DISTRICT **HEATING** GUIDE



Comprehensive Reference

Planning & System Selection • Central Plants • Distribution Systems
• Heat Transfer Calculations • System O&M • Consumer Interconnection

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District Heating Guide

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Acronyms

ACFB	atmospheric circulating fluidized bed
ASME	American Society of Mechanical Engineers
CAD	computer-aided design
CCS	combustion control system
CHP	combined heat and power
CMMS	computerized maintenance management system
CO	carbon monoxide
CO_2	carbon dioxide
DDT	drainable, dryable, testable
EOR	Engineer of Record
EPA	U.S. Environmental Protection Agency
FGD	flue gas desulfurization
FGR	flue gas recirculation
FRP	fiberglass-reinforced plastic
GDH	geothermal district heating
HAP	hazardous air pollutant
HDPE	high-density polyethylene
HRSG	heat recovery steam generator
HTW	high-temperature water
IDEA	International District Energy Association
LCC	life-cycle cost
LCCA	life-cycle cost analysis
LCD	liquid-crystal display
LFI	loose fill insulation
LTW	low-temperature water
MTW	medium-temperature water
NFPA	National Fire Protection Association
NO_x	nitrogen oxides
NPV	net present value
O&M	operation and maintenance
OSHA	Occupational Safety and Health Administration

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PC	pulverized coal
PM	particulate matter
SCADA	supervisory control and data acquisition
SO_x	sulfur oxides
VFD	variable-frequency drive
VSD	variable-speed drive
WSL	water spread limiting

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1 Introduction

PURPOSE AND SCOPE

The purpose of this design guide is to provide guidance for all major aspects of district heating system design. The guidance is organized in such a manner as to be of use to the inexperienced designer of district heating systems as well as to provide a comprehensive reference to those immersed in the district heating industry. In addition to design guidance, information on operation and maintenance has also been included.

DISTRICT HEATING BACKGROUND

District heating distributes thermal energy normally in the form of hot water or steam from a central source to residential, commercial, and/or industrial consumers for use in space heating, domestic hot water heating, process heating, cooking, and humidification. Thus, the heating effect comes from a distribution medium rather than being generated on site at each facility.

Whether the system is a public utility or user owned, such as a multi-building campus, it has economic and environmental benefits depending largely on the particular application. Political feasibility must be considered, particularly if a municipality or governmental body is considering a district heating installation. Historically, successful district heating systems have had the political backing and support of the community.

District heating was proposed as early as 1613 in London; however, it would seem that the first known examples where hot-water systems installed in St. Petersburg, Russia, in the 1840s (Pierce 1994). In the United States it appears that the first district heating system was installed at the Naval Academy in Annapolis, Maryland, in 1853 (Pierce 1994). Birdsell Holly is often credited with the invention of district heating in Lockport, New York, in 1877, but he was just the first to really make a commercial enterprise of the practice, a business that he ultimately grew to cities beyond Lockport (Pierce 1994). Most major cities in the U.S. soon were served by steam-based district heating systems, with the majority of those systems still surviving today, the largest being in New York City. While steam systems were also built in a number of major European cites, hot-water-based district heating saw significant growth in Europe, in part due to the reconstruction after World War II. Also following World War II, the construction/expansion of many U.S. military bases was an ideal application for district heating, and both steam and high-temperature hot-water systems were built. In Europe, especially Scandinavia, hot-water-

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based district heating systems adopted low temperatures for supply; that trend continues today with systems using supply temperatures of 158°F (70°C) or lower.

APPLICABILITY

District heating systems are best used in markets where the thermal load density is high and the annual load factor is high. A high load density is needed to cover the capital investment for the transmission and distribution system, which usually constitutes a significant portion of the capital cost for the overall system, often amounting to 50% or more of the total cost. This makes district heating systems most attractive in serving densely populated urban areas and high-density building clusters with high thermal loads, especially tall buildings. Urban settings where real estate is very valuable are good settings for district heating systems since they allow building owners to make maximum use of their footprint by moving most of the heating equipment off-site. Low-density residential areas do not represent the most attractive markets for district heating. However, through the use of low-temperature hot water, Denmark has one million detached family homes on district heating (Zinko et al. 2008).

The annual load factor is important because the district heating system is capital intensive and maximum utilization of the equipment is necessary for cost recovery. Thus, in general district heating systems are more economic in colder climates. However, the use of absorption air conditioning by customers can also provide summer load for systems operating at high enough supply temperatures. Other methods to increase the annual load factor for district heating systems are discussed by Zinko et al. (2008).

COMPONENTS

District heating systems consist of three primary components (see Figure 1.1):

- Central plant or production source
- Distribution network piping (steam or hot water)
- Consumer interconnection (direct or indirect)

In the central plant (see Chapter 3), hot water or steam is produced by one or more of the following methods/fuels:

- *Heat only, fuel fired.* Fuel sources: all fossil fuels, biomass, refuse-derived fuel (RDF).
- *Cogenerating heat and electric power, steam cycle.* Fuel sources: all fossil fuels, biomass, RDF.
- *Cogenerating heat and electric power, combustion turbine.* Fuel sources: oil, gas, syngas from coal, biomass, RDF, etc.
- *Cogenerating heat and electric power, internal combustion engine/generator.* Fuel sources: oil, gas, syngas from coal, biomass, RDF, etc.
- *Heat pump.* Heat sources: sewage, seawater, geothermal (ground water, ground-coupling, surface water), industrial waste heat, heat recovery from cooling/refrigeration, etc.
- *Geothermal direct use.* Heat sources: geothermal hot water or steam.

The second component is the insulated distribution or piping network that conveys the hot water or steam (see Chapter 4). The piping may be the most expensive portion of a district heating system. These networks require substantial permitting and coordinating with nonusers of the system for right-of-way if not on the owner's property. Because the initial cost is high, it is important to maximize use of the distribution system.

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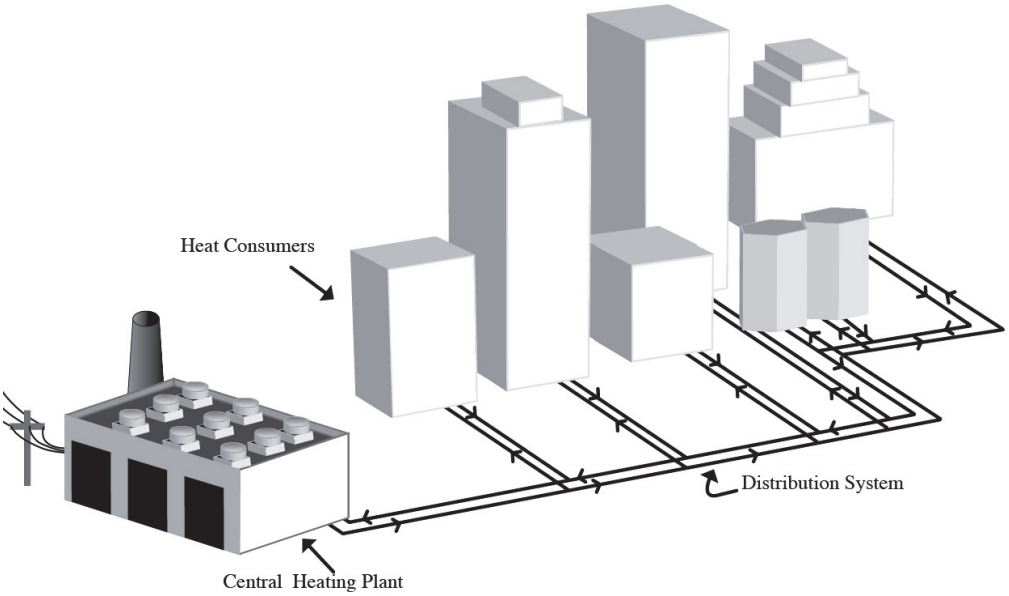


Figure 1.1 Basic components of a district heating system.

The third component is the consumer system, which includes in-building equipment. Hot water or steam may be used directly by the building systems or isolated by a heat exchanger (see Chapter 5).

BENEFITS

Environmental Benefits

Generating heat in a central plant is normally more efficient that using in-building equipment and, thus, the environmental impacts are normally reduced. The greater efficiencies arise due to the larger equipment and the ability to stage that equipment to closely match the load yet remain within the equipment range of highest efficiency. District heating systems may take advantage of diversity of demand across all users in the system and may also implement technologies such as thermal storage more readily than individual building heating systems.

When fuels are burned to generate district heat within a central plant, emissions are easier to control than those from individual plants, and control technologies that are not technically or economically viable on a small scale may be used. For example, a central plant that burns high-sulfur coal can economically remove noxious sulfur emissions, whereas individual combustors could not. With concerns about global warming it is also clear that carbon capture and sequestration will be easier to accomplish for a central plant than for many smaller in-building heating plants.

District-scale systems also offer the ability to use fuels that would not be viable to use on an individual building scale. For example, the thermal energy from municipal wastes can provide an environmentally sound system, an option not likely to be available on a building-scale system. Biomass may be burned in a district system with well-controlled emissions; on an individual building scale this is being done in some areas residentially, but the results from an emissions perspective have not been favorable. Geothermal

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resources, normally uneconomical to develop on an individual building scale, can sometimes be more effectively applied as a source for district heating.

Finally, from an emissions and efficiency standpoint generating heat in a central plant has the additional advantage of higher quality of equipment, higher seasonal efficiencies due to demand diversity, less system heat loss from cycling, and higher levels of maintenance to maintain performance.

Economic Benefits

A district heating system offers the following economic benefits. Even though the basic costs are still borne by the central plant owner/operator, because the central plant is large, the customer can realize benefits of economies of scale. The economic benefits are outlined below and are discussed in more detail in Chapter 2.

Operating Personnel

One of the primary advantages of a district heating system for a building owner is that operating personnel for the HVAC system can be reduced or eliminated. Most municipal codes require operating engineers to be on site when high-pressure boilers are in operation. Some older systems require trained operating personnel to be in the boiler/mechanical room at all times. When hot water or steam is brought into the building as a utility, depending on the sophistication of the building HVAC controls there will likely be opportunity to reduce or eliminate building-plant-related personnel.

Insurance

Both property and liability insurance costs may be significantly reduced with the elimination of boilers from within the building and fuel storage from the site since risks of fire, accident, and fuel spill/release are reduced or eliminated.

Usable Space

Usable space in the building increases when a boiler and related equipment are no longer necessary. The noise associated with such in-building equipment is also eliminated. In retrofit applications, this space cannot usually be converted into prime office space; however, it does provide the opportunity for increased storage or other use.

Equipment Maintenance

With less mechanical equipment, there is proportionately less equipment maintenance, resulting in less expense and a reduced maintenance staff.

Higher Efficiency

A larger central plant can achieve higher thermal and emission efficiencies than can several smaller units. When strict regulations must be met for emissions, water consumption, etc., control equipment is also more economical for larger plants. Partial-load performance of central plants may be more efficient than that of many isolated small systems because the larger plant can operate one or more capacity modules as the combined load requires and can modulate output.

Available Primary Energy

As noted in the Environmental Benefits section, on a building scale it may not be practical to generate heat from some fuel sources that may be used in a district system central plant.

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INITIAL CAPITAL INVESTMENT

The initial capital investment for a district heating system is usually the major economic driving force in determining if there is an acceptable payback for implementation. Normally, the initial capital investment includes four components:

- Concept planning
- Design
- Construction
- Consumer interconnection

Concept Planning

In concept planning, three areas are generally reviewed. First, the technical feasibility of a district heating system must be considered. This includes factors such as looking at the heating load density, potential locations for the central plant, and an acceptable corridor for the distribution system. Financial feasibility is the second consideration. For example, a municipal or governmental body must consider availability of bond financing; a private entity must be able to secure financing at an acceptable rate. Alternative choices of potential customers for heat generation must be reviewed because consumers are often asked to sign long-term contracts in order to justify district heating systems and their economics must be understood.

Design

There are many decisions that must be made in the detailed design of the heating plant, distribution system, and consumer interconnect, as discussed in Chapters 3, 4, and 5, respectively. For the central plant these decisions will be driven by the location (i.e., availability of water, land, etc.) and size of the heating plant. The distribution system accounts for a significant portion of the initial investment. Distribution design depends largely on the type of distribution system construction that will be used. The routing of the system will also be very important in the design of the distribution system. Failure to consider these key variables results in higher-than-planned installation costs. An analysis must be done to determine how much insulation is warranted; this process is outlined in Chapter 6.

Construction

The construction costs of the central plant and distribution system depend on the quality of the concept planning and design. Although the construction cost usually accounts for most of the initial capital investment, neglect in any of the other three areas could mean the difference between economic success and failure. Field changes usually increase the final cost and delay start-up. Even a small delay in start-up can adversely affect both economics and consumer confidence. It is extremely important that the successful contractors have experience commensurate with the project. Capital costs of district heating projects range greatly and are dependent upon site conditions such as

- labor rates,
- the construction environment (slow or busy period, high- or low-cost area, etc.),
- the distance for shipping of equipment,
- fuel choice/availability,
- permits and fees (franchise fees),
- local authorities (traffic control, allowed times for construction in city streets),
- soil conditions (clay, bedrock),
- the quality of equipment and controls (commercial or industrial),
- the availability of materials,

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- the size of piping in the distribution system,
- the type of distribution system installation (insulated, uninsulated, welded/fused or mechanical joints, cathodic protection, etc.),
- the depth of bury and restoration of existing conditions (city streets, green areas),
- below-grade conflict resolutions, and
- economies of scale.

Lead time needed to obtain equipment may determine the time required to build a district heating system. In some cases, lead time on major components in the central plant can be over a year. Installation time of the distribution system depends in part on the routing interference with existing utilities. A distribution system in a new development is simpler and requires less time to install than a system being installed in an established business district.

Consumer Interconnection

Interconnection costs are usually borne by the consumer. High interconnection costs may favor an in-building plant instead of a district heating system. The nature of the consumer's in-building heating system may have a large impact on the ability to connect to a district heating utility (see Chapter 5 for details on building conversion). For this reason, in either new construction or retrofit situations, particular attention must be paid not just to the consumer interface but in addition the remainder of the heating system within the building.

TYPICAL APPLICATIONS

District heating has seen a wide variety of applications; some case studies of examples are provided in Appendix C. These applications span all major sectors of the building market: residential, commercial, institutional, and industrial. For many of the applications, such as college campuses, medical complexes, and military bases, the loads are "captive" (i.e., there is a common owner for the district heating plant and the buildings being served). At the opposite end of the spectrum are district heating systems that operate as commercial enterprises in urban areas and compete with in-building equipment for cooling loads. Between these two extremes are many other business models such as district heating providers, who operate under contract, plants owned by developers of real estate projects, etc. Business models and business development for district heating enterprises are largely analogous to those for district cooling enterprises; information on the latter may be found in IDEA (2008).

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2
Planning and System Selection

PLANNING OVERVIEW

For buildings, the cost of utility services and infrastructure needed to provide these services is significant and may even exceed the cost of the buildings themselves over their lifetimes. Planning has the potential to reduce both the initial and the future costs. The objective of planning should be to guide decision making such that cost savings in providing utilities over the life expectancy of the building and the district heating system are realized. Due to their capital-intensive nature, the need for planning is significant for district heating systems.

The term *master plan* will be used to refer to planning in this design guide, but there are several levels of planning. A master plan covers all levels of planning and is typically integrated with the development of both new and existing sites. Throughout this section the development of utility master plans will typically be applicable to private, public, and utility-owned systems. Differences in planning for the different systems will be identified whenever those differences are significant.

For totally new systems in a greenfield project, master planning is an essential first step to ensure that the owner's requirements are fulfilled in the delivered system. Appropriate planning will have significant impacts not just on the first cost of the project but also on the future operation and maintenance (O&M) costs. The master plan also will provide valuable information to those responsible for the O&M of the system; thus, it is essential that the individuals who will be responsible for the O&M of the system be involved in the planning process. For sites with existing systems/other utilities, involvement of the system operators in the development of a master plan is essential; there is no substitute for the corporate knowledge when dealing with buried systems. A plan properly prepared will also be of benefit to the users served by the system, so it may be prudent to engage these representatives in the planning process. Potential stakeholders in the development of a master plan include the following:

- Building/campus/site owner
- Owner's project engineer
- Site master planners
- Utility system operators
- Operators/engineers of other utilities on site or within utility right-of-way
- Potential contractors