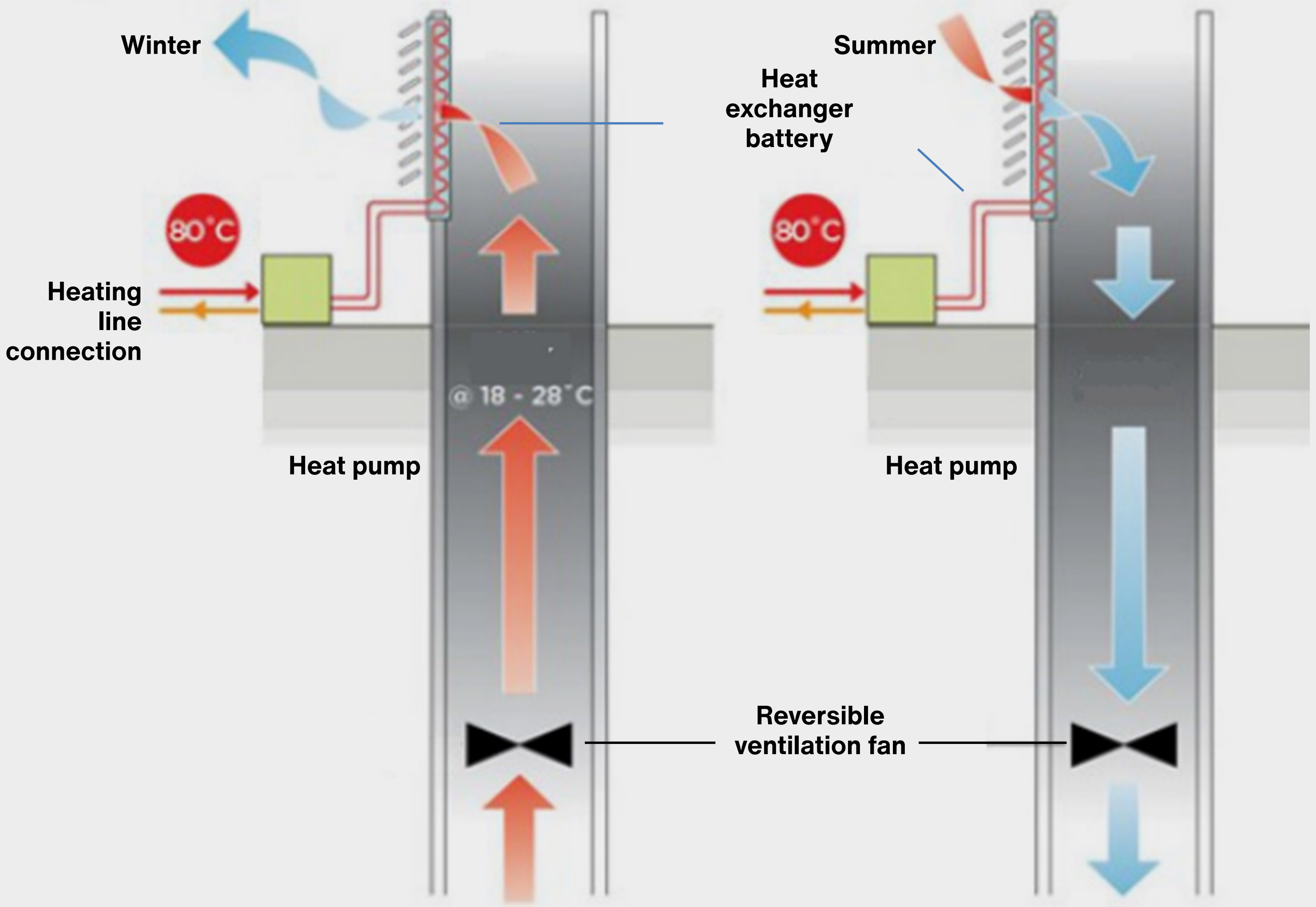
The new energy center and pipelines have extended the existing Bunhill Heat and Power district heating network, launched in 2012 in Islington, to include 550 more residences and a primary school. The existing network currently serves over 800 homes and two sports centers with heating and hot water. The new energy center has increased the system's capacity to meet the heating needs of 2,200 homes.

Bunhill Project Pipeline Installation

Bunhill Project Energy Center

Two-Stage Ammonia Heat Pump

Bunhill District Heating Project



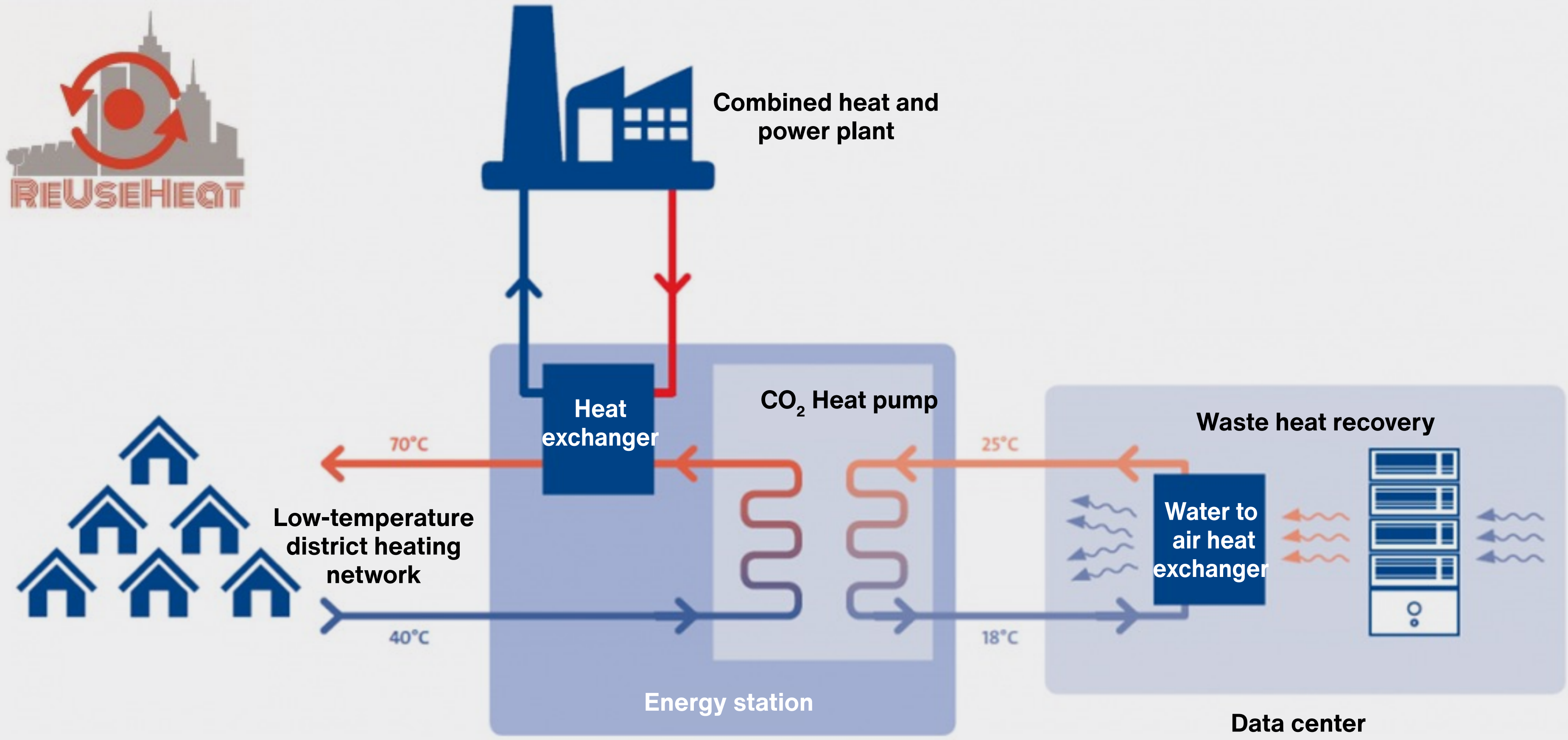
Heat Recovery from Metro Ventilation Shaft

5.2. The Brunswick District Heating System

Location: Germany

Data Center Waste Heat Utilization + Heat Pump

In the Brunswick district heating system, the use of waste heat from a data center became possible thanks to a request from a local real estate developer to connect to the district heating system. The heating demand for residential areas was evaluated alongside the construction of the data center on an adjacent plot, and an innovative district heating approach was developed by utilizing the data center's waste heat. This new development area, designed with low heat loss and consisting of 600 high-performance residential units with a total net area of 48,000 m², features a low-temperature 4th generation central heating network. The maximum heating demand of the system has been calculated to be approximately 1.8 MW, with base load being met by waste heat recovery. Due to the low temperature of the heat source, a heat pump has been added to the system to reach the desired temperature. However, the heat pump keeps the district heating system supply temperature at the lowest possible level to maximize system efficiency.



Brunswick District Heating Project [29]

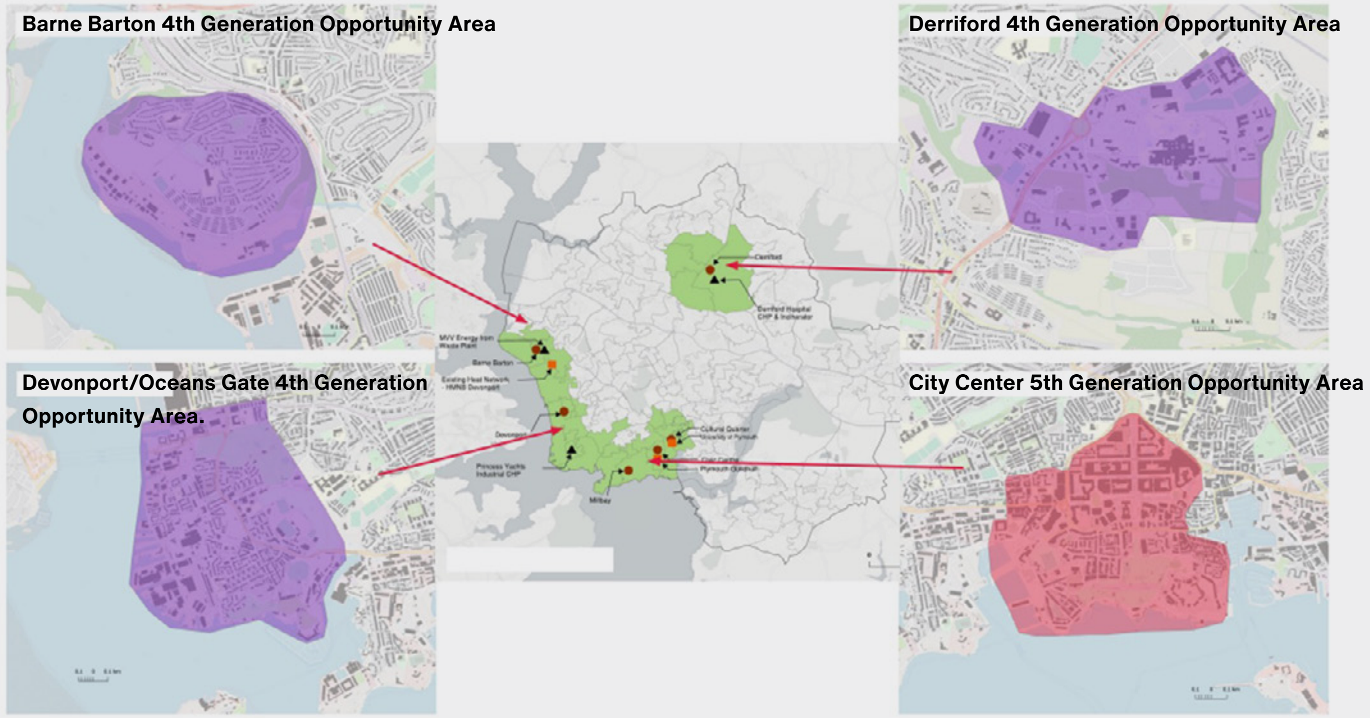
Brunswick District Heating Project Heat Pump Installation @ ReUseHeat [28]

5.3. The Plymouth District Heating System Master Plan

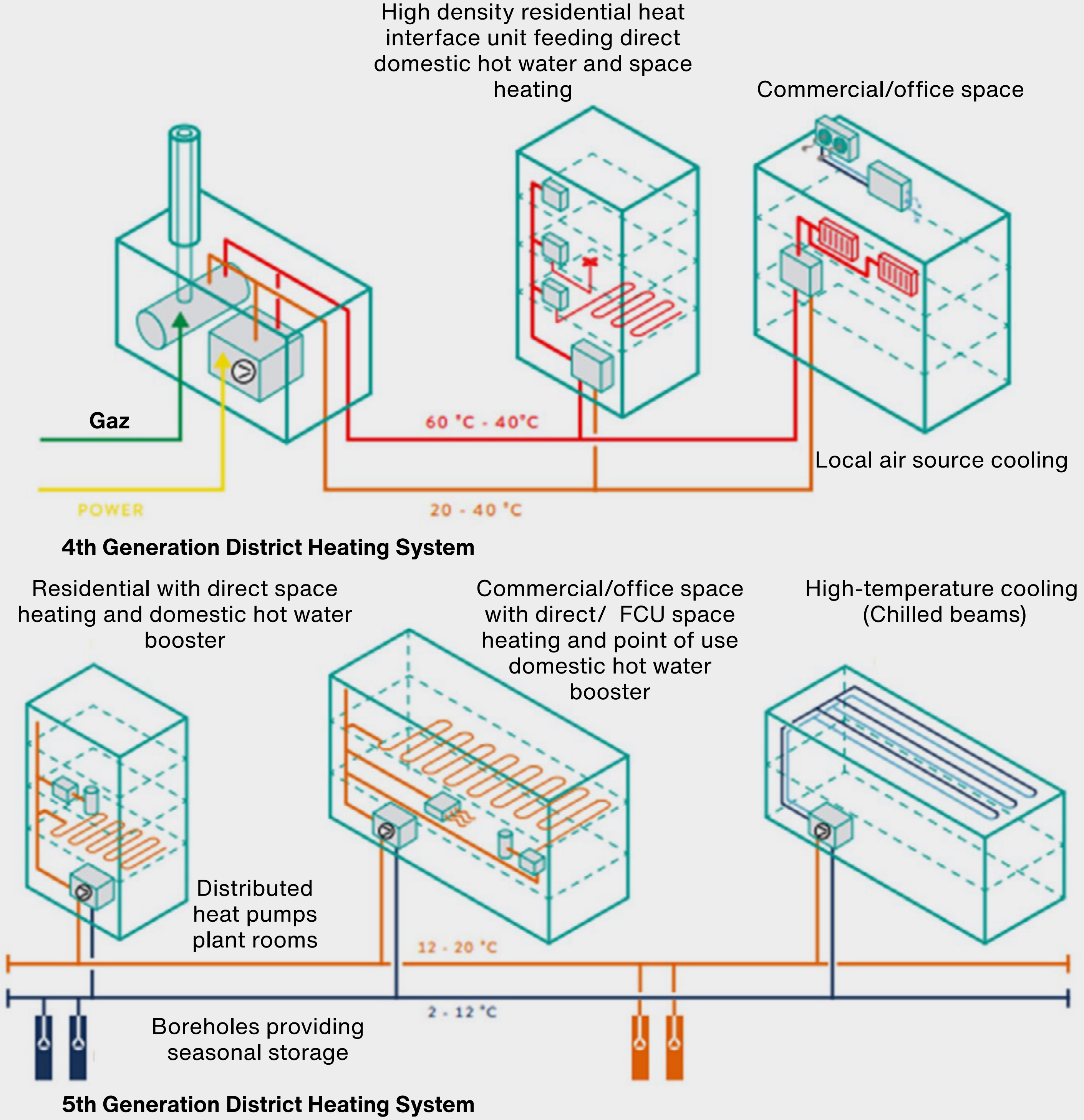
Location: England

5th Generation District Heating and Cooling System

As part of the HeatNet project, a master plan for a 5th generation heating and cooling system has been developed for Plymouth City Centre and Millbay areas, with a total investment value of £15-20 million. The main principle of the system is based on the use of renewable energy through water-sourced heat pumps from the main aquifer beneath the limestone rock in the region. In later stages of the plan, the inclusion of seawater-sourced heat pumps is also planned. The 5th generation district energy system approach allows for the recovery of waste heat from cooling systems, and this heat can be used for either simultaneous or seasonal heating. Within the framework of the master plan, the complete electrification of heating through an open-loop ground-sourced heating system is targeted within 15 years, with an expected CO_2 savings of 37,000–40,000 tons during this process.



Plymouth District Heating Project Master Plan [12]



Plymouth 4th and 5th Generation System Implementation Principles @ReUseHeat [12]

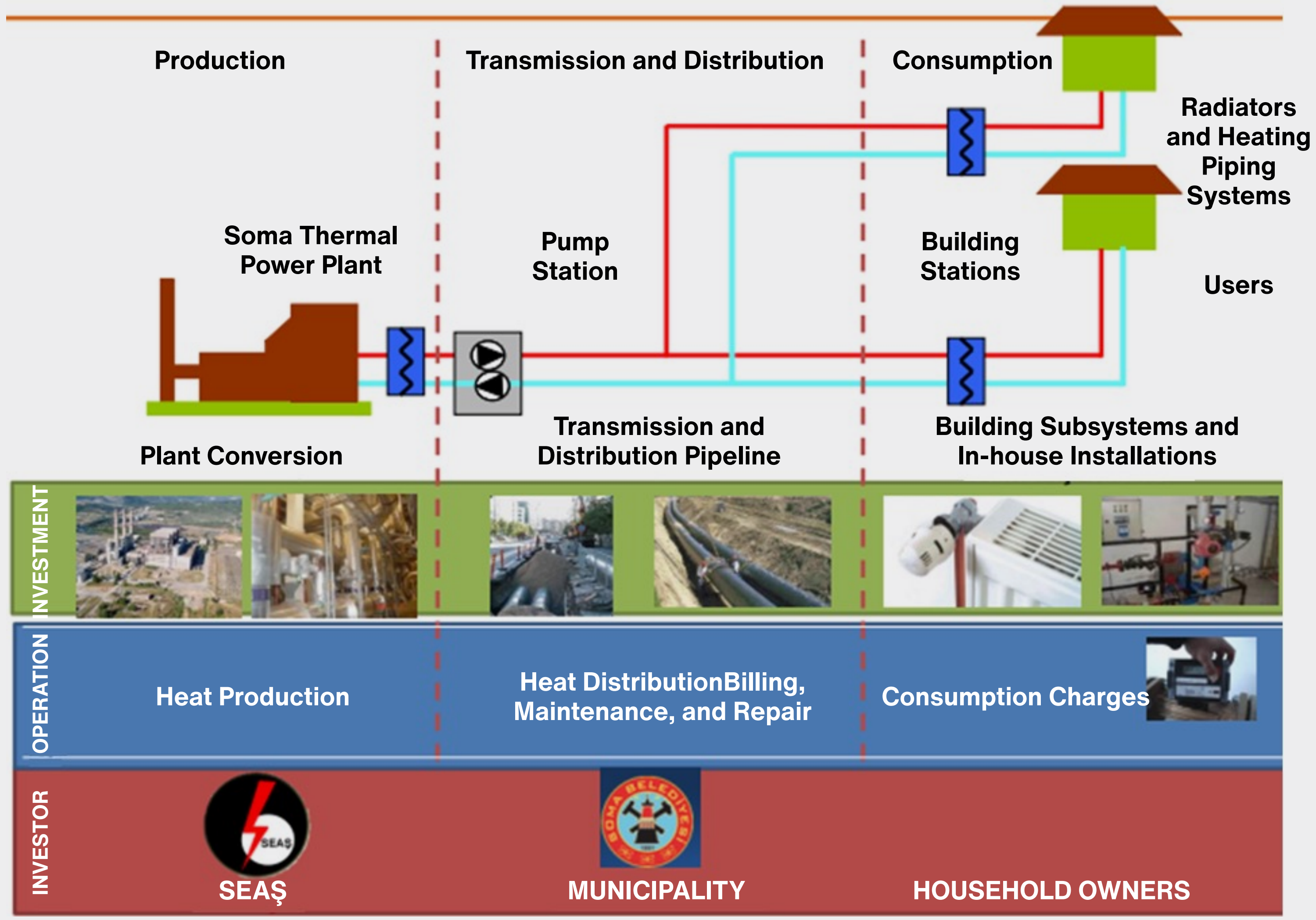
5.4. The Soma District Heating System Pilot Implementation Project

Location: Türkiye
Research and Development of Methods for Converting Thermal Power Plant Waste Heat to Utility in Order to Increase Energy Efficiency and Heating Applications in Buildings (TSAD) Project

Between 2006 and 2011, under the TÜBİTAK Public Institutions Research and Development Projects Support Program, the waste heat potential of 14 thermal power plants and their applicability for heating were evaluated. The primary goal of the project was to recover waste heat from public fossil fuel-based thermal power plants and contribute it to the economy. As part of the project, the first pilot implementation was carried out in the Soma district of Manisa. As a result of this pilot, the heating needs of 8,100 homes were met.

Soma District Heating System Pump Station

Soma District Heating System Pipeline Installation



Responsibility Distribution of Soma District Heating System [28]

References

[1] www.arup.com. (2019). Five-minute guide: Energy in Cities. https://www.arup.com/globalassets/downloads/insights/five-minute-guide-energy-in-cities.pdf

[2] Elsman, P. & Copenhagen Energy Ltd. (2009). Global District Energy Climate Awards – Copenhagen DH – Application 2009. https://www.districtenergyaward.org/wp-content/uploads/2012/10/Copenhagen_Denmark-District_Energy_Climate_Award.pdf

[3] Huang, P., Copertaro, B., Zhang, X., Shen, J., Löfgren, I., Rönnelid, M., Fahlen, J., Andersson, D., & Svanfeldt, M. (2019). A review of data centers as prosumers in district energy systems: Renewable energy integration and waste heat reuse for district heating. Applied Energy, 258, 114109. https://doi.org/10.1016/j.apenergy.2019.114109

[4] CopenHill | BIG | Bjarke Ingels Group. (2019) https://big.dk/projects/copenhill-2391

[5] Peta4. (2022). https://heatroadmap.eu/peta4/

[6] London Heat Map. (2024). https://apps.london.gov.uk/heatmap/

[7] Andrews Tipper, H., Ashcroft, E., Salmeri, M., (2019). Stakeholder Engagement in Heat Networks. A Guide for Project Managers. https://assets.publishing.service.gov.uk/media/5b292b11ed915d2cc0270d9f/Stakeholder_Engagement_in_Heat_Networks_-_a_guide_for_project_managers.pdf

[8] Dodd, N., King, M., Shaw, R. (2008). Urban Planning for a Low Carbon Future. http://urbed.coop/sites/default/files/Community%20Energy%20Guide_0.pdf

[9] Lund, H., Østergaard, P. A., Chang, M., Werner, S., Svendsen, S., Sorknæs, P., Thorsen, J. E., Hvelplund, F., Gram Mortensen, B. O., Mathiesen, B. V., Bojesen, C., Duic, N., Zhang, X., & Möller, B. (2018). The Status of 4th Generation District Heating: Research and Results. Energy, 164, 147-154. https://doi.org/10.1016/j.energy.2018.08.206

[10] Lund, H., Østergaard, P. A., Nielsen, T. B., Werner, S., Thorsen, J. E., Gudmundsson, O., Arabkoohsar, A., & Mathiesen, B. V. (2021). Perspectives on fourth and fifth generation district heating. Energy, 227, 120520. https://doi.org/10.1016/j.energy.2021.120520

[11] Araner. (2020) District Heating Technical Reference eBook. https://www.araner.com

[12] Plymouth CC, Plymouth Concepts Team, Jones, P., Dunham, C., & Davidson, C. (2019). Plymouth 4 & 5DHC Roadmap. In Part 1. UK Context. https://guidetodistrictheating.eu/wp-content/uploads/2019/12/HeatNetNWE_Plymouth-Transition-Roadmap_Part-1-and-2.pdf

[13] García-Céspedes, J., Herms, I., Arnó, G., & De Felipe, J. J. (2022). Fifth-Generation District Heating and Cooling Networks Based on Shallow Geothermal Energy: A review and Possible Solutions for Mediterranean Europe. Energies, 16(1), 147. https://doi.org/10.3390/en16010147

[14] Boesten, S., Ivens, W., Dekker, S. C., & Eijdems, H. (2019). 5th generation district heating and cooling systems as a solution for renewable urban thermal energy supply. Advances in Geosciences, 49, 129–136. https://doi.org/10.5194/adgeo-49-129-2019

References

[15] Low-temperature district heating: heating our homes at lower cost – Analysis - IEA. (2021). https://www.iea.org/articles/low-temperature-district-heating-heating-our-homes-at-lower-cost

[16] Jones, P., Woods, P., Crane, M. (2020). Heat networks: Code of Practice for the UK. https://www.cibse.org/knowledge-research/knowledge-portal/cp1-heat-networks-code-of-practice-for-the-uk-2020-pdf

[17] Burton, T., Naughton, T., Jones, G., Harcourt, F., FairHeat, & Anthesis. (2023). Heat Network Optimisation Guide., Department for Energy Security & Net Zero. https://assets.publishing.service.gov.uk/media/649567a0831311000c296255/heat-network-optimisation-guide.pdf

[18] District heating. (2024). https://www.danfoss.com/en-us/markets/district-energy/dhs/district-heating/#tab-overview

[19] IEA SHC Task 68. (2023). Solar Heat for Cities, Towns and Energy Communities. In IEA SHC Task 68 - Efficient Solar District Heating Systems. https://task68.iea-shc.org/Data/Sites/1/publications/Solar-District-Heating-Info-Package-of-IEA-SHC-Task-68.pdf

[20] Peeters, L., Troch, E. (2019). Heat pump driven district heating systems solution booklet. https://smart-cities-marketplace.ec.europa.eu/sites/default/files/2021-02/scis_solution_booklet_heat_pump_driven_district_heating_systems.pdf

[21] Østergaard, P. A., Werner, S., Dyrelund, A., Lund, H., Arabkoohsar, A., Sorknæs, P., Gudmundsson, O., Thorsen, J. E., & Mathiesen, B. V. (2022). The four generations of district cooling - A categorization of the development in district cooling from origin to future prospect. Energy, 253, 124098. https://doi.org/10.1016/j.energy.2022.124098

[22] Fraunhofer Institute for Energy Economics and Energy System Technology (IEE), (2023). Guidebook for the Digitalisation of District Heating: Transforming Heat Networks for a Sustainable Future D. Schmidt (Ed.), DHC Annex TS4.. https://www.iea-dhc.org/fileadmin/documents/Annex_TS4/IEA_DHC_Annex_TS4_Guidebook_2023.pdf

[23] Sharabaroff, A., Maurer, L. T. A., Glenting, C., International Finance Corporation, Public-Private Infrastructure Advisory Facility, World Bank, Unlocking the Potential for Private Sector Participation in District Heating. In International Finance Corporation [Report]. https://www.ppiaf.org

[24] European Commission: Directorate-General for Energy, Beutel, J., & Vorkapić, V. (2024). District heating toolkit : a technology overview and pathways towards decarbonisation, Publications Office of the European Union. https://data.europa.eu/doi/10.2833/666287

[25] Imana Sobrino, J., Pesce, G., Junasová, L., Giulia Malafarina, Valérie Séjourné, Dirk von Bracht, Paolo Cresci, Giulia Cittadini, Richard Martin, Urrutia, K., Torrens, I., Rodríguez Perez-Curiel, F., Peeters, L., Troch, E., & Agata Smok. (2024). District Heating and Cooling Solution Booklet. In Smart Cities Marketplace https://smart-cities-marketplace.ec.europa.eu/sites/default/files/2024-08/2024%20SCM%20Solution%20Booklet-District%20heating%20and%20cooling.pdf

References

[26] Warmtenetwerk Vlaanderen, Interreg's COBEN project, (2021). Heat networks guideline for municipalities. https://northsearegion.eu/media/7117/energielandschap-toolkitwarmtenetten-a4lig-bw-cc18_en_web-2.pdf,

[27] Bunhill Heat and Power Network (2021) https://www.islington.gov.uk/~/media/sharepoint-lists/public-records/energyservices/information/leaflets/20212022/20210923bunhillheatandpowernetworkbrochure.pdf

[28] ReUseHeat. (n.d.). Waste heat in district heating systems. https://celsiuscity.eu/files/wp-content/uploads/2021/12/211126_reuseheat_celsius_summit.pptx.pdf

[29] ReUseHeat. (2022). Brunswick - ReUseHeat. https://www.reuseheat.eu/brunswick/

[30] H.H.Erdem, Termik santrallerde atılan enerji ve bölge ısıtma uygulaması,(2014) https://mmo.org.tr/sites/default/files/gonderi_dosya_ekleri/ae46f18f573fbb0_ek_3.pdf

[31] London Climate Ready Partnership. (2024). https://climatelondon.org/

[32] Sunko, R., Sunko, B., Rutz, D., Mergner, R., Doczekal, C., Pukšec, T., Jensen, L. L., Skupina. (2017). Guideline on Improved Business Models and Financing Schemes of small renewable heating and cooling grids. https://www.coolheating.eu/images/downloads/CoolHeating_D5.1_Guideline.pdf

[33] Wiltshire, R., Williams, J., Woods, P., (2014). A technical guide to district heating, BRE https://bregroup.com/store/bookshop/a-technical-guide-to-district-heating-fb-72-download

[34] Lagoeiro H, Revesz A, Davies G, et al. Investigating the opportunity for cooling the London underground through waste heat recovery. Building Services Engineering Research and Technology. 2022;43(3):347-359. https://journals.sagepub.com/doi/10.1177/01436244221084913

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