Heat Highway

Task 3.6 Lean long-distance network technology & prototype

D3.3: Overview paper on optimal choice & combination of DH pipeline technologies

June 2024

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1 Introduction

1.1 Motivation and background

District heating (DH) systems are pivotal in addressing the challenges of energy efficiency and sustainability in urban environments globally. They serve as a cornerstone for delivering reliable and environmentally friendly heating solutions to communities, integrating seamlessly with centralized sources such as power plants or renewable energy installations. These systems distribute thermal energy through a network of pipelines to residential, commercial, and industrial consumers, offering significant advantages over individual heating systems in terms of efficiency, cost-effectiveness, and environmental impact reduction.

District heating transmission networks (in analogy to the high-voltage electricity network, i.e. no pure long-distance stub lines are meant) have hardly been scientifically researched and, with the exception of some networks that realize partial aspects or only extend over shorter distances, are hardly in use. In theory, district heating transmission networks support primary energy efficiency and CO_2 emission reduction by offering the possibility of better tapping industrial waste heat sources and distributing risks. This innovative topic is particularly interesting for Upper Austria and Styria with its energy-intensive companies (high waste heat volumes) and plant manufacturers (construction of the new type of pipelines). Due to the fact that district heating transmission networks are not yet in use, the above advantages and disadvantages need to be evaluated, as part of the Heat Highway project.

The environmental benefits of district heating extend beyond efficiency gains. By utilizing waste heat from industrial processes or renewable energy sources like geothermal or solar thermal, DH systems contribute to reducing greenhouse gas emissions and enhancing local air quality. They also support the transition towards sustainable energy practices, aligning with global climate goals and regulatory frameworks aimed at reducing carbon footprints in urban areas.

As cities continue to grow and face increasing demands for energy efficiency and resilience, district heating systems represent a sustainable solution that integrates seamlessly with urban planning and development strategies. The ongoing innovation and optimization of DH pipeline technologies play a crucial role in meeting these challenges, ensuring that communities worldwide can benefit from efficient, reliable, and environmentally responsible heating solutions both now and in the future.

1.2 Aim and method

The optimal selection and combination of DH pipeline technologies are critical aspects in the successful implementation and operation of district heating infrastructures. Engineers and planners must carefully evaluate various factors when designing these networks, including the geographical layout of the area, the energy demand profile, available energy sources, environmental considerations, and economic feasibility. Each decision impacts the overall performance and sustainability of the district heating system, influencing factors such as heat loss, energy efficiency, maintenance requirements, and long-term operational costs.

In recent years, there has been a notable evolution in DH pipeline technologies, driven by advancements in materials science, manufacturing techniques, and digitalization. Traditional materials like steel remain widely used for their strength and durability, particularly in larger diameter pipes and high-pressure applications. However, there is increasing adoption of advanced materials such as high-density polyethylene and cross-linked polyethylene, which offer advantages such as corrosion resistance, flexibility, and ease of installation.

This overview paper aims to delve into the complexities surrounding the choice and integration of DH pipeline technologies. It addresses the diverse range of materials and systems available, ranging from traditional options like steel to advanced composite materials and innovative plastic solutions. Each material offers distinct advantages in terms of thermal performance, durability, environmental impact, installation flexibility, and lifecycle cost.

By synthesizing current research, case studies, and industry practices, this paper aims to provide insights into how stakeholders (including planners, engineers, policymakers, and energy providers) can make informed decisions to optimize the design, construction, and management of DH pipeline systems. The goal is to foster sustainable development, improve energy efficiency, and meet the heating demands of urban populations effectively in the face of evolving energy landscapes and climate challenges.

Through a comprehensive examination of DH pipeline technologies, this overview paper seeks to contribute to the advancement of resilient and environmentally responsible district heating infrastructures that support the transition towards a low-carbon future.

Another objective is to develop and construct a lean-physical heat highway demonstrator, reflecting the technical specifications and criteria outlined in this deliverable. This physical demonstrator will be showcased at the Ars Electronica Center (AEC) as part of a sustainability exhibition. The exhibit aims to effectively communicate the fundamental principles of sustainable district heating and increase visitor awareness regarding heat supply. The design is intended to facilitate a clear understanding among visitors of the core concepts behind sustainable district heating, emphasizing its significance in contemporary energy systems and its role in mitigating environmental impact. It will support the developed interactive virtual-demonstrator of WP8.

2 Heat networks

The term district heating (DH) is defined differently depending on the source. Some existing definitions of district heating in the literature are explained in more detail below.

- District heating refers to the central supply of heat to buildings of different owners via a district heating network (DHN), either from a combined heat and power (CHP) or heating plant (HW) [1].
- In contrast, in Switzerland's overall energy statistics, district heating is described as follows: "District heating is defined as a heat supply in which public land is used for the main transport and distribution network and in which heat is sold to third parties" [2].
- District heating is also defined as a piped energy for supplying heat to customers via the energy carriers heating water or steam. The heat is provided centrally in a combined heat and power plant or heating plant, or drawn from another heat source. It is transported to the heat consumer for space heating, hot water heating or production purposes via heat distribution networks [3].
- According to the Article 24(6) of Directive 2012/27/EU, district heating or cooling is the distribution of thermal energy in the form of steam, hot water or chilled liquids from a central source of production through a network to several buildings or sites for the use of space or process heating or cooling [4].

The term "waste heat" is also ubiquitous, so this will also be briefly discussed:

Waste heat is the sum of all thermal energy flows leaving the balance space under consideration, and because of which an energy loss occurs (excluding conversion losses). The waste heat consists of the convection, conduction, and radiation losses as well as the thermal enthalpy of the exiting material flows. In the context of waste heat utilization, it can be used specifically in another process. If the waste heat is not supplied to other energy conversion processes, then this waste heat is released unused to the environment [3].

2.1 Classification of heat networks

Heat networks can be divided into five generations of district heating networks [5, 6] and are shown in Figure 1:

- The first generation of district heating systems used **steam above 150°C** as the heat transfer medium. These systems were first introduced in the USA in the 1880s. Typical components include steam pipes in concrete ducts, steam traps, and expansion joints. Such systems are currently considered an obsolete technology because high steam temperatures produce significant heat losses and severe accidents from steam explosions endanger human lives. In addition, condensate return tubes are often corroded, which has resulted in condensate losses and lower energy efficiency. The primary motivation for introducing these systems was to replace decentralized boilers in residential buildings to reduce the risk of boiler explosions and increase comfort [7, 8].
- The second generation of systems used **pressurized** hot water as the heat transfer medium, with **supply temperatures** usually **above 100°C.** These systems emerged in the 1930s and dominated all new systems until the 1970s. Typical components included water pipes in concrete ducts, large shell-and-tube heat exchangers, and material-intensive, large, heavy valves. In general, the primary motivation for using this technology was to achieve better comfort and fuel savings through the use of cogeneration [8].
- The third generation was introduced in the 1970s. **Pressurized water** is still the heat transfer medium, but **supply temperatures are** often **below 100°C.** Typical components are prefabricated, pre-insulated pipes buried directly in the ground, compact transfer stations with stainless steel plate heat exchangers, and low-material components. All expansions and all new systems in China, Korea, Europe, USA and Canada use this third generation technology. In general, the main motivation is to increase the security of supply, which was strongly influenced by the two oil crises [6].

- A future fourth generation of district heating technology should include lower distribution temperatures circa between 50 °C and 70 °C, assembly-oriented components, and more flexible pipe materials. In addition, an important framework for the need for further development of district heating infrastructures and district heating technologies is the change in primary motivation in various societies, namely the transformation to a future sustainable energy system. The change in temperature demand can be further improved by the introduction of heating systems that use **flow temperatures of 40 °C** and can cool the district heating water to near room temperature (20-22 °C) [8].
- Fifth-generation district heating and cooling networks are characterized by flow temperatures in the ambient range of **15-25 °C**, which not only reduces heat losses but also allows the integration of various types of low-temperature waste heat sources. The ability of these networks to absorb normally unrecoverable waste heat makes them an attractive solution for the future energy supply of urban areas [5].

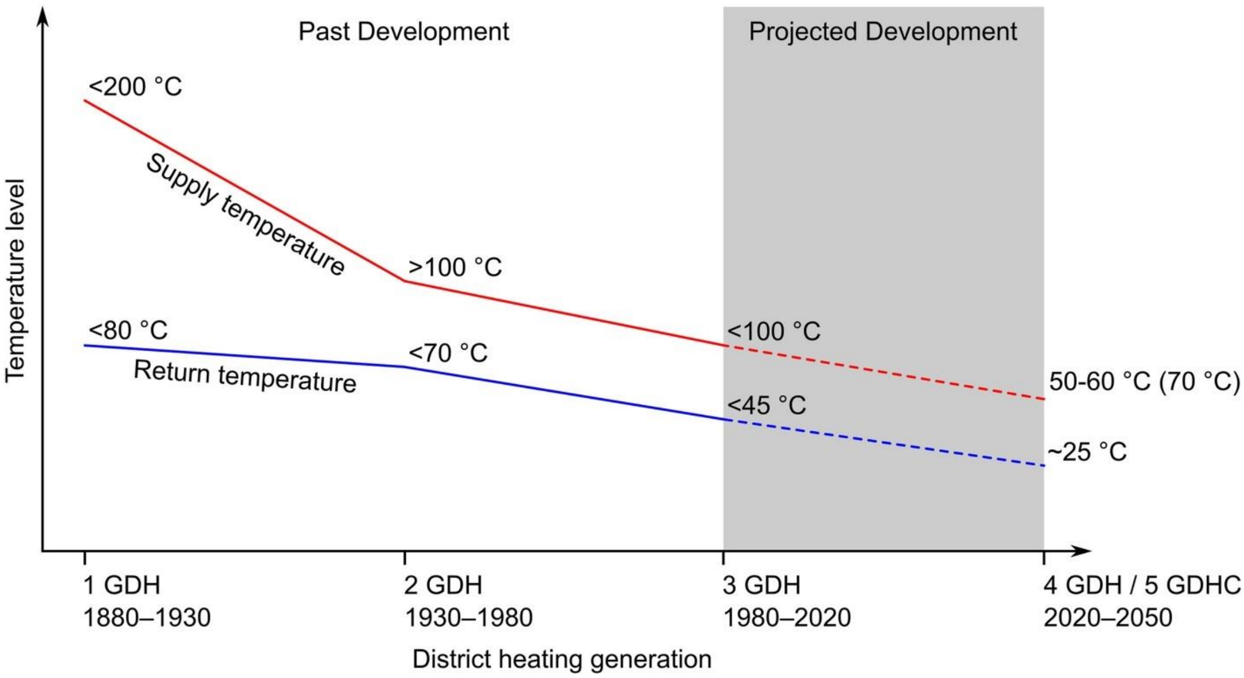

Figure 1: Generations of district heating[6]

The **return temperatures depend** on the following boundary conditions: Age and condition of the building structure to be heated, type of hot water preparation, type of hydraulic integration at the heat consumers. In addition, there are requirements for the return temperatures on the part of the heat source. In some cases, the heat utilization requires low return temperatures. In Table 1 practical values and target values for return temperatures are given. For example, the return temperatures of waste incineration plants (WIP) are between 55 and 65 °C in practice. The definition of the maximum return temperatures should be included in the heat supply contract or in the technical connection regulations (TAV). A differentiated requirement of the maximum return temperature for heating and for hot water heating is recommended. The dependence of the energy price on the return temperature could cause the achievement of the lowest possible return temperatures. The evaluation of the return temperature or temperature spread should be carried out for existing and also new district heating networks. On the basis of this, optimization potentials and malfunctions in transfer stations can be quickly identified [2].

Table 1: Guide values and practical values for return temperatures[2]

Heat Network		Return temperature
WIP > 10 MW	practice value	55-65°C
Wood firing with flue gas condensation	practice value target value	> 45°C ≤ 45°C
New build quarter value	practice value target value	> 38°C ≤ 35°C

A minimum temperature of 60 °C is required for domestic hot water heating in the house stations to ensure safety with regard to legionella. Legionella proliferation occurs mainly at temperatures of 25 to 45 °C, but at a temperature of 55 °C or higher, legionella begin to die off. This results in a minimum flow temperature for district heating pipes of 70 °C; in modern networks, 50 °C is already sufficient [1, 2].

2.2 Types of heat networks

2.2.1 District heating pipeline

District heating is also defined as a piped energy used to supply heat to customers via the energy carriers heating water or steam [3]. This energy transport from A to B takes place via district heating pipelines.

The vision of district heating pipelines [9]:

- sustainable energy supply (environmentally friendly and regional)
- Efficient heat supply with waste heat from production
- cross-industry, partnership-based cooperation

with the aim of generating a significant, positive environmental effect through particulate matter and CO_2 reduction.

Energy-economic significance of a district heating pipeline [9, 10]:

- No additional emissions from additional heating plants (e.g. gas, biomass, etc.)
- Lower emissions reduce particulate pollution and thus lead to better air quality and increased quality of life for the population
- Greater independence from natural gas and thus increased security of supply
- Image gain for all involved (CO_2 -neutral, crisis-proof, future-oriented, regional)
- Regional value creation and thus domestic job security
- No purchase and storage of fuels

2.2.2 District heating transmission network

Integrated District Heating Grids are defined as the equivalent of virtual power plants in the electricity industry. The main goal and task of these is to ensure a resource-efficient, secure, low-emission and regional supply. To this end, various regional energy feed sources such as power plants, combined heat and power plants as well as industrial waste heat sources and heat consumers are interconnected to form an energy network [1].

The transmission system is basically the part of the power grid used to transmit electrical energy over long distances [11]. Similarly, a district heating transmission network refers to the part of the district heating network used to transport heat over long distances.

A *distribution network* is a network that serves the fine distribution of e.g. electrical energy, natural gas or heat to the individual consumers [12]. As an example, the subnetworks and different levels (pressure and temperature differences exist) in an existing district heating network can be mentioned.

An interconnected grid is created by connecting several small grids. The term is mostly used in the context of electricity grids, but is also used for grids for the distribution of natural gas or other energy sources [13]. Similarly, a district heating interconnection network can mean the interconnection of several networks for the distribution of district heating, and thus symbolize a district heating transmission network.

Summary understanding of a district heating transmission system:

We understand district heating transmission networks (DTCs) to be analogous to the high-level electricity grid and define it as connecting a) multiple industrial waste heat and other sustainable sources, b) one or more district heating networks and other large consumers, c) industrial process heat sinks, d) and/or storage.

2.3 Structure of the heat networks

The main components of a district heating supply system are discussed below:

- District heating generation plant: As a consequence of the relatively high investment of district heating distribution, low-cost district heating generation by heat sources is a fundamental requirement for district heating to be competitive with decentralized systems. Consequently, district heating is usually generated from a combination of CHP plants and peak load boilers, and augmented with heat storage as needed. An integration of industrial waste heat is equally suitable with simple decoupling and low heat production costs [1].
- Heat carrier: The most commonly used heat carrier in district heating networks is water, which is available in both liquid and gaseous form. It is transported to the heat consumers in the flow pipe of a two-wire network and returned to the heat source in a return pipe [2]. The heat transfer media normally used for district heating networks are high-pressure steam (approx. 2-15 bar gauge pressure and 120-160 °C operating temperature), high-pressure hot water (approx. 6-20 bar gauge pressure and 120-180 °C operating temperature), low-pressure hot water (approx. 4-6 bar gauge pressure and 70-120 °C operating temperature) and hot water (below 100 °C operating temperature) [14].
- Pumping station: usually the pumping station of district heating networks consists of three pumps connected in parallel, where two of the three pumps are operated continuously to supply the network and the third serves as a reserve. The pumps must have the same zero head among themselves and be of the same size [1]. Circulating pumps, driven by an electric motor, are used for water circulation in district heating networks. The operation of these takes place either at constant speed or with stepless control, which is nowadays already prescribed. A distinction is made between axial and radial designs on the one hand, and between glanded and glandless pumps on the other. Glanded pumps are used for larger district heating networks. Glandless pumps, on the other hand, are used in building services and also in small district heating networks [2].
- Pressure maintenance system: An important point in network planning and operation is the system pressure. A distinction is made between the nominal pressure, the geodetic pressure, the pump pressure and the resting pressure. Hot water district heating networks are designed for nominal pressure levels PN 16 or PN 25 (PN stands for pressure nominal). The nominal pressure is determined via the geodetically lowest point in the network. The pressure at this point must not exceed the permissible system pressure in any operating case, not even in the event of pressure surges. [1]. The pressure is also limited by the EN 13941 design standard.
- District heating network: The district heating network can be divided into main, branch and house connection pipes [2]. The typical distribution and pipe systems as well as the existing installation methods are explained in more detail below in this chapter.
- House connection, house transfer station and house distribution: The house connection consists of the house connection line to the district heating network, the house transfer station and the distribution system [1]. The

house connection pipe serves to connect the district heating network with the house transfer station. The heat transfer station is defined as the link between the house connection pipe and the house central unit [2].

2.3.1 Distribution systems

The district heating network can be divided into main, branch and house connection lines. The main line corresponds to the first line from the heat center (also called trunk line or transport line). Branch lines or distribution lines originate from the main lines and act as distributors to the individual supply areas. To connect a heat consumer to a main or branch line, house connection lines are used [2].

The modern design of district heating networks is exclusively as a closed two-pipe system with water as the heat transfer medium and one supply and one return pipe each. However, there are two other possibilities, the three-pipe and the four-pipe system (Figure 2) [2].

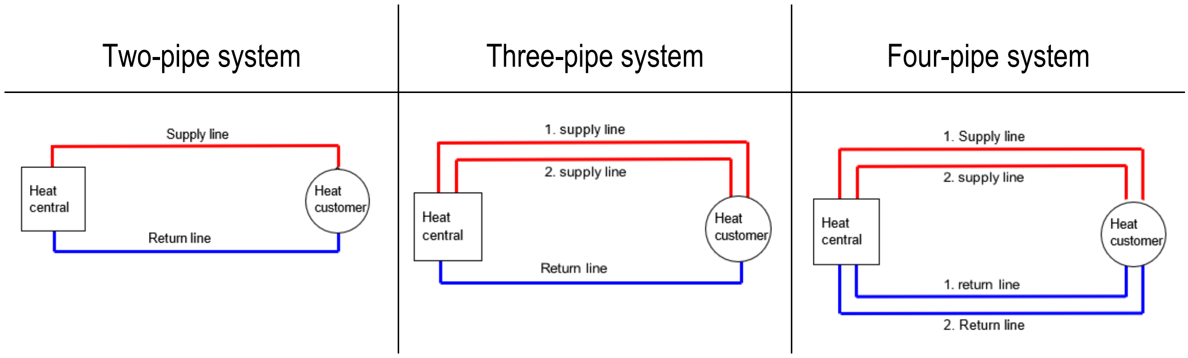

Figure 2: Subdivision according to the number of lines [2]

For district heating distribution via the pipeline network, two basic types can be distinguished, analogous to electricity networks, namely **star networks and mesh networks** [15].

As a rule, district heating networks are initially constructed as star networks. The dimensioning of flow and return is usually the same or symmetrical. The diameter of the pipelines decreases with the distance to the heat generator [2].

Advantages of a star network are the low construction costs and heat losses due to the short line lengths and small diameters. Disadvantages, on the other hand, are the hydraulic problems of subsequent extensions and the lower security of supply, because in the event of a network fault the entire line has to be shut down. [2]. A special case of the star network is the **line network**. This consists of only one main line with short service lines [15, 16, 17].

Mesh networks can be formed due to growth and densification, as well as when multiple thermal networks merge (Figure 3). A major advantage of these is a high level of supply security as a result of multiple supply routes. Mesh networks often have multiple heat centers. Pure mesh networks are rather rare, because star networks are usually connected at the periphery [2].

A special case of the mesh network is the **ring network**. This supply system has a mesh (ring) and some house connection lines [15, 16, 17].

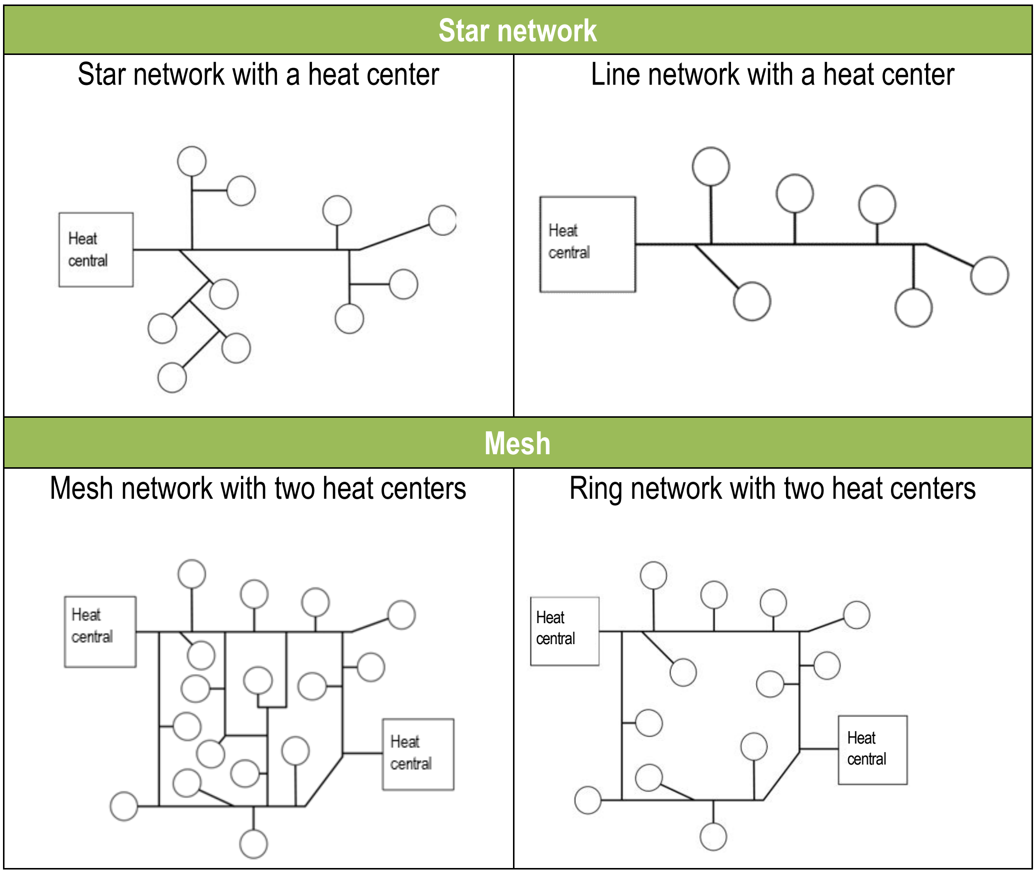

Figure 3: District heating network variants [2]

2.3.2 Transfer stations

The heat transfer station is defined as the link between the house connection pipe and the house central station. The task of the heat transfer station is to transfer the heat or the heat transfer medium to the building control center as intended with regard to pressure, temperature and volume flow [2].

The house transfer station includes the shut-off valves, the heat quantity meter, the water quantity limiter and the safety units. A distinction can be made between direct and indirect connection. The house network and the district heating network are hydraulically interconnected in the case of direct house transfer stations, whereas in the case of indirect systems there are two circuits separated by a heat exchanger. In addition, a domestic water heater (BWWB) is usually integrated [1].

2.4 Control, organization and operation

District heating network operators have two options for controlling the heat supplied to customers. Either by varying the flow rate, or by varying the temperature. Under normal operating conditions, these two variables are adjusted simultaneously. Typically, changes in volumetric flow are used for faster responses, while changes in temperature are preferred for longer-lasting responses. The greater the flow rate and the higher the supply temperature, the higher the transfer pressure and heat losses. It is the operator's responsibility to find the optimum combination while meeting the requirements with allowable tolerances. It is desirable that both the network operator and the consumer have the highest possible temperature difference in supply and return lines, so that the maximum amount of heat can be taken from the network. To avoid frost damage to the equipment, the network always maintains a minimum temperature in the pipes [7]. In this subchapter, temperature control is discussed in more detail.

For the course of the network flow temperature, there are basically three common operating modes. Figure 4 shows the flow temperature from the heat station as a function of the outdoor temperature for the three different operating modes of district heating networks (gliding-constant, constant, gliding) [2].

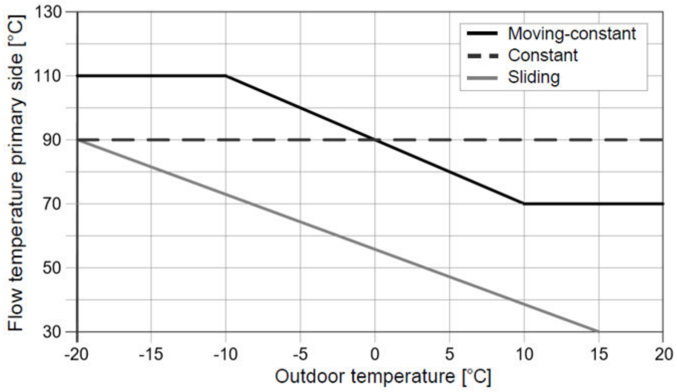

Figure 4: Three different modes of operation of district heating networks [2]

2.4.1 Sliding driving mode

The flow temperature is controlled on a sliding scale depending on the outdoor temperature. When the outdoor temperature drops, the network flow temperature is increased to the maximum value. If the outdoor temperature rises, the network flow temperature is reduced on a sliding basis until the heating limit is reached and the heat supply is stopped. The sliding mode is only suitable for supplying room heating. For consumers that are not dependent on weather conditions, such as process heat and hot water, the variable mode is unsuitable [2].

2.4.2 Moving-constant driving

The network flow temperature is controlled within defined limit values depending on the weather. If the outdoor temperature drops, the network flow temperature is increased to the maximum value on a sliding scale. When the outdoor temperature increases, however, it is reduced to the minimum value. This minimum value is determined by the minimum required network flow temperature. The gliding-constant mode is the most commonly used mode and also enables simultaneous supply for space heating, hot water and process heat. The currently measured outdoor temperature is rarely used as a reference variable for the network flow temperature. The outdoor temperature determined over a longer period of time can be used as a basis, if necessary including outdoor temperature forecasts [2].

Usually, district heating pipes are designed for a maximum flow temperature of 130 °C, which results from the polyurethane thermal protection of the plastic jacket pipes due to the material. However, the flow temperature is controlled on a sliding basis between 70 and 130 °C depending on the outside temperature [2].

2.4.3 Constant driving

In the constant mode, the network flow temperature is kept constant regardless of the outdoor temperature. In principle, all common heat consumers can be supplied if the available constant flow temperature is sufficient for the intended use. In the house station, a flow temperature control must be planned in accordance with the requirements of the respective heat consumer. Due to the constant mode of operation, there is a possibility of offering the heat output to be kept in reserve even at higher outdoor temperatures. This fact is of great importance for process heat and hot water heating. In the transitional period and in summer operation, however, this mode of operation results in high heat distribution losses [2].

2.5 Existing district heating transmission pipelines in Europe

In this section, long-distance heat transmission feed pipelines that serve as supply lines for district heating distribution networks are shown (Table 2). These pipelines connect heat sources and consumers over substantial distances. Unlike networks interconnecting multiple systems, the primary focus here is the efficiency of transporting energy over long distances. Insights gleaned from existing feed pipelines offer valuable information, such as the economical distances and the energy capacities achievable with different pipe diameters.

Table 2: District heating transmission pipelines in Europe [18]

City	Country	Capacity [MW]	Length [km]	Diameter [mm]
Linkoping-Mjolby	Sweden	25	28	-
Lindesberg	Sweden	26	17	-
Oslo	Norway	275	13	600
Helsinki	Finland	490	20	1000
Turku	Finland	340	25	800
Tilburg	Netherlands	170	25	500
Diemen-Almere	Netherlands	260	8.5	700
Almere	Netherlands	170	10	500
Viborg	Denmark	58	12	-
Oradea	Romania	546	86.3	-
Akranes	Iceland	60	62	400
Aachen	Germany	85	20	-
Gothenburg-Mölndal	Sweden	10	1.1	-
Gothenburg-Kungälv	Sweden	19	22	-
Lippendorf-Leipzig	Germany	300	15	800
Mannheim-Speyer	Germany	40	21.2	300
Boxberg-Weißwasser	Germany	40	16	400
Zolling-Flughafen München	Germany	150	28	500
Nesjavellir-Riykjavik	Iceland	290	27	800
Kozani	Greece	137	16.5	500
St. Pölten	Austria	50	31	425

2.6 Practical cost considerations for heat transmission pipelines

This section provides relevant cost considerations for heat transmission pipelines based on practical examples. Specific cost details to specific pipe technologies are elaborated in the next chapter.

Figure 5 shows typical prices for the costs of KMR pipes[1], which include laying and civil engineering. The civil engineering costs are further subdivided into trench costs in the corridor (open terrain without a paved surface) and laying in street (paved surfaces such as roads and sidewalks), which must be restored after the work is completed. Therefore, excavation costs are relatively independent of pipe diameter. However, excavation costs for laying pipes in streets are higher due to the additional expenses associated with restoration work.

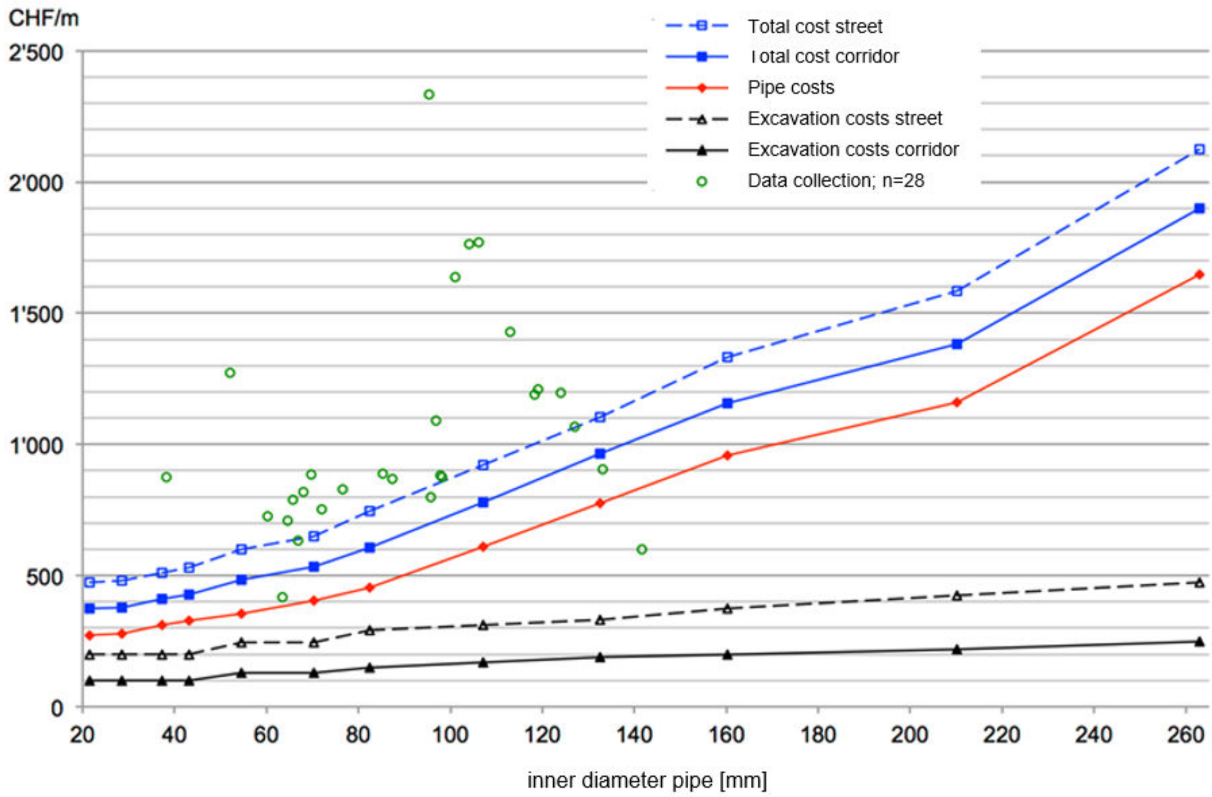

Figure 5: Projected cost of heat transmission pipelines structured into pipe and trench costs, and further divided into street and corridor costs

In Austria exist four examples that realized a long-distance heat transmission pipeline:

- **Section Arnoldstein – Villach, Kärnten:** In 2018, a 16 km district heating pipeline from the waste incineration plant in Arnoldstein was completed. The pipeline transfers 100 GWh of waste heat at a maximum supply temperature of 130 °C and 25 bar, covering about 90% of Villach's heat demand. It is a double-pipe system with an inner diameter of 30 mm each. The heat transfer station to Villach's district heating network consists of four heat exchangers with a total capacity of 19 MW. The pipeline cost €16 million (€1,000 per meter), and an additional €1 million was invested in the extraction facility at the waste incineration plant. Besides the waste heat from Arnoldstein, Villach's district heating network also utilizes waste heat from Omya GmbH in Weißenstein, biomass heating from KELAG Energie & Wärme GmbH in St. Agathen, a private biomass heating plant, and smaller amounts from landfill gas utilization and a solar plant. Natural gas is only used as a backup or for peak demand. With around 1,000 connections, the Villach district heating network has a total length of over 100 km and a heat output of approximately 200 GWh. Currently, there are no connections along the route between Arnoldstein and Villach, but this may be reviewed in the future [19, 20].
- **Section Gratkorn – Graz, Steiermark:** In the fall of 2017, an 11-kilometer district heating pipeline from Gratkorn to Graz was commissioned, utilizing waste heat from the Sappi paper mill to supply around 40,000

[1] KMR pipes will be discussed in the next chapter

households in Graz. The project partners include Bioenergie Fernwärme BWS and Energie Graz. The pipeline is a DN 300/500 (inner/outer diameter) system for supply and return lines. With a maximum connection capacity of 45 MW, it delivers about 150 GWh annually (approximately 15% of Graz's heat demand), saving around 50,000 tons of CO2 per year. Simulated heat losses range between 3.7% and 5.5%. The heat extraction costs were approximately €8 million, and the pipeline cost around €12.5 million. Therefore, the total heat transmission costs were around €1140/m. The total investment was around €23 million, with about €7 million covered by district heating subsidies from KPC, the state of Styria, the EU, and the federal government. In addition to Sappi, the steel and rolling mill Marienhütte and solar plants also feed renewable energy into Graz's district heating network. Future projects of this kind are planned to reduce the ecological footprint. Currently, about 25% of the heat demand is met from renewable sources, with plans to increase this to 50% by 2030. The largest fossil fuel contributor to the district heating network is the Mellach power plant. In case of a total failure of heat producers, the natural gas power plant of Energie Steiermark, equipped with reserve boilers, will provide the necessary heat energy [9, 21].

- **Section Leoben – Trofaiach, Steiermark:** At the end of 2014, an 8.2 km district heating pipeline connecting the Donawitz steel mill with Trofaiach was commissioned. This was made possible through a partnership between Stadtwerke Leoben, the Donawitz steel mill, and KELAG Wärme. Stadtwerke Leoben supplies KELAG Wärme with waste heat from the steel mill's production processes. The pipeline delivers 32 GWh annually to Trofaiach with a waste heat output of 18 MW, meeting the heating needs of approximately 6,500 households and saving about 6,000 tons of CO2 per year. The heat extraction facility cost Stadtwerke Leoben around €1 million, while KELAG Wärme invested approximately €6.5 million in the pipeline. This led to total heat transmission costs of around €800/m [22].
- **Section Dürnrohr – St. Pölten, Niederösterreich:** In 2009, EVN Wärme commissioned the district heating pipeline from Dürnrohr to St. Pölten. At 31 km, it is the longest district heating pipeline in Austria, supplying almost two-thirds of the district heating for the Lower Austrian capital. Heat is provided by the Dürnrohr power plant, the AVN waste incineration plant, and a biomass plant. The pipeline, with a DN 450 supply line and a DN 400 return line, transmits 200 GWh annually into the St. Pölten district heating network via two transfer stations, each with a capacity of 25 MW, saving around 40,000 tons of CO2 emissions per year. The maximum supply temperature is 140 °C, and the maximum pressure is 40 bar, with a temperature loss of 2 °C over the 31 km distance. The St. Pölten district heating network covers around 78 km and serves 10,000 customers, including the local hospital, which is also supplied with district cooling. In addition to the waste heat from Dürnrohr, the network is supplied by the North and South combined heat and power plants and a CHP plant at the Salzer paper mill in cooperation with EVN. To comply with the Paris Climate Agreement, EVN decided to shut down the Dürnrohr coal power plant in the fall of 2019. To ensure continued electricity and heat production in the region, EVN will invest around €20 million in a photovoltaic system and an expansion of the waste incineration plant. In the future, sewage sludge will also be used at the site for electricity and heat production [23, 24, 25, 26].

Based on the analyzed examples, the total cost for heat transmission (excluding extraction or integration) varies between €800 and €1,140 per meter. These figures highlight the significant investment required for district heating infrastructure, reflecting both the material and installation costs associated with different projects. Despite the high initial costs, these systems provide substantial long-term benefits, such as significant CO_2 savings and efficient utilization of waste heat, contributing to more sustainable heating solutions.

3 Heat pipes

Important influencing parameters for the selection of the pipe system and the suitable installation technique are the network temperature and the network pressure. Apart from this, the site conditions (e.g. surroundings, roads, groundwater, soil conditions, etc.) play an important role [2].

The most commonly installed pipe systems, and thus the standard, are plastic multilayer pipes (KMR), which are particularly suitable due to their stability, pressure and temperature resistance, and low material costs. In the field of sub-distribution and house connection lines, flexible pipe systems such as plastic medium pipes (PMR) and metal medium pipes (MMR) are mainly used [2]. The individual pipe types are explained in more detail below.

Table 3 contains an overview of the most common pipe systems and their most important properties.

Table 3: Overview of the pipe systems [2, 27, 28]

Tube system	Scope				Available lengths			
	Maximum permissible operating temperature	Continuous operating temperature	Nominal pressure PN	Nominal diameter DN	Rods	Rollers	Double pipe design up to DN	Feature
	°C	°C	bar	-	m	m	-	-
PMR	95	80	6	20-150	12*	Up to 780	DN50	Relatively favorable→ Limited pressure and temperature resistance
KMR	160	Up to 130 (140 only for peak temp.)	25	20-1200 (usually DN20 - DN800)	6/12/16*	-	DN200	Due to the standardization and robustness the most widely used pipe system
GRP	160	160	16	25-1000	6*	-	-	Relatively expensive→ only for special corrosion resistance requirements
MMR	180	Up to 160	25	20-150	12*	Until 1000	DN50	Relatively expensive→ justified if the laying conditions make it necessary
HTR	-	250	-	20-400	-	-	-	Relatively expensive→ only if temperature conditions make it necessary
SMR	400	400	64	25-1200	16*	-	**	Relatively expensive→ only if the pressure, temperature or installation conditions make it necessary

*Standard length/s, other lengths available on request. ** Special designs possible on request (e.g. multiple tube design).

Double tube designs are available for the KMR, MMR and PMR pipe systems in the lower nominal size. The steel casing pipe can be used in double or multiple pipe design for special applications. Double-pipe and multiple-pipe systems have the following advantages over single-pipe systems: low installation costs (smaller trench width), lower specific heat losses, halved number of socket joints, core hole drilling and wall seals for house entry, and lower number of expansion legs. The thermal insulation in the double pipe is intended to keep the heat transfer from the flow to the return low so that the return temperature is not increased undesirably. A disadvantage of double-pipe designs is the high cost of subsequent installation of a branch. In addition, due to the stiffness of the KMR double pipes, the pipe routing must be precisely excavated. The available standard nominal diameters from established companies are listed in Table 4 [2].

Table 4: Standard available nominal diameters (highlighted in gray) for the pipe systems KMR, MMR, and PMR (including details of insulation thickness and offer for duo-pipe design; based on availabilities of the companies: Brugg Rohrsysteme, Isoplus and Logstor)

DN	KMR			KMR–Duo			MMR		MMR–Duo		PMR		PMR–Duo	
	DS1	DS2	DS3	DS1	DS2	DS3	S	V	S	V	S	V	S	V
20	■	■	■	■	■		■		■		■	■	■	■
25	■	■	■	■	■		■	■	■		■	■	■	■
32	■	■	■	■	■		■	■	■		■	■	■	■
40	■	■	■	■	■		■	■	■		■	■	■	■
50	■	■	■	■	■		■	■	■	■	■	■	■	
65	■	■	■	■	■		■	■			■	■		
80	■	■	■	■	■		■	■			■	■		
100	■	■	■	■	■		■				■	■		
125	■	■	■	■	■		■				■			
150	■	■	■	■	■		■				■			
200	■	■	■	■	■									
250	■	■	■											
300	■	■	■											
350	■	■	■											
400	■	■	■											
450	■	■	■											
500	■	■	■											
600	■	■	■											
700	■	■	■											
800	■	■	■											
900	■	■												
1000	■													

Note:

- DS: Insulation thicknesses for KMR, ascending in thickness from 1 to 3
- S: Standard insulation for MMR and PMR
- V: Reinforced insulation for MMR and PMR.

3.1 Plastic composite pipe (Kunststoffverbundmantelrohr – KMR)

3.1.1 Characteristics

The most commonly used district heating pipes are plastic multilayer pipes (KMR). They have high pressure and temperature resistance, which is why they can be used in many situations. The main components of rigid KMR are a steel service pipe, an insulation layer of rigid polyurethane foam (PUR), a casing pipe of high-density polyethylene (HDPE), and a sensor for leakage controls (see Figure 6). It is a non-self-compensating pipe system, therefore thermal expansion is transferred to the overall pipe system [2].

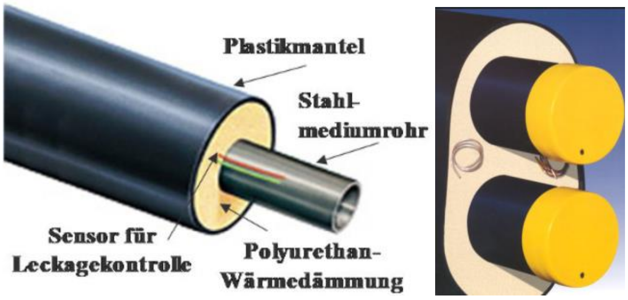

Figure 6: KMR in single (right) and double tube version (left) [1]

According to various manufacturers, continuous operating temperatures of up to **140°C (peak temperature)** at a pressure of up to **25 bar are** guaranteed. Existing nominal widths are listed in Table 5. Many fittings are necessary in case of complicated routing and difficult conditions (plant pipelines, etc.), consequently the installation is relatively expensive. However, due to the low material costs and in order to guarantee a high level of operational reliability, KMR have basically established themselves as the standard solution, especially for larger diameters from DN 100. The individual pipes are usually joined by welding or, in the case of smaller nominal diameters (up to DN 100), also by press-fitting [2].

KMR-pipes are the most common way for district heating up to +130°C. There are light differences in manufacturing of the foaming (continuous vs discontinuous). Continuous foaming is only available in longer pipe pieces and up to DN200. An advantage of continuous foaming is a about 10% better heat transfer coefficient [28].

Discontinuous foaming is able for all available pipe dimensions in all variations [28].

The manufacturing has to be according to EN 253 to fulfill the regulatory requirements. The German technical standard AGFW FW 401 has also to be fulfilled in many projects [28].

Generally, the legal requirements of district heating is the "Rohrleitungsgesetz StF: BGBl. Nr. 411/1975" (with all changes). The "Druckgerätegesetz StF: BGBl. I Nr. 161/2015" (with all changes) can only be used in power- or heat exchanger stations [28].

Table 5: KMR dimensions and specific heat loss for nominal diameters of DN20 - DN1000 (based on data from the manufacturers Brugg Pipesystems, Isoplus and Logstor)[2]

Nominal width	Medium inner pipe				Outer diameter of casing pipe (insulation thickness)			Specific heat loss per meter of track		
	Outer diameter	Wall thickness	Inside diameter	Inner pipe volume	DS1	DS2	DS3	DS1	DS2	DS3
DN	mm	mm	mm	l/m	mm	mm	mm	W/(m K)	W/(m K)	W/(m K)
20	26.9	2.65	21.60	0.37	90	110	125	0.284	0.248	0.229
25	33.7	2.60	28.50	0.64	90	110	125	0.342	0.291	0.266
32	42.4	2.60	37.20	1.09	110	125	140	0.354	0.317	0.290
40	48.3	2.60	43.10	1.46	110	125	140	0.403	0.356	0.322
50	60.3	2.90	54.50	2.33	125	140	160	0.450	0.398	0.350
65	76.1	2.90	70.30	3.88	140	160	180	0.527	0.446	0.393
80	88.9	3.20	82.50	5.35	160	180	200	0.547	0.469	0.416
100	114.3	3.60	107.10	9.01	200	225	250	0.576	0.490	0.432
125	139.7	3.60	132.50	13.79	225	250	280	0.663	0.562	0.482
150	168.3	4.00	160.30	20.18	250	280	315	0.777	0.633	0.531

200	219.1	4.50	210.10	34.67	315	355	400	0.844	0.670	0.555
250	273.0	5.00	263.00	54.33	400	450	500	0.820	0.656	0.556
300	323.9	5.60	312.70	76.80	450	500	580	0.933	0.744	0.578
350	355.6	5.60	344.40	93.16	500	560	630	0.912	0.719	0.589
400	406.4	6.30	393.80	121.80	560	630	730	0.964	0.744	0.579
450	457.2	6.30	444.60	155.25	630	670	800	0.970	0.839	0.605
500	508.0	6.30	495.40	192.75	710	800	900	0.941	0.728	0.595
600	610.0	7.10	595.80	278.80	800	900	1000	1.125	0.836	0.679
700	711.0	8.00	695.00	379.37	900	1000	1100	1.266	0.938	0.761
800	813.0	8.80	795.40	496.89	1000	1100	1200	1.409	1.042	0.842
900	914.0	10.00	894.00	627.72	1100	1200	-	1.542	1.141	-
1000	1016.0	11.00	994.00	776.00	1200	1300	-	1.678	1.241	-

3.1.2 Costs

The basis of the cost comparison is the KMR pipe, as this system is the most widely used. For a typical network of 5 km pipe length (flow and return) in DN200, the costs are approximately 460 EUR/pipe meter (material and installation, without earthworks; not route meter). For a route length of 1 km (flow and return) in DN50 for house connections, the costs are approximately 280 EUR/line meter.

Prices for the same network with KDMR pipes (double tube version) are: DN200 appr. 560 and 225 EUR/pipe meter (material and installation, without earthworks; not route meter).

The price basis is the year 2023 [28].

3.2 Plastic medium pipe (Kunststoffmediumrohr – PMR)

3.2.1 Characteristics

The main components of flexible plastic medium pipes (PMR) are a medium pipe made of cross-linked polyethylene (PEX) or polybutene (PB), a diffusion barrier for oxygen, a sensor for leakage control, a thermal insulation, and a jacket with a similar design to KMR, cf. Figure 7 [2].

Figure 7: PMR in single (right) and double tube version (left) [29]

The maximum operating temperature is 95 °C and the pressure limit is 6 bar (heating) and 10 bar (sanitary, drinking water). The continuous operating temperature, on the other hand, is 80 °C and the maximum pressure is 6 bar, guaranteeing a service life of 30 years. Due to the limited operating parameters of temperature and pressure, the use of PMR is limited to small to medium-sized district heating networks. The individual pipes are connected by means of press couplings or welding [2].

Compared to CMR, PMR can be more easily adapted to local conditions. Compared to the metal medium pipes (MMR) described below, PMR are cheaper, more flexible and allow tighter radii. The demands on construction and installation personnel are also lower [2]. Further advantages are absolute corrosion resistance, compensation-free installation, short installation times and easy handling due to low weight. [1]. As a result of these advantages, PMR are mostly preferred over MMR when the lower pressure and temperature resistance allow it. The disadvantages, however, are the cost-intensive fittings, the complex technology of subsequent connection and the higher material costs, which increase disproportionately with the diameter [2].

Table 6: PMR dimensions and specific heat loss for nominal diameters of DN20 - DN150 (based on data from the manufacturers Brugg Pipesystems and Isoplus)[2]

Nominal width	Medium inner pipe				Outer diameter of casing pipe (insulation thickness)			Specific heat loss per meter of track		
	Outer diameter	Wall thickness	Inside diameter	Inner pipe volume	DS1	DS2	DS3	DS1	DS2	DS3
DN	mm	mm	mm	l/m	mm	mm	mm	W/(m K)	W/(m K)	W/(m K)
20	25.0	2.30	20.40	0.33	75	90	-	0.264	0.235	-
25	32.0	2.90	26.20	0.54	75	90	-	0.321	0.279	-
32	40.0	3.70	32.60	0.83	90	110	-	0.332	0.284	-
40	50.0	4.60	40.80	1.31	110	125	-	0.341	0.307	-
50	63.0	5.80	51.40	2.07	125	140	-	0.378	0.340	-
65	75.0	6.80	61.40	2.96	140	160	-	0.405	0.356	-
80	90.0	8.20	73.60	4.25	160	180	-	0.429	0.380	-
100	110.0	10.00	90.00	6.36	160	180	-	0.557	0.476	-
125	125.0	11.40	102.20	8.20	180	-	-	0.567	-	-
150	160.0	14.60	130.80	13.44	250	-	-	0.511	-	-

3.2.2 Costs

Based on the KMR pipe system the cost for material and installation are about 80% of the KMR System (DN50).

3.3 Metal medium pipe (Metallmediumrohr – MMR)

3.3.1 Characteristics

Metal medium pipes (MMR) are composed of a carrier pipe, insulation material and jacket (cf.Figure 8). The latter are designed in the same way as for MMR. To ensure the flexibility of MMR, the carrier pipes usually consist of a corrugated copper or steel pipe or, for small pipe diameters, also of soft-annealed straight steel or copper pipes [2].

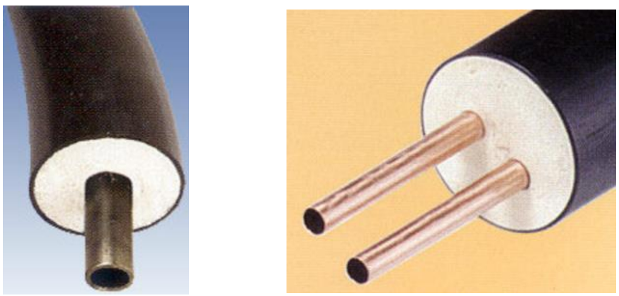

Figure 8: MMR in single and double tube design [29]

In continuous operation, MMR are used up to a temperature of **160 °C** and a pressure of **25 bar.** Existing nominal widths are listed in Table 7. The corrugated pipe systems are produced in rolls up to DN 150 and are fully self-compensating. The straight pipe systems, on the other hand, are self-compensating to a limited extent and are therefore only offered in rolls for small diameters. Accordingly, both systems do not require any compensation measures and allow flexible routing. For this reason, MMR are used for service lines [2].

One consequence of the corrugated profile is an increased pressure loss, which is why a larger nominal size must sometimes be selected for corrugated pipes than for smooth pipes. Another disadvantage is the complicated subsequent connection, which is only possible when the network is out of service. Advantages, however, are the simple installation and the low civil engineering volume. Due to the higher cost of MMR compared to PMR, MMR is only used when the higher pressure and temperature resistance are necessary [2].

MMR are a flexible pipe system, delivered in rolls. Therefore, the connection work (f.e. welding) is reduced. Bending diameters have to be considered in planning.

Table 7: MMR dimensions and specific heat loss for nominal diameters of DN20 - DN150 (based on data from the manufacturer Brugg Pipesystems)[2]

Nominal width	Medium inner pipe				Outer diameter of casing pipe (insulation thickness)			Specific heat loss per meter of track		
	Outer diameter	Wall thickness	Inside diameter	Inner pipe volume	DS1	DS2	DS3	DS1	DS2	DS3
DN	mm	mm	mm	l/m	mm	mm	mm	W/(m K)	W/(m K)	W/(m K)
20	25.5	0.3	22.00	0.38	91	-	-	0.245	-	-
25	34.0	0.3	30.00	0.71	91	111	-	0.307	0.265	-
32	43.8	0.4	38.90	1.19	111	126	-	0.325	0.294	-
40	54.5	0.5	48.50	1.85	111	126	-	0.401	0.354	-
50	66.5	0.5	60.00	2.83	126	142	-	0.443	0.390	-
65	85.6	0.60	75.80	4.51	178	-	-	0.396	-	-
80	109.2	0.80	98.00	7.54	178	233	-	0.542	0.394	-
100	142.9	0.90	127.00	12.67	233	-	-	0.540	-	-
125	162.7	1.00	147.00	16.97	233	-	-	0.683	-	-
150	218.0	1.20	197.50	30.64	313	-	-	0.693	-	-

3.3.2 Costs

The MMR system is not used in a high quantity or only for special cases. Therefore no prices are available for the material. We estimate for the MMR pipe system an about 100% higher price than for KMR at the same temperatures. The price factor increases 5-fold at higher temperatures, as expansion compensation with elbows is necessary.

3.4 Glass fiber reinforced plastic pipe (Glasfaserverstärktes Kunststoffrohr – GRP Rohr)

3.4.1 Characteristics

A GFRP pipe consists of a rigid glass fiber reinforced plastic, namely an epoxy resin pipe (cf. Figure 9). This has an insulating layer of PUR and a PE jacket. GRP pipes have low weight and their main advantage is corrosion resistance, which is why GRP pipes are mainly used for corrosive media such as geothermal spring water. The load limit in continuous operation is **160 °C** and **16** bar [2, 30].

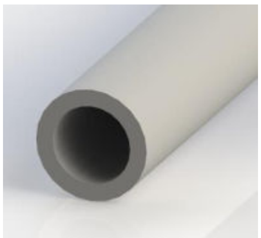

Figure 9: GRP in single tube design [31]

The individual pipes and fittings are connected by bonding. One advantage of FRP is the simpler pipe network statics than with CMR. A disadvantage is that subsequent connections can only be made when the pipeline is empty. In addition, depending on the pipe length, concrete abutments have to be realized for changes of direction. Due to the high material price, GRP pipes are only used for special requirements and in particular for corrosive media. [2].

3.4.2 Costs

The GRP system is not used in a high quantity, but only for special cases. Therefore, no general prices are available for the material and specific enquiries must always be made.

3.5 Pre-insulated high-temperature pipe (Hochtemperaturrohr – HTR)

3.5.1 Characteristics

A pre-insulated pipe basically consists of three components: Media pipe, insulation and jacket. The media pipe is located inside and is usually a steel pipe. This is surrounded by an insulation layer, which in the case of the high-temperature system consists of two layers. A layer of mineral wool on the inside and a layer of polyurethane foam (PUR) on the outside. The mineral wool protects the PUR insulation from temperatures exceeding 140 °C. To prevent moisture from penetrating the insulation, the pipe is externally covered with a protective jacket made of polyethylene (PE), see Figure 10 [27].

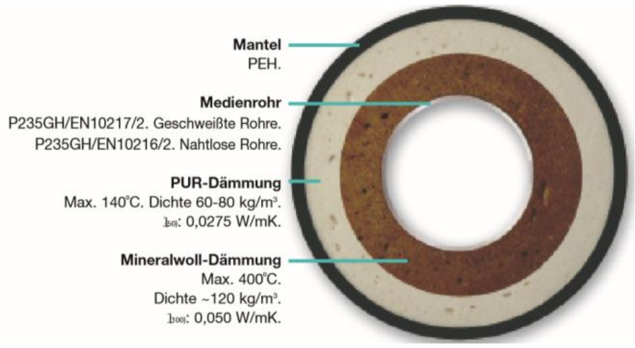

Figure 10: Structure of a HT pipe in single pipe design [27]

Preinsulated high-temperature pipes can be installed both above ground and underground and are used for operating temperatures from **120 to 250 °C** [27].

The inner insulation layer is made of mineral wool to reduce the temperature in a suitable technical value. The mineral wool insulation is also used to compensate the thermal expansion of the steel pipe. This is necessary to prevent an overload of the plastic layer on the outside of the pipe.

Therefor the usable temperature is up to +250°C. When using fluid water as heating media the limit is at about +215°C (evaporation pressure 20 bar → operating pressure at least 25 bar). 250°C can only be used with a media, which do not need a higher pressure (f.e. water steam).

3.5.2 Costs

The HT system is used only for special cases (higher temperature). The price factor increases 5 to 10-fold at higher temperatures compared to KMR, as expansion compensation with elbows is necessary.

3.6 Steel cased pipe (Stahlmantelrohr – SMR)

3.6.1 Characteristics

In contrast to KMR, in steel casing pipes (SMR) the casing pipe is made of steel, cf. Figure 11. As a result, temperatures of up to **400 °C** and pressures of up to **64 bar** are possible. Due to the high cost of SMR, they are only used in very large heat networks with high temperatures or for industrial purposes. A permanent vacuum is created between the jacket pipe and the media pipe, which acts as a thermal insulation. Thanks to this, heat losses are lower than in other systems and at the same time it serves for leakage detection. A layer of mineral fiber is also installed to reduce heat radiation. The connection of the individual pipe sections is done by welding [2].

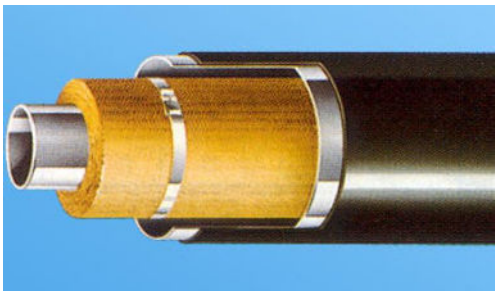

Figure 11: Structure of an SMR in single tube design [29]

3.6.2 Costs

The SMR system is used only for special cases (higher temperature). The price factor increases more than 10-fold at higher temperatures compared to KMR, as expansion compensation with elbows is necessary.

3.7 Other pipe systems

There are numerous specialized district heating pipe systems that are designed for specific applications, each tailored to meet specific operational or environmental requirements. These systems often have unique features or configurations, making them ideal for certain niche uses but not suitable for handling high levels of power transmission over large networks. While they may offer advantages in terms of efficiency, flexibility, or compatibility for smaller-scale projects, their limited capacity and specialized design prevent them from being employed in large-scale energy distribution systems where significant heat or power needs to be transmitted efficiently over long distances. In large-scale applications, standard technology is typically employed primarily for cost efficiency.

3.8 Manufacturers

There are several manufacturers in Europe offering a broad portfolio of district heating pipe technologies:

- **Denmark:** LOGSTOR, Isoplus
- **Switzerland:** Brugg Pipesystems

- **Finland:** Uponor Infra, KWH Pipe
- **Netherlands**: Thermaflex
- **Germany:** Rehau, Aquatherm, Mannesmann, KMR Service GmbH
- **United Kingdom:** Pipetech, PermaPipe
- **Sweden:** Powerpipe Systems,
- **Poland:** ZPU Międzyrzecz
- **Austria:** POLYGON Rohrsysteme GmbH, RK Infra GesmbH, Uponor GmbH, PERMA PIPE Austria GmbH

4 Laying types

To ensure a network life of at least 30 years, attention should be paid to protecting the strength and thermal insulation from mechanical stress when laying district heating pipelines [1]. The many main installation options are above-ground or underground, the latter of which can be in a duct, in a trench, or trenchless [2].

4.1 Above ground laying

Above-ground installations preferably take place on concrete bases, on supports (concrete or steel columns) or suspended from pendulum supports and mostly occur in industrial areas without special design requirements, cf. Table 8 [1].

Disadvantages of above-ground installation are the high stress on the pipe supports due to the fluid mass and the forces from thermal expansion, the high demands on architecture and landscape design, the consideration of weather influences (UV radiation, frost, corrosion) and the taking of measures against vandalism. Two important advantages of above-ground installations are the attractive operating technology and the good economic efficiency, since overhead lines are basically the most cost-effective type of installation [1, 2].

4.1.1 Heat losses of above ground pipelines

The heat loss can be calculated using Eq. (1) where the internal heat transfer coefficient and the thermal conductivities of the pipes are assumed to be infinite for simplification. The specific heat loss rate can be determined using Eq. (2) can be determined. For thermally insulated pipes in buildings and ducts, an average value of approximately 9.7 W/m²K can be used for the external heat transfer coefficient. For overhead lines, on the other hand, the external heat transfer coefficient depends on the wind speed. A value of 23.2 W/m²K can be used as an average value [2].

$$\dot{Q}_V = U_R \; A_R \; \Delta T = \frac{2 \; \pi \; l \; (T_a - T_i)}{\frac{1}{\lambda_D} \ln\left(\frac{r_D}{r_R}\right) + \frac{1}{r_D \; \alpha_a}} \tag{1}$$

$$\dot{q}_V = \frac{\dot{Q}_V}{l} = \frac{2 \; \pi \; (T_a - T_i)}{\frac{1}{\lambda_D} \ln\left(\frac{r_D}{r_R}\right) + \frac{1}{r_D \; \alpha_a}} \tag{2}$$

$\dot{q}_V$... Specific heat dissipation [W/m]

U_R ... Heat transfer coefficient related to the outer pipe radius of the pipe carrying the medium [W/m² K].

ΔT... Temperature spread [K]

A_R... Jacket area of the outer media-carrying pipe [m²]

r_R... Outer pipe radius of the pipe carrying the medium [m].

r_D... Radius of thermal insulation [m]

α_a... External heat transfer coefficient [W/m² K].

λ_D... Thermal conductivity of the insulation [W/mK].

$\dot{Q}_V$... Heat loss [W]

T_i... Inside temperature [K]

l... Length of the pipe [m]

T_a... Outdoor temperature [K]

4.2 Underground laying

4.2.1 Underground laying in the channel

Their share in the totality of the installation methods used was very high in the past. The pipes in the ducts were usually insulated with glass or rock wool mats or shells and then covered with bituminous felt. The advantages of underground laying in impassable ducts are the solid, robust and safe construction and the resulting long service life. The disadvantages of this are the high laying costs and the large area required for the civil engineering work. For this reason, this type of installation is only used in exceptional cases for new developments [1, 2].

4.2.2 Underground laying in the trench

Underground installation in trenches with casing pipes is the most common installation method because of its numerous advantages, some of which are: a low level of civil engineering work required compared with the other underground installation methods, elimination of costly shaft structures, possible use in difficult ground conditions (e.g. groundwater areas), high installation speed due to a high degree of prefabrication of the prefabricated components, and great flexibility in routing due to prefabricated fittings. A disadvantage of this installation method is that special care is required in making and thermally insulating the joints under site conditions. Consequently, this work is offered as a service only by specialized companies [2].

4.2.3 Trenchless laying

Tunneling techniques (e.g. flush drilling, culverts, etc.) are used to pass under objects (e.g. roads, railroad lines, etc.). In the case of trenchless installation techniques, a distinction can be made between soil displacement and soil removal methods. The latter are distinguished between steerable and non-steerable methods. A sufficiently precise alignment of the borehole must take place at the beginning in the case of the non-controllable methods. In the soil displacement method, a cavity is created by a displacement cone driven into the soil, into which the pipe is pushed. In the soil extraction method, on the other hand, the earth material is loosened by a rotating drill head or a horizontally driven open pipe and transported mechanically, hydraulically or pneumatically into the starting pit [2].

Table 8 shows practical installation examples of district heating pipelines:

Table 8: Practical examples of laying district heating pipelines

Relocation	Overhead line	In the channel	In the trench	Trenchless
Image				
Sources	[1]	[32]	[33]	[34]

Table 9 provides an overview of the advantages and disadvantages of the different types of buried CMR.

Table 9: Overview, advantages and disadvantages of laying buried CMR [2]

Laying		Advantage	Disadvantage
Cold laying method 1	Cold laying	Low axial stresses from thermal expansion Pipe trench can be backfilled immediately	Maximum permissible operating temperature ≤ 85°C
	Conventional	Maximum permissible axial stress is not exceeded Pipe trench can be backfilled immediately	The permissible installation length must be maintained by arranging the necessary expansion legs (L, Z, U)
Cold laying method 2	Concerning self-biasing	Pipe trench can be backfilled immediately Saving of expansion legs Possibly also possible in the sliding area	Extremely large expansion movements Risk of buckling Axial stresses exceed the yield strength of the material Night-time tapping not possible
Therm. preload		Limiting the axial tension Any laying length Low axial elongation Saving on expansion legs	Pipe trench must be kept open until the prestressing has been completed Depending on the method, an adjustable operating medium or a 380 V

5 Technical basics

In this chapter, the heat and pressure losses of the district heating pipeline are explained in more detail. The heat and pressure losses on the consumer and producer side are not considered. The pipe system (material, dimensioning, insulation thickness, laying, etc.) and the operating conditions of the district heating network (temperature level, temperature spread, operating regime, etc.) influence the heat losses of the district heating distribution. In this chapter, the two most common pipe systems are discussed in more detail - above-ground pipes and buried pipes.

5.1 Heat losses

In principle, heat losses occur in both above-ground and buried pipelines. The heat losses are dependent on the material of the pipe, the insulation, and the diameter. However, the calculation of the occurring heat losses of these two installation options differs.

5.1.1 Heat losses from above-ground pipes

The heat loss can be calculated using Eq. (3), whereby the internal heat transfer coefficient and the thermal conductivities of the pipes are assumed to be infinitely large for simplification purposes. The specific heat loss can be determined using Eq. (4). For thermally insulated pipes in buildings and ducts, an average value of approx. 9.7 W/m²K can be used for the external heat transfer coefficient. For overhead lines, on the other hand, the external heat transfer coefficient depends on the wind speed. A value of 23.2 W/m²K can be used as an average value [2].

$$\dot{Q}_V = U_R \; A_R \; \Delta T = \frac{2 \; \pi \; l \; (T_a - T_i)}{\frac{1}{\lambda_D} \ln\left(\frac{r_D}{r_R}\right) + \frac{1}{r_D \; \alpha_a}} \tag{3}$$

$$\dot{q}_V = \frac{\dot{Q}_V}{l} = \frac{2 \; \pi \; (T_a - T_i)}{\frac{1}{\lambda_D} \ln\left(\frac{r_D}{r_R}\right) + \frac{1}{r_D \; \alpha_a}} \tag{4}$$

$\dot{q}_V$… Specific heat loss capacity [W/m]
U_R… Heat transfer coefficient related to the outer pipe radius of the media-carrying pipe [W/m^{2}K]
ΔT... Temperature spread [K]
A_R… Surface area of the outer media-carrying pipe [m^2]
r_R… Outer pipe radius of the media-carrying pipe [m]
r_D… Radius of the thermal insulation [m]
α_a… External heat transfer coefficient [W/m^{2}K]
λ_D… Thermal conductivity of the thermal insulation [W/mK]
$\dot{Q}_V$… Heat loss capacity [W]
T_i… Internal temperature [K]
l… Length of the pipe [m]
T_a… Outside temperature [K]

5.1.2 Heat losses of buried pipes

District heating pipes are usually laid underground. Steel or plastic pipes are solidly designed with thermal insulation and are encased by a jacket pipe [35]. The heat transport can be considered approximately as a stationary process, because the following statements are valid [2]:

- In the insulation material of the pipe, the reduction of about 80 to 90% of the temperature difference between the pipe and the earth's surface occurs [2].
- The ground temperature, due to the large damping, is only influenced in the immediate vicinity of the pipe by temperature oscillations with short period durations and can therefore be neglected. [2]
- For the outdoor temperatures of the earth's surface or the outdoor air and groundwater, temporal mean values are used [2].

The total heat transfer coefficient is composed of three parts: a) the mutual influence of the two pipes, b) the heat conduction through the soil, and c) through the insulation material of the pipe (cf. Figure 12). Analogous to the previous chapter, the thermal conductivity of the pipes and the internal heat transfer coefficient are neglected [2].

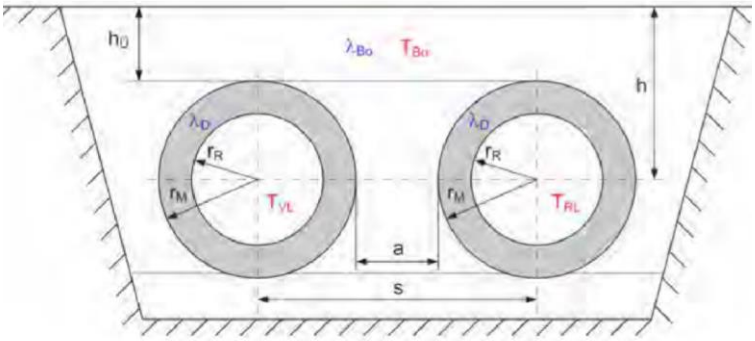

Figure 12: Buried district heating pipes in single pipe design [2]

For the sake of simplicity, the remainder of this section deals with buried district heating pipelines with steel medium pipes in single pipe design (KMR). Flexible pipe systems such as MMR and PMR can be calculated in an analogous way. The following properties apply to the simplified calculation of the specific heat loss performance for underground district heating pipelines with rigid steel service pipes in single pipe design: service pipe is made of steel, jacket pipe is made of plastic (PE), polyurethane foam (PUR) firmly bonded to the service and jacket pipe as insulation material, the flow and return pipes have the same nominal diameter and only the individual calculation of a partial pipe run is possible [2].

Eq. (5) is used to calculate the heat loss for the supply and return lines of a partial line. The specific heat loss can be determined using Eq. (6) to determine the specific heat loss. Eq. (7) on the other hand, is used to calculate the specific heat loss per linear meter of pipe of district heating pipelines laid underground [2].

$$\dot{Q}_V = \frac{4\,\pi\,L\left(\frac{T_{VL}+T_{RL}}{2}-T_{Bo}\right)}{\frac{1}{\lambda_D}\ln\left(\frac{r_M}{r_R}\right)+\frac{1}{\lambda_{Bo}}\ln\left(\frac{4\left(h_Ü+r_M\right)}{r_M}\right)+\frac{1}{\lambda_{Bo}}\ln\left\{\left[\left(\frac{2\left(h_Ü+r_M\right)}{a+2\,r_M}\right)^2+1\right]^{0.5}\right\}} \tag{5}$$

$$\dot{q}_V = \frac{4\,\pi\left(\frac{T_{VL}+T_{RL}}{2}-T_{Bo}\right)}{\frac{1}{\lambda_D}\ln\left(\frac{r_M}{r_R}\right)+\frac{1}{\lambda_{Bo}}\ln\left(\frac{4\left(h_Ü+r_M\right)}{r_M}\right)+\frac{1}{\lambda_{Bo}}\ln\left\{\left[\left(\frac{2\left(h_Ü+r_M\right)}{a+2\,r_M}\right)^2+1\right]^{0.5}\right\}} \tag{6}$$

$$\dot{q}_{VL} = \frac{4\,\pi}{\frac{1}{\lambda_D}\ln\left(\frac{r_M}{r_R}\right)+\frac{1}{\lambda_{Bo}}\ln\left(\frac{4\left(h_Ü+r_M\right)}{r_M}\right)+\frac{1}{\lambda_{Bo}}\ln\left\{\left[\left(\frac{2\left(h_Ü+r_M\right)}{a+2\,r_M}\right)^2+1\right]^{0.5}\right\}} \tag{7}$$

$\dot{q}_{V,L}$... Specific heat loss per line meter of pipe [W/mK].

U_R... Heat transfer coefficient related to the outer pipe radius of the pipe carrying the medium [W/m² K].
A_{VR}... Jacket area of both outer media-carrying pipes for supply and return line [m²]
r_R... Outer radius of the pipe carrying the medium [m]. r_M... Radius of thermal insulation [m]
$\dot{q}_V$... Specific heat loss rate [W/m] $\dot{Q}_V$... Heat loss rate [W]
ΔT_L... Temperature spread for buried lines [K]. l... Length of a partial line [m]
λ_D... Thermal conductivity of the insulation [W/ (m- K)]. $h_{Ü}$... Cover height [m]
λ_{Bo}... Thermal conductivity of the soil [W/ (m- K)]. a... clear pipe spacing [m]
T_{Bo}... Floor temperature [K] T_{VL}... Flow temperature [K] T_{RL}... Return temperature [K]

The thermal conductivity of the soil varies between 0.5 W/mK and 2.5 W/mK depending on the composition, structure and moisture content. The installation depth of the pipe is about 0.6-1.2 m, and the soil temperature is relatively stable. Table 10 includes typical thermal conductivities and prices of insulating materials [36].

Table 10: Thermal conductivities and price values of insulating materials [36]

Insulating materials	Conductivity mW/(m K)	Price ($/m³)
Foam board e.g. PUR	0,027	193
XPS	0,031	224
Rock wool	0,04	95
EPS	0,028	155
Fiberglass	0,033	350

5.2 Pressure losses

The pressure losses that occur are determined in different ways, depending on whether the pipeline or pipe installation is straight or corrugated [2].

5.2.1 Pressure losses of straight pipelines and pipeline internals

The flow losses in piping systems consist of the pressure losses of the straight or corrugated pipe sections and the sum of all individual losses of the piping internals, such as butterfly valves, branch pieces, gate valves, etc. [37].

Using Eq. (8) the pressure loss due to pipe friction can be determined for straight pipe sections. Eq. (9) on the other hand, is used to calculate the pressure loss for pipe fittings [2].

$$\Delta p_V = \lambda \frac{l}{d_R} \rho_W \frac{w_m^2}{2} \qquad (8)$$

$$\Delta p_V = \zeta \rho_W \frac{w_m^2}{2} \qquad (9)$$

λ... Pipe friction coefficient of the pipe flow [-]. l... Length of the pipe [m]
Δp_V... Pressure loss of straight pipe sections [Pa]. ζ ... Resistance coefficient [-]
w_m... Mean flow velocity [m/s]. ρ_W ... Density of water [kg/m³]
d_R... Inner diameter of the pipeline [m].

In the case of short lines, the pressure loss due to individual resistors usually predominates, whereas in the case of long lines their influence is small because there are few of them [1]. If the sum of the ζ-values (loss coefficients) of the individual resistances is not yet known, they can be added to the pipe length in the order of 10% to 20% [2].

The ζ-value of internals takes into account all losses due to the installation of a fitting versus the losses of the straight pipe. As an example, in the Table 11 some loss coefficients of various fittings at full opening are given. The manufacturer's specifications of the respective internals should be consulted in the exact design [2].

Table 11: Loss coefficients of various fittings at full opening [38]

Type of fitting (fully open)	DN	Loss coefficient ζ
Ball valve (almost no losses)		0.00 – 0.02
Flat side valve, depending on type		0.12 – 0.28
Wedge gate valve, depending on design		0.15 – 0.30
Throttle valve, vertical or horizontal		0.20 – 0.75
Ring piston slide valve (ring slide valve)		0.75 – 2.00
Non-return valve	DN 400	0.95 – 1.10
	DN 200	1.15 – 1.25
DIN globe valve	DN 50	5.00 – 5.20
	DN 100	5.45 – 5.65
	DN 200	6.25 – 6.40

The Reynolds number is a dimensionless ratio, which is defined according to Eq. (10) is defined. It is used in fluid mechanics to reflect the ratio of inertial to viscous forces [2].

$$\mathrm{Re} = \frac{w_m \; d_R}{\upsilon} \qquad (10)$$

Re... Reynolds number [-]
v... Kinematic viscosity [m^2 /s]
w_m... Mean flow velocity [m/s].
d_R... Inner diameter of the pipeline [m]

The pipe friction coefficient of the pipe flow (λ) depends on the dimensionless Reynolds number, the roughness of the pipe and, depending on the flow regime, on the inside diameter. A pipe roughness less than or equal to 0.01 mm is recommended as a guideline value for district heating pipes [39].

The pipe friction coefficient of the pipe flow of a pipe section (λ) can be read in a Moody diagram using the Reynolds number (Re), the inner diameter (d_R) and the pipe roughness (k) (cf. Table 12), see also Figure 13 [37].

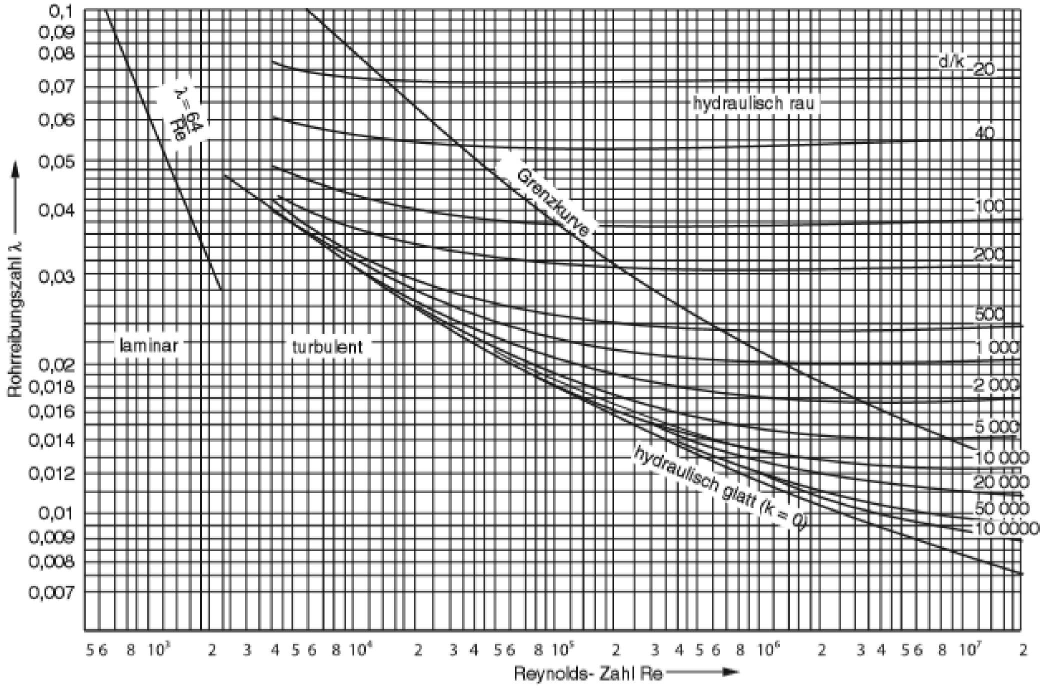

Figure 13: Moody diagram [40]

Table 12: Roughness values k in mm of various pipe materials and surfaces [40]

Material and pipe type	Condition	k in mm	
		from	to
Drawn and pressed Pipes made of copper and brass, glass pipes, stainless steel, plastic pipes, new	Technically smooth, even tubes with metal fiber cover (copper, nickel, chromium)	0.00135	0.00152
Rubber pressure hose	Smooth	0.00162	
Seamless case rolled steel pipes or drawn (commercially available), new	Typical rolled skin	0.02	0.06
	Stained	0.03	0.04
	Unstained	0.03	0.06
	For narrow pipes		0.1
	Occasionally stainless steel, with metal spray coating	0.05	0.09
	Clean galvanized (immersion process)	0.07	0.1
	Standard galvanized	0.1	0.16
Welded from sheet steel pipes, new	Typical rolled skin, longitudinal welding	0.04	0.1
	Bituminized	0.01	0.05
	Cemented		About 0.18
	Galvanized for ventilation		About 0.008
Steel pipes, used	Uniform rust scars		About 0.15
	Moderately rusted, light encrustation	0.15	0.4
	Medium incrustation		About 1.5
	Heavy incrustation	2	4
	cleans after prolonged use	0.15	0.2

For the mathematical determination of the pipe friction coefficient, the equations from Table 13 can be applied.

Table 13: Approximation formulas depending on the range of validity and flow type [2, 41]

Flow	Validity range	Approximation formula
Laminar	$Re < 2\,320$	$\lambda = \frac{64}{Re}$ (11)
Hydraulic smooth	$2320 < Re < \frac{d_R}{k} \log\left(0.1 \frac{d_R}{k}\right)$ (12)	$\lambda = \frac{0.309}{\left(\log \frac{Re}{7}\right)^2}$ (13)
Transition area	$\frac{d_R}{k} \log\left(0.1 \frac{d_R}{k}\right) < Re < 400 \frac{d_R}{k} \log\left(3.715 \frac{d_R}{k}\right)$ (14)	$\lambda = \frac{0.25}{\left[\log\left(\frac{15}{Re} + \frac{k}{3.715\, d_R}\right)\right]^2}$ (15)
Hydraulic rough	$Re > 400 \frac{d_R}{k} \log\left(3.715 \frac{d_R}{k}\right)$ (16)	$\lambda = \frac{0.25}{\left(\log \frac{3.715\, d_R}{k}\right)^2}$ (17)

λ... Pipe friction coefficient of the pipe flow [-]

Re... Reynolds number [-]

d_R... Inner diameter of the pipeline [m].

k... Pipe roughness [-]

5.2.2 Corrugated pipe pressure drops

The pipe friction coefficient of pipe flow for a corrugated pipe (cf. Figure 14) in the laminar region is similar to that for the smooth pipe, which is inversely proportional to Reynolds number [2].

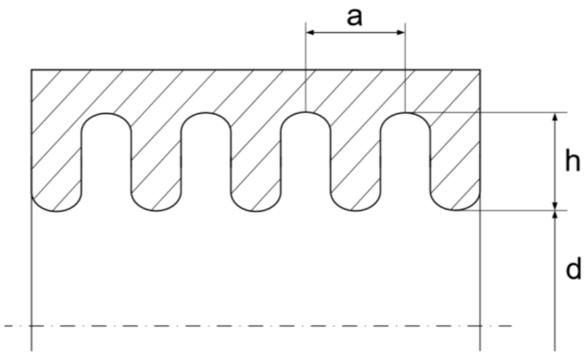

Figure 14: Section through a corrugated tube [2]

In the literature, data for pipe friction coefficient relationships in turbulent regions for corrugated pipes are hard to find. Likewise, the Reynolds number dependence is not secured in the entire technically relevant range. For the following ranges of validity (Eq. 18 and 20), the respective approximations (Eq. 19 and 21) are valid [42].

Table 1: Approximation formulas depending on the range of validity [42]

Validity range	Approximation formula
$5*10^4 < Re < 3*10^5$ $0.2 < \frac{h}{a} < 0.6$ $0.0455 < \frac{h}{d} < 0.0635$ (18)	$\lambda = 3400 \left(\frac{h}{d}\right)^{4.13} \left(\frac{h}{a}\right)^{230 \left(\frac{h}{d}\right)^{2.1} - 0.7} Re^{0.193\, e^{\left[-3300 \left(\frac{h}{d}\right)^{2.6} \frac{h}{a}\right]}}$ (19)
$Re = 5*10^4$ $0.2 < \frac{h}{a} < 1.2$ (20)	$\lambda = 0.2 \left(\frac{h}{d}\right)^{0.6} \left(\frac{a}{h}\right)^{0.7}$ (21)

d... Diameter of the pipeline without shafts [m]. h... Amplitude of the wave [m]

λ... Pipe friction coefficient of the pipe flow [-]. a... Wavelength [m]

Re... Reynolds number [-]

From a Reynolds number of 4 $*10^4$, the pipe friction coefficients of turbulent flows in corrugated pipes typically grow. This phenomenon can be attributed to the formation of different vortex shapes (primary and secondary vortices) in the wall bulges. The corrugated pipes usually have the shape of a thread, which causes the medium to move not only axially but also rotationally. However, this fact hardly influences the resistance behavior. The intensity of the rotation, on the other hand, plays an important role for heat transfer, because it can prevent the formation of "dead water zones" in the grooves [42]. With identical Reynolds numbers, corrugated tubes have a greater tube friction coefficient than smooth tubes, namely a factor of 2 to 15 greater. Corrugated pipes usually have to be designed one to two nominal diameters larger than smooth pipes, because otherwise the specific pressure loss per lineal meter would become too high [2].

6 Key considerations of DH pipeline technologies

The design and implementation of DH pipes and systems involve a careful balance of various factors to optimize efficiency, cost, and reliability. Here, we explore several critical aspects of district heating pipes.

6.1 Relevant aspects

- **Pipe dimensions and heat losses**

Heat losses in district heating systems are a substantial concern as they directly affect the system's efficiency and operational costs. The dimensions of DH pipes significantly impact heat losses. In general, heat losses from a pipe occurs through its surface area. The larger the surface area (i.e. pipe diameter), the higher the heat losses. However, the area to volume ratio (A/V) decreases as the pipe diameter increases, meaning that larger pipes have a smaller surface area relative to their volume. This reduced surface area leads to lower heat losses per unit volume of the fluid being transported. Essentially, the larger the pipe, the less heat it loses relative to the amount of heat it carries.

The material and construction of the pipes themselves affect heat losses as well. Steel pipes have a high thermal conductivity, so they require good insulation. Plastic pipes have a lower thermal conductivity than steel, potentially reducing heat losses but may have other limitations in terms of pressure and temperature tolerance. Heat losses do not occur uniformly along the length of the pipe. Joints, valves, elbows, and other components can be points of significant heat losses too (as they are often less insulated than the main pipes and can cause turbulences) and must be part of the pipe routing planning process.

- **Insulation thickness**

The thickness of the insulation surrounding the pipes is another critical factor in minimizing heat losses. Thicker insulation layers provide better thermal resistance, reducing heat loss but at an increased cost. Therefore, there is a trade-off between the insulation cost and the savings from reduced heat losses, necessitating a careful economic analysis to determine the optimal insulation thickness. Common insulation materials include mineral wool, polyurethane foam, and polyethylene. The choice of material depends on its thermal conductivity, cost, and ease of application.

- **Capital expenditure (CAPEX)**

Smaller pipe dimensions generally result in lower initial capital expenditures (CAPEX). The material cost, transportation, and installation of smaller pipes are lower compared to larger pipes. However, smaller pipes also introduce higher pressure losses due to increased flow velocity and friction, potentially increasing operational costs.

- **Pressure losses**

Pressure losses in district heating systems occur due to pipe friction and components such as valves, elbows, and measuring equipment. The pipe friction coefficient (λ) is dependent on the flow velocity and the pipe diameter, making these parameters interdependent. Higher flow velocities in smaller pipes lead to higher pressure losses, which must be balanced against the lower CAPEX of these pipes.

It has been shown that a flow velocity of 1.5 to 2.5 m/s results in tolerable losses. The pressure losses should be at about 100 Pa/m, max. 200 Pa/m. A limiting factor for the flow velocity is the maximum possible pump pressure, which results from the pressure limits of the pipe system used. In the pressure loss calculation, the height differences and standby pressures (due to pressure maintenance systems or district heating storage tanks) must also be taken into account, which also have an influence on the maximum pressure in the pipe system.

- **Buried vs. above ground laying**

The decision to lay pipes underground or above ground depends on local characteristics and constraints. A careful consideration of space availability, the need for new pipe bridges, the structural load of pipes and foundations, expansion arches to accommodate thermal stresses is required. It must also be determined whether existing pipes (e.g., power grid/cables, gas pipelines) exists. The routing of pipes is influenced by whether the system is located in urban or rural areas, where space availability and construction constraints differ significantly. Typically buried pipes experience lower heat losses because the ground provides additional insulation compared to above ground pipes.

In urban regions or where there is a high density of underground installations in the route area, district heating pipes can also be installed in micro tunnels. Especially in areas with existing critical infrastructure (e.g. main power cables, traffic junctions, etc.), which cannot be interrupted, micro tunnel technology represents a more favorable alternative.

- **Flexibility and parallel pipes**

Using parallel pipes instead of a single larger pipe (e.g. 2xDN600 instead 1xDN1200) can provide greater operational flexibility. In the event of maintenance or failure, one pipe can be shut down without disrupting the entire system. This redundancy ensures a continuous heat supply, enhancing the reliability of the district heating network.

- **Connection of pipes**

The connection of pipes and fittings (e.g. bends) is also made by welding for larger dimensions. A form-fit and maintenance-free connection is particularly important for permanent and uninterrupted operation in underground installations. The weld seams are usually subjected to 100% volumetric non-destructive testing (X-ray or ultrasonic testing). After welding, the leak warning wires are connected, the joint is sealed with insulating half shells and foamed. This achieves the necessary diffusion tightness.

- **Installation under pre-tension**

District heating pipes are usually installed under pre-tension. This eliminates the need for additional expansion bends, which take up a lot of space with larger dimensions. Pre-stressing is achieved by heating the pipe to a medium temperature (usually with hot water) and then filling the trench. For larger pipe dimensions, however, this means that the larger pipe trenches remain open for longer, as the preheating time and backfilling time are considerably longer. Furthermore, large quantities of water are required, which must first be conditioned and then emptied again.

One method for filling with water is to fit the pipe sections with shut-off valves and leave the water in the pipe after pre-tensioning. When the next section is pre-tensioned, the valves are opened and the water required for the next section is added. This eliminates the need for draining.

- **Integration with heat pumps**

An intelligent combination of district heating pipes consisting of several temperature levels can be utilized to enhance system efficiency, particularly through the integration of heat pumps. Heat pumps can boost the temperatures within the network, providing an efficient way to meet varying thermal demands.

- **Operational processes**

District heating systems typically operate the whole year, but the availability of waste heat from production processes can vary. Waste heat is not always available continuously; it often depends on the weekday and seasonality. Moreover, the temperature level might change. This variability requires careful planning and integration into the district heating system to ensure a consistent heat supply. Additionally, system shutdowns are scheduled during maintenance periods to minimize disruption.

➢ **Economic considerations**

The costs associated with additional insulation must be weighed against the benefits of reduced heat losses. A lean pipe design that minimizes costs while maintaining efficiency is essential. Additionally, the welding options for pipes made from different materials, including metals, plastics, and glass fiber, must be considered to ensure a durable and cost-effective installation.

6.2 Lessons Learned

In conclusion, the design of district heating pipes involves a complex interplay of factors including dimensions, insulation, CAPEX, pressure losses, and routing. Each of these elements must be carefully balanced to create an efficient, cost-effective, and reliable district heating system.

The current market for district heating pipe systems adequately meets the project's requirements, particularly concerning nominal width and temperature specifications. However, certain limitations exist with specific types of pipes regarding their nominal width or temperature suitability for the particular use case, necessitating a case-by-case evaluation.

An overview of the pipe technologies regarding their characteristics is shown in Figure 15, based on the data provided in Table 3. The existing pipe technologies are:

- KMR: Plastic composite pipe (Kunststoffverbundmantelrohr)
- PMR: Plastic medium pipe (Kunststoffmediumrohr)
- MMR: Metal medium pipe (Metallmediumrohr)
- GRP: Glass fiber reinforced plastic pipe (Glasfaserverstärktes Kunststoffrohr)
- HTR: Pre-insulated high-temperature pipes (Hochtemperaturrohr)
- SMR: Steel casing pipe (Stahlmantelrohr)

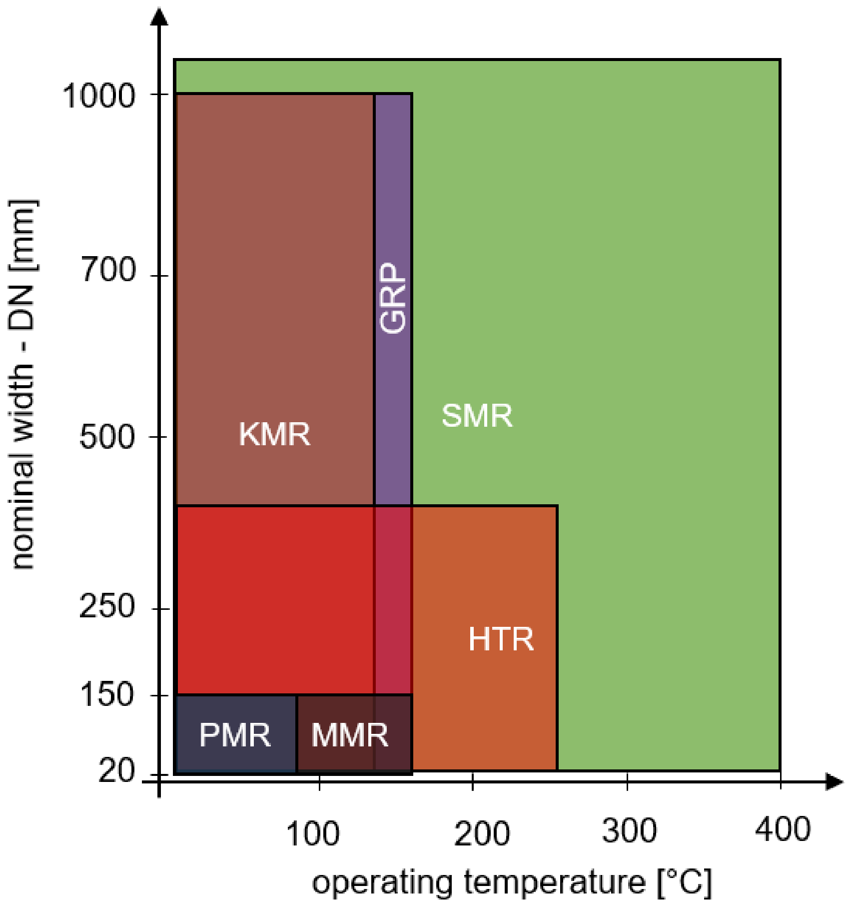

Figure 15: Existing pipe technologies on the market

Specific demands, such as transporting a particular heat capacity, can only be met by certain pipe types. Furthermore, as pipe diameter increases, their need becomes less frequent, leading to specialized requests that manufacturers must address.

In summary, while the existing market generally aligns with project needs in terms of nominal width and temperature requirements, specialized considerations and requests are often essential to fulfill specific project demands, especially concerning heat capacity and larger pipe diameters.

7 Summary and outlook

Constructing a lean district heating pipe system involves optimizing various factors to achieve minimal heat losses, temperature requirements, ease of installation, cost efficiency, and reliable welding processes. To minimize heat losses, it is essential to select pipe diameters that balance minimal heat loss with manageable pressure losses, as larger pipes with a lower surface area to volume (A/V) ratio reduce heat losses. Effective insulation is crucial, and using high-performance materials like polyurethane foam or mineral wool with optimized thickness helps balance heat loss reduction and cost, but they must be economically viable.

A summary of existing heat pipe technologies is provided in Table 3. Cost comparisons are based on the KMR pipe technology. PMR pipes are approximately 20% less expensive, while MMR pipes are roughly twice as expensive. No general pricing data is available for glass fiber pipes (GRP). HTR pipes are estimated to cost 5 to 10 times more, and SMR pipes about 10 times more. Although pipe technology prices provide a rough estimate for cost calculations, they need to be evaluated on a case-specific basis, considering the following aspects.

Flexible pipe materials are key to a lean design. For smaller diameters, pre-insulated plastic pipes are suitable, while flexible steel or composite pipes work well for larger diameters. Maintaining consistent temperatures involves ensuring the insulation quality, with materials that have low thermal conductivity and are protected from moisture and mechanical damage. Temperature control systems are also important for maintaining consistent fluid temperatures.

Ease of installation can be achieved by using flexible, pre-insulated pipe materials and modular systems. Joint and component design should focus on easy assembly and disassembly, which reduces installation time and errors. Solutions should be provided for both above ground and buried installations to accommodate different environmental and logistical challenges. Above ground installations require consideration of aesthetics and protection from physical damage, while buried installations need to address soil conditions, potential moisture ingress, and ease of access for maintenance.

For the welding process, selecting materials like steel, which offer strong and durable welds, is essential. Employing high-quality welding techniques and automated welding machines can ensure consistency for both steel and plastic pipes, enhancing the reliability and durability of the joints. Advanced welding methods, such as automated welding and robotic welding, can significantly reduce human error, increase precision, and speed up the installation process.

Cost efficiency can be enhanced by selecting cost-effective materials that do not compromise performance, such as composite materials. These materials can offer a good balance between cost, weight, and durability. Standardizing pipe sizes and using modular components streamline manufacturing and reduce costs. Simplifying the installation process and training installation teams can reduce labor costs and time. Furthermore, the use of modular systems allows for easier scaling and adaptability, which can be particularly beneficial in areas with varying demands or future expansion plans. Designing the system to be adaptable to future technological advancements, such as new insulation materials or more efficient heat exchangers, can extend its operational life.

Integrating intelligent systems and technologies can further enhance the efficiency and reliability of district heating networks. For example, incorporating smart meters and sensors throughout the system can provide real-time data on temperature, pressure, and flow rates. This data can be used for predictive maintenance, identifying potential issues before they become critical, and optimizing system performance to reduce energy consumption and costs.

By integrating these strategies, a district heating pipe system can be designed to be lean, efficient, and cost-effective, ensuring long-term reliability and performance. Effective pipe sizing, high-performance insulation, flexible materials, reliable welding, and cost-efficient practices all contribute to a robust and sustainable district heating network. This comprehensive approach not only optimizes the current performance but also prepares the system for future demands and advancements, ensuring it remains a viable and efficient solution for thermal energy distribution.

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