

Comparison of District Heating Systems Used in China and Denmark

Lipeng Zhang^{1,2,*}, Oddgeir Gudmundsson², Hongwei Li¹, Svend Svendsen¹

¹Civil Engineering Department, Technical University of Denmark, Anker Engelunds Vej Building 118, Kgs.Lyngby, Denmark

²Danfoss A/S, District Energy Division, Application Center, Nordborgvej 81, Nordbrg, Denmark

Email address:

lipz@byg.dtu.dk (Lipeng Zhang)

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Abstract: China has one of the largest district heating (DH) markets in the world with total district heat sales in 2011 amounting to 2,810,220 TJ. Nevertheless, it still has great potential for further expanding its DH supply, due to rapid urbanization and the demand to improve the quality of life. However, the current DH system in China is in great need of system improvements, technology renovation, and optimization of operations and management. As one of the world's leading countries in terms of DH supply, Denmark has state-of-the-art DH technologies and rich experience in the design and operation of DH systems. Experiences learned from the Danish DH system are useful for improving the current Chinese DH system. This article provides an overview of the technological differences between the two countries, focusing on: a) heat generation, b) the DH distribution network, c) DH network control, and d) the end consumer. The paper looks at the obvious differences between these two countries in terms of DH supply and concludes that there is significant, achievable potential for improvement regarding both energy efficiency and user comfort in the Chinese DH system, through technological advancement and implementing the operational know-how of more modern DH systems.

Keyword: District Heating, Energy Efficiency, Technical Measure, China, Denmark

1. Introduction

Denmark is one of the most energy-efficient countries in the world. A wide range of pro-active, energy-saving measures have decreased energy consumption and increased the use of renewable energy and technological development. Since the 1980s, Denmark's energy consumption has consequently remained steady, while the economy has continued to grow. The widespread use of district heating (DH) and combined heat and power (CHP) has made a major contribution to Denmark's drive towards efficiency and energy self-sufficiency (Dyrelund, 2012). The country's DH system combines space heating (SH) and domestic hot water (DHW) and runs continuously throughout the year. Denmark develops diverse heat generation technologies, powered by renewables and otherwise wasted energy (Lund et al., 2010)(Alberg et al., 2010)(Mathiesen et al., 2012)(Münster et al., 2012), as well as gradually reducing fossil fuel. Furthermore, well-oriented and supportive policies issued by the Danish government have resulted in the technical success. Commercial companies carried out the research and development of DH-relevant products and solutions, along

with universities, consultancies, as well as trade associations—all made substantial contributions to the revolution of DH technology.

The Chinese DH system had developed based on standard Soviet-era technology, which provided only heat, not DHW. There is considerable potential for improving the Chinese DH system and reducing greenhouse gas (GHG) emission. Coal, as the dominant heat source fuel, has resulted in a series of environmental, health, and economic challenges (U.S.Environmental Protection Agency, 2008). Furthermore, this kind of single heat source also heavily highlights issues of supply security, since energy consumption keeps increasing along with rapid urbanization and industrialization. The huge growth of the DH sector has made China the fastest growing DH market in the world. However, heat generation, distribution energy efficiency, heat demands, and fulfillment of user comfort requirements are not comparable with some European DH systems, such as Denmark. In China, heating energy consumption for 1m² is almost 2 times that of developed countries in the same latitude (Liu et al., 2011)(Xu et al., 2009). Currently, China's heat reform is still in process, with the aim of improving

building energy efficiency, updating the overall DH system, as well as establishing new heat metering and billing mechanisms based on actual consumption. Meanwhile, Danish DH experience will be a good resource from which China can learn.

This article looks at the obvious technical differences by comparing the main elements of DH systems between Denmark and China. It aims to identify the potential within the Chinese DH system, along with opportunities for integration of Danish DH technologies. It is important to note that these technical measures, that are essential to the Danish system, are appropriate and feasible for China at a practical level.

1.1. Historical Perspective and Future Prospects

1.1.1. Denmark

Since the first waste incineration and CHP plant-based DH system was built in Denmark in 1903 (DBDH, 2013), the Danish DH supply has gone through moderate development over the past 100 years. In 1973, the worldwide oil crisis tremendously affected the Danish economy, due to nearly 100% importation of foreign oil. The Electricity Supply Act of 1976 implemented the policy that all new power capacity after 1976 had to be CHP and the Heat Supply Act of 1979 ensured the least cost integration of power, heat, gas, and waste sectors in Denmark (Gerlach, 1991). The development of CHP on both a large scale (city-wide) and small scale (communities and institutions) and the associated DH have been booming since the 1980s (Mortensen, 1992). Such measures significantly increased energy supply efficiency and enhanced energy supply security, which has helped Denmark become energy independent since 1997 (Christensen, 2008). In 2012, the Danish government set forth an ambitious energy target: by the year 2035, the electricity and heat supply will be covered 100% by renewable energy and, by the year 2050, all the energy supply in Denmark should be 100% from renewable sources (Danish Energy Agency, 2013). DH once again became one of the key measurements and the share of total DH supply will increase from 60% to 70%, with the rest of the heating demand met by heat pumps (Lund and Mathiesen, 2009).

The future trend of the Danish DH is expected to be towards 4th generation DH (4GDH) (Lund et al., 2014), which is defined by smart thermal grids utilizing low quality energy like renewables, with optimized combinations of heat sources to supply appropriate lower temperatures to low-energy demand buildings through a high-efficiency DH network (Li and Svendsen, 2012).

1.1.2. China

During China's first five-year plan period (1953-1958), the first batch of thermal power plants were constructed, aided by the Soviet Union. In 1958, Beijing established China's first thermal power plant to supply heat to a few public buildings; this was the starting point of China's urban central heating. Afterwards, central heating utilizing CHP as the heat

generation came almost to a standstill for quite a long period, due to unexpected errors related to heat capacity. In the 1970s, the number of CHP plants began to increase again. However, these plants typically belonged to factories and enterprises, mainly meeting their own heat demands (Xu, 2010). During the early 1980s and into the late 1990s, CHP plants grew rapidly. Since the 1980s, CHP units started to supply heat for public, residential and commercial buildings. In 1986, the state council of China released the No. 22 document (Xu, 2000), which set the general direction for the development of CHP. Moreover, the central government increased funding and policy support. In this way, CHP was promoted. After the late 1990s, more and more heat-only boilers (HOBs) were built, gradually equaling CHP as the heat generation units, later even surpassing CHP. Although CHP should be preferred, due to better primary energy usage, there can be certain conditions that favor HOBs when it comes to DH, especially in the starting phase. HOBs played a transition role; after CHPs were built to supply the base load, they can be used efficiently for peak load. In 2007, China's total hot water DH sales amounted to 1,586,410 TJ, central HOBs contributed 1,047,750 TJ and accounted for 66%, and CHP represented 33% at 522,880 TJ (Xu, 2010).

The development of DH in China has gone hand in hand with rapid urban expansion and economic growth over the past ten years. In 2008, out of China's 655 cities, approximately 329 were equipped with DH facilities (Baeumler et al., 2012). The district heated floor space has expanded rapidly from 2.16 billion square meters in 2004 to 4.74 billion square meters in 2011 (China National Bureau of Statistics, 2012). At the same time, CHP more than doubled in capacity between 2001 and 2005, rising from 32 GW to 70 GW (IEA, 2007).

In China's 12th five-year plan report, improving energy efficiency is specifically mentioned as an important issue (Thomson, 2014). The DH sector has received further focus by policies that, among other things, actively promote urban clean energy retrofitting, strengthen building energy-efficiency retrofitting, develop CHP and DH, and eliminate a number of small coal-fired boilers, along with the phasing out of decentralized heating coal stoves in rural areas by encouraging the utilization of renewable energy. A prior policy of eliminating scattered coal boilers by consolidating them into large central heating systems with high energy efficiency and pollution control will continue (Lo and Wang, 2013) (Price et al., 2011).

1.2. Climate and Heating Periods

1.2.1. Denmark

Denmark has a temperate marine climate with mild winters and cool summers. The coldest month is January with average daytime temperatures of 2°C and nighttime temperatures of 2.9°C. During the winter, strong wind can quickly change the outside temperatures (Global Talent, 2013). The theoretical heating period is from October to the following April. Nevertheless, the fact is that an internal building heating system, connected to a DH system, can be

turned on or off according to heat consumers' comfort; actually the heat users can decide for themselves how long the heating period is. In addition, during the non-heating period, the DH supplies water for DHW preparation only.

1.2.2. China

China stretches over a large area with various winter climates classified from warm to severe cold. Figure 1 shows the climate zones map of China (Gao et al., 2014) and Table 1 gives the population information and the proportion of residential and commercial buildings in the different climate zones. Cold and severe cold zones cover about 70% of

national territory and account for 43% of the total residential and commercial buildings in the country (Baeumler et al., 2012). All 13 provinces and cities belong to the cold and severe cold climate zones (Ministry of Construction of China & General Administration of Quality Supervision Inspection and Quarantine of the P. R. China, 2012), which are geographically located north of the Qinling Mountain Range and the Huaihe River. The cold and severe cold zones are defined as having at least 90 days of average outdoor temperature at or below 5°C (the Ministry of Construction of China & State Bureau of Technical Supervision, 1993).

Table 1. Distribution of population, residential and commercial buildings in different climate zones of China[21]

Climate zones	Inhabitants (million)	Residential and commercial buildings ratio
Severe-Cold and Cold zones	550	43%
Hot-Summer and Cold-Winter zone	500	42%
Hot-Summer and Warm-Winter zone	160	12%
Temperate zone	90	3%



Figure 1. Climate zones map of China

Generally, in China, the heating season is specified from October to the following March. Despite being shorter or longer for some areas, the average heating period is around 150 days. Once the heating season is over, the DH supply is turned off, meaning that DHW preparation by heat from DH is uncommon. The common DHW solutions in China are: a) small and decentralized DHW systems, such as HOBs that generate DHW and supply a building block, e.g. gas-fired boilers produce hot water for a residential community or b) individual water heaters that produce hot water in each household, such as solar, electric, or gas water heaters.

2. Methods

In this paper, the technical comparison elaborates four main DH elements: heat production, DH distribution network, DH network control, as well as the end consumer. In addition, the specific DH technologies, successfully

applied in Denmark, are analyzed, having potential for development in Chinese DH systems. However, wholesale adoption of the exact technologies would not be wise, as different national situations must be considered; otherwise the advantages of the technologies would be compromised potentially leading to failure.

2.1. Heat Generation and Fuel Sources

When discussing heat generation technology for DH, it is notable that the technology is independent of the heat source and many different fuels can supply the system, such as renewables, waste to energy, and fossil fuels. The only requirement is that the temperatures of the heat sources are sufficiently high to heat the buildings. This capability both increases the security of supply and allows for optimization of the cost of heat generation, a remarkable advantage with which individual heating solutions cannot compete. Historically, DH has developed in relation to CHP. There is a clear benefit to having a CHP plant supplying the heat to the DH network. If the fuel source for the DH is fossil-based, it has also been shown that the CHP creates the lowest carbon footprint of all fossil-fuel burning plants (Orchard, 2009).

2.1.1. Denmark

In the Danish DH system, heat is supplied from either CHP plants or heating plants. 665 CHP plants include 16 centralized CHP plants in large cities, whereas most decentralized CHP plants are in small cities or for private supply for enterprises or institutions. CHP supplies 77% of the heat, with the remaining 23% (Odgaard, 2013) being supplied by various other heat-only devices, such as biomass boilers, geothermal heat plants, solar plants, and waste heat from industry. A total of 230 DH plants can be found in Denmark (Dansk Fjernvarme, 2013). In 2011, the energy supply composition for DH source was composed of: recycled heat including indirect use of renewables 69.8%,

direct renewables 19.3%, and others 10.9% (EURO HEAT & POWER, 2014).

Figure 2 shows the development of energy source for DH between the years 2001 and 2010 in Denmark (Werner and Frederiksen, 2013). A clear trend of a gradual decrease in the use of fossil fuels is evident in the DH sector; in contrast, the increased usage of renewable energy, such as biomass, waste energy, geothermal and solar energy, provided environmentally friendly heat to the DH network. The inspiration from these examples is that during the progressive establishment of a smart energy consumption pattern, the orientation directives of the Danish government played an important role. They masterfully use the economic levers of taxes and subsidies to set the national energy development direction.

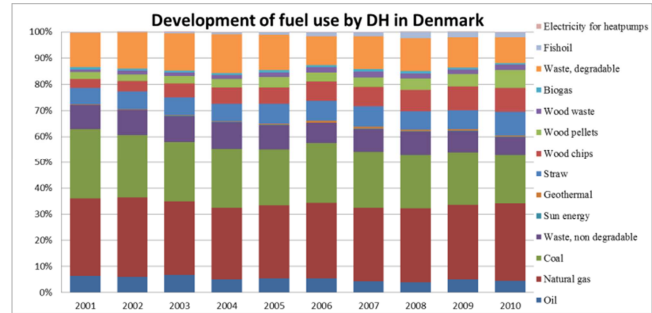


Figure 2. Developement of energy source for DH in Denmark 2001-2010

Biomass accounted for approximately 70% of renewable-energy consumption in 2010, mostly in the form of straw, wood chips, and pellets, while biogas accounted for less (Bertelsen and Tafdrup, 2014). The “Danish Biomass Action Plan of 1993” had forced power plants to use biomass to generate power and heat, a political decision that reoriented biomass energy consumption, resulting in a four-fold increase from 1980 to 2005 (Jørgensen, University of

Copenhagen). The Avedøre 2 CHP plant is known as the world’s largest and most efficient biomass-fuelled CHP plant (Ottosen and Gullev, 2004). Two units in this plant with a total capacity of 810 MW of electricity and 900 MW of heat, run on a wide variety of biomass fuels, as well as less coal, oil, and natural gas. In 2027, the plant is expected to run 100% on biomass (Wikipedia, 2014).

Denmark is at the forefront of the development of large-scale solar DH systems in Europe. Of the top 10 large-scale solar heating plants in Europe, nine are located in Denmark. The number 1 plant, Marstal Fjernvame solar DH system, was established in 1996 (SDH, 2013). This is, so far, the largest solar heating plant in the world, with 33,300m² of ground-mounted flat panel collectors, with a thermal capacity of 23,300 KW. There are two energy systems (new and existing) that, together, have an annual production of 56,000MWh of heat (Extranet, n.d.). Water thermal energy storage systems can provide seasonal and diurnal storage for the energy systems. According to the “solar thermal strategy” of the Danish Energy Agency, in 2030, 10% of Danish DH load will come from solar thermal and in 2050, nearly 40% of the DH load is estimated to come from solar heat generation (Runager and Nielsen, 2009).

There is great potential for developing geothermal DH in Denmark due to the presence of assessed geothermal resources in large parts of the country. In 2012, DH extracted and used about 300TJ of geothermal heat. Table 2 shows three representative geothermal plants in Denmark to demonstrate the development status of deep geothermal. In addition, shallow geothermal will likely expand in the coming years, especially in areas with no DH or natural gas supply. Furthermore, current ground source systems cover more horizontal collectors, as well as a small proportion of borehole heat exchangers, when considering groundwater protection and drinking water quality (Mahler et al., 2013).

Table 2. Three representative geothermal plants utilized deep geothermal energy in Denmark

	Year	Location	Heat capacity	Flow volume	Temp.	Depth	Saline amount
1	1984	Thisted,Denmark	7MW	200m ³ /h	44°C	1.24 km	15%
2	2005	Copenhagen,Denmark	14MW	235m ³ /h	73°C	2.6 km	19%
3	2013	Søderborg,Denmark	12MW	350m ³ /h	48°C	1.2 km	15%

Over many years of policy-making in Denmark, waste has experienced a role reversal from being a health problem in the 1960s to a resource since 2000. Waste incineration is the method for recovering energy from waste. Danish waste incineration plants are connected to the energy grid, providing DH and electricity to the Danish market, while, at the same time, decreasing the volume of waste by up to 70% (Andersen and Mortensen, Copenhagen Cleantech Cluster). Municipal solid waste (MSW) and household waste are an important source of heat for the DH sector. In Denmark, all MSW is incinerated, and household waste is not allowed to go to landfills. Typically, Danish incineration plants generate approximately 2 MWh of heat and 2/3 MWh of electricity from every ton of waste incinerated, that implies that the

operation of waste incineration plants produces nearly 80% heat and 20% electricity (Vestforbrænding, 2013). Therefore, waste incineration plants are well suited as a heat source for DH. Moreover, with a high priority on efficient energy usage, waste heat from industry has also become an important heat source for the DH sector. For example, in the town of Fredericia, the DH network distributes waste heat from local chemical plants to 55,000 households (Eldrup, 2013).

Denmark has achieved a highly efficient energy system based on CHP, which is already widespread and successful in this country, due to consistent prioritization over the past few years. On the other hand, Denmark never stops pursuing renewable heat sources for DH, as well as developing thermal storage technology. In this way, Denmark already

has the foundation stones for delivering high efficiency for its DH systems and, in addition, it will continue to consolidate and optimize over the coming years.

2.1.2. China

There are three main heating production modes in China: 1) CHP plants and DH plants, 2) HOBs, and 3) small, scattered HOBs or individual stoves for single buildings or individual households. Since DH has evident economic benefits in highly populated areas, the first two modes are common in cities, where the fuels are coal, natural gas, or oil. The third mode is the heating solution generally used in suburban and rural areas by burning coal, oil, or crop waste.

Figure 3 shows the proportional change in the trend of heat sources in northern China from 1996 to 2008. The heated area in northern China nearly quadrupled from 2.4 billion m² in 1996 to 8.8 billion m² in 2008, the proportion of individual coal stoves drastically decreased from 50% in 1996 to less than 10% in 2008, and the percent of natural gas gradually rose to 5% of total heating areas in 2008 (China National Bureau of Statistics). The share of the heating supply coming from CHP accounts for one third of the heat supplied in the DH sector, while the remaining heat comes from HOBs, mostly fueled by coal.

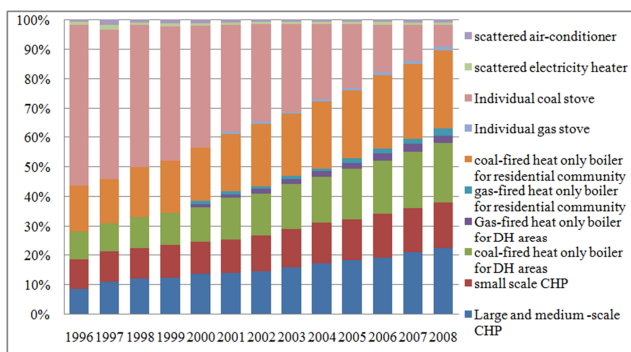


Figure 3. Proportional change in the trend of heat sources in northern China from 1996 to 2008.

For CHP plants, large-scale, high-capacity installations are actively encouraged, in order to realize the goal of saving energy and reducing emissions. This implies that large CHP plants will more easily obtain construction approvals and financial support than smaller ones. Currently, large extraction-condensing steam turbines, namely 200MW, 300MW, and 600MW (Tsinghua University building energy research center, 2011), are the leading type in China. This kind of CHP system can generally offer a 2.0-10.0 heat-to-power ratio and 60%-80% overall efficiency.

Coal is the dominant fuel source in the Chinese heating sector; this situation will continue in the coming years. Burning non-clean coal influences the efficiency of the boilers and causes excessive consumption of coal, as well as environmental pollution. According to the data from China's State Statistics Bureau in 2008, the national heating sector consumed 145.4 million tons of raw coal—about 91% of the total energy supply of the sector, in addition to 5% petroleum products and 4% natural and other gases, of which around one third is used in low efficiency HOBs (China National Bureau of Statistics).

Coal-fired HOBs are reported to have an efficiency of 60-65% (WADE, 2010), which can be considered quite low compared to the efficiency levels experienced in Western Europe. Currently, China's main cities have planned to restrict new heating plants to gas-fired technology. This fuel conversion is a long-term solution to deal with the consistent pollution issues faced today and to improve the efficiency of boilers. For Beijing city, the long-term plan is that gas heating will cover 51% of Beijing's heating areas in 2015. At the same time, heating areas of Beijing will expand from 680 million m² in 2010 to 850 million m² in 2015 (Beijing Heating group, 2011). Beijing has pledged to shut down most coal-fired boilers in central city areas before 2016, as part of its efforts to reduce fine particle pollution, especially during the heating season. This will result in a nearly 5-million-ton reduction in coal use, compared to 26.35 million tons in 2010 ("Beijing shuts coal-fired boilers for clean air," 2013). However, according to Li et al., (2009), this fuel conversion policy would lead to a significant increase in overall costs if building energy efficiency is not simultaneously taken into consideration.

Since coal is the main fuel for CHP plants and HOBs, this brings up a series of challenges for health, the environment, and the economy. On the other hand, the situation will continue in the coming years. At the same time, urbanization and industrialization are speeding up along with the economic growth, such that China faces the great challenge of energy supply security. According to 2011 *Annual Report on China Building Energy Efficiency* (Tsinghua University building energy research center, 2011), utilizing the surplus heat from industrial processes as the heat source in DH sector, otherwise discharged into the environment (Ajah et al., 2007), would enable China to realize energy goals and meet the challenges. Table 3 lists available surplus heat from the industrial processes around cities (Tsinghua University building energy research center, 2011).

Table 3. Available surplus heat from industrial processes around cities of China

Code	Available low quality energy	Temp. level	Extractable heat amount
1	Gas emissions from coal and gas combustion	50-180°C	10%-20% of fuel total calories
2	Heat emission from the condenser of power plant	20-40°C	70%-200% of generated electrical energy
3	Surplus heat from industrial production, e.g. industrial furnaces, steel plants, non-ferrous metals plants, chemical plants	30-200°C	30%-80% of consumed energy in the plant
4	Heavy after-sewage water treatment	20°C	Recycled water per ton can release heat of around 12kwh if temperature lowered to 10°C

Fang *et al.*, (2013) introduce a demonstration project and present the huge potential to utilize surplus heat from industrial processes in China's DH sector. Li *et al.*, (2011) introduce a new method for improving energy efficiency and the capacity of the DH system.

2.2. DH Distribution Network

Distribution cost is a critical factor for the profitability of a DH system (Gebremedhin, 2012). Furthermore, heat loss is a major issue for the distribution pipelines. According to Werner and Frederiksen, (2013), annual relative heat loss is influenced by four factors: total heat transmission coefficient from the insulation heat resistance, average pipe diameter, distribution temperature level, and the linear heat density.

2.2.1. Linear Heat Density

In (Persson, 2010), the definition of linear heat density is: Q_s (GJ), heat sold annually in a DH system, divided by the trench length of the piping system L (m), which is symbolized by equation (1), with the unit GJ/m. This ratio indicates the level of DH distribution system utilization, and is a good indicator of the ratio of revenue to distribution cost.

$$\text{Linear heat density} = Q_s/L \quad (\text{GJ/m}) \quad (1)$$

As is well known, most of the cost of a DH system lies in the distribution pipe work. Regions with high linear heat density can allocate more infrastructure costs to DH pipeline, thereby maintaining the competitiveness of DH. In Denmark, 80% of the DH companies face an average heat density within the interval of 1.2 – 5 GJ/m/year (Finn Bruus and Halldor Kristjansson, 2004), while, according to (Baeumler *et al.*, 2012), the average heat load density in China is about 38.88 GJ/m/year. Table 4 shows the annual average linear heat density in Denmark and China based on equation (1) and the data from Euroheat & Power (EURO HEAT & POWER, 2014). China has higher linear heat density than Denmark because densely populated cities with high-rise buildings are always in the DH supplied areas.

Table 4. Linear heat density in Denmark and China in 2007 and 2011

Year	Country	Total DH sales (TJ)	Trench length of DH pipeline system (km)	Linear heat density (GJ/m)
2007	Denmark	94,271	27,851	3.38
	China	2,250,150	102,986	21.85
2011	Denmark	101,940	30,288	3.37
	China	2,810,220	147,338	19.07

2.2.2. Denmark

For a large-scale Danish DH network, the complete pipeline system generally consists of the transmission system, distribution system, and municipal network, with different companies being in charge of each part—a good example is Copenhagen's DH system.

The Danish DH systems have evolved over time by

utilizing innovative methods to reduce distribution heat loss. One of the main contributing strategies has been to operate the distribution network with relatively low supply temperatures and as high a differential temperature between forward and return pipes as possible; this both insures good cooling of the supply and minimizes mass flows in the system, which results in pump savings later on. Currently, the operating temperatures of the DH system are typically 70/40°C during the heating season and 65/25°C during the non-heating period. Moreover, Denmark is in the transition from 3rd generation DH to 4th generation DH, the DH system will be working under 50/20°C in the future, instead of the former 70/40°C (Brand and Svendsen, 2013). An international research center, 4DH, has carried out relevant research work (4DH, 2014.). Further investigation is seeking even lower supply temperatures. Low network temperature increases the quality match between heating demand and supply (Li and Svendsen, 2012), minimizes heat loss in the distribution network, improves the network's economic feasibility, and enables easier adaption to renewable energy (Dalla Rosa *et al.*, 2013)(Dalla Rosa *et al.*, 2011).

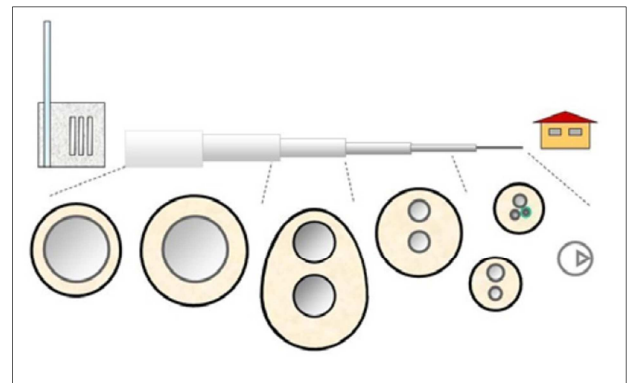


Figure 4. Innovation of DH distribution pipes in Denmark

Another notable contribution is the invention of the concept of pre-insulating steel pipes and covering the insulation with a water-resistant casing. Moreover, the service pipes are designed with optimized geometry (Figure 4), in order to reduce the relatively high heat loss of small pipes and consolidate the competitiveness of DH in low heat density areas, where single-family houses or new energy-efficient buildings are common. Transmission pipes from local CHP/DH plants generally have larger dimensions and use signal piping made of pre-insulated steel. The distribution pipeline from local heating substations likewise uses mainly pre-insulated steel pipe work; if the pipe size is small enough, the twin-pipe structure will be used. For municipal networks, with final distribution based on all plastic pipe work and insulation, twin-pipe or even triple-pipe is used. The triple-pipe is described as two forward lines and one return line, generally combined with a booster pump in the house, not only in order to achieve smaller heat loss than traditional service pipes, but also to provide better hot water comfort. Twin-pipe means that two pipes are located

within a common circular insulation with an outer casing. Twin-pipe is energy-efficient because the return pipe is arranged close to the temperature field generated by the supply pipe. In that case, heat resistance due to coinciding temperature fields becomes greater, resulting in lower heat loss from the return pipe (Werner and Frederiksen, 2013). Heat loss savings of 37% and investment cost reduction of 12% can be achieved by using twin pipes instead of two single pipes (Finn Bruus and Halldor Kristjansson, 2004). In addition, to achieve large differential temperatures and hydraulic balance in a DH system, it is necessary to have high-efficiency heat exchangers and control valves installed in the network.

2.2.3. China

China greatly extended the DH pipelines along with the expansion of heating areas, rapid economic development, and accelerating urbanization. It could be said that large dimensions and high temperature levels are the characteristics of the Chinese DH network. Single pipe is the most common structure. One of the reasons for this is that high heat density in urban areas needs a larger dimension of pipes. In addition, more and more DH transmission systems utilize directly buried pre-insulated pipes, instead of the former concrete trenches where the insulation foam for pipelines was applied on site. Typically, the service pipe is steel and is covered by insulation foam with rigid polyurethane. The outer protection is commonly a glass steel tube or high-density polyethylene tube. A DH temperature range of 115~130°C for supply and 50~80°C for return is typical (Ministry of Housing and Urban-Rural Development of China, 2010).

Heat loss is a big issue influencing the efficiency of a DH network. According to (Yan et al., 2011), around 30% of total supply heat is lost in Chinese DH systems due to hydraulic imbalance and water leakage. Around 30% of total supply heat is lost in Chinese DH system due to hydraulic imbalance and water leakage. Tsinghua University has conducted research to clarify energy loss items by taking a typical Beijing residential building as an example. In order to meet the annual heat demands, 0.30 GJ per square meter is required, whereas heat generation has to produce 0.45 GJ to ensure 18 °C statutory indoor temperature in the heating season (Tsinghua University building energy research center, 2011). That means 33% of total produced heat is lost when heat is delivered from heat generation to end users.

Among the factors, hydraulic imbalance accounts for quite a significant amount of total energy loss, and excess heat supply could be one result. This reflects the general lack of automatic control measures in the Chinese DH system. For the hydraulic balance of the DH network, it is important to have accurate flow control to substations, buildings, and end users, so that the heat demand can be better matched with exact energy consumption. Since in China the common case is one in which a large substation supplies heat to a group of high-rise or multi-story buildings, which contain a number of apartments in a building. For this kind of large and complex

DH system, it is inevitable to have hydraulic imbalance, if there are no control or adjustment devices in the individual branches: proximal end users get more flow than needed, and the distal receive less than required. Moreover, the apartments in a single building are located in different orientations and positions; therefore, the indoor temperature differs from room to room. Under this condition, when the distal end user's basic thermal comfort is met, the proximal user's environment might be overheated. Furthermore, there are no adjusting devices at the ends of the internal building's heating system. Naturally, proximal heat users are likely to open a window to bring the indoor temperature down, as needed, according to their comfort. Additionally, if the supplied heat cannot be adjusted according to the varying weather, the heat could be excessively supplied during the entire heating season. Hydraulic balance in a DH system can be achieved by using the differential pressure of the system to insure an adequate flow through the branches; usually, valves and pumps are the basic components for solving the hydraulic imbalance issue. Boysen and Thorsen, (2007), analyze how to establish hydraulic balance in a DH system. Weather compensation controllers can adjust the produced heat according to weather changes to meet the heat demands.

2.3. DH Substations-Network Control Methods

Since an increasing number of DH experts recommend applying the indirect-connection in modern DH systems (Thorsen and Gudmundsson, 2012), substations play a key role in securing energy-efficiency and no-risk operation. Substations provide hydraulic separation between heat generation and heat consumers, thereby avoiding the contamination of internal building heating systems.

2.3.1. Denmark

When comparing substation technology between Denmark and China, one finds that a large community-level substation is the most common case in China and one substation generally supplies heat to 50,000-200,000 m² floor area (Xu et al., 2009). In Denmark, a substation may be a customer substation, which is installed in each building, referred to as a building-level substation. The sub-station may even be in each flat, apartment, or single-family house, known as a flat station. At the same time, a typical Denmark substation will supply both space heating and DHW. Generally, the closer the control equipment is to the heat consumer the better the network control that is achieved. Moving the control components towards the heat consumers has been a continuous trend in Danish DH systems and has played a crucial role in the increased efficiency and economic performance of the Danish DH industry.

The importance of good control in order to achieve high energy efficiency cannot be stressed enough. As DH is a hydraulic system, the draw off by one consumer will inevitably have consequences for the other consumers, therefore, the closer the control is to the consumer the less affected they become. The optimum control is achieved when all consumers have their own substation (Thorsen, 2010).

Moreover, the additional benefits of utilizing small substations are that they can be pre-manufactured and insulated, and achieve great space savings. Compared to

large substations, building-level substations improve energy efficiency and allow for the application of more advanced solutions.

Table 5. Large substation and building level station based on a real case in China

Heating zone	Heating area (m²)	Scenario 1:Large substation		Scenario 2:Building-level substation		
		Heat capacity	Unit	Heat capacity	Unit	Sum
1#	48390	2900kw	1	200kw	5	11 units, total 3100kw
				250kw	2	
				300kw	1	
				400kw	2	
				500kw	1	
2#	48381	2900kw	1	100kw	1	14 units, total 3100kw
				150kw	1	
				200kw	8	
				250kw	2	
				200kw	5	
3#	48547	2900kw	1	200kw	6	14 units, total 3350kw
				250kw	5	
				300kw	3	
4#	47020	2900kw	1	200kw	9	13 units, total 3100kw
				250kw	2	
				400kw	2	
5#	37600	2300kw	1	150kw	5	14 units, total 2800kw
				200kw	6	
				250kw	2	
				350kw	1	
6#	43068	2600kw	1	150kw	1	6 units, total 2700kw
				200kw	1	
				250kw	2	
				550kw	1	
				1300kw	1	
7#	48773	2700kw	1	100kw	1	12 units, total 2900kw
				150kw	3	
				200kw	5	
				250kw	2	
				900kw	1	
8#	21360	1200kw	1	800kw	1	2 units, total 1300kw
				500kw	1	
Pipes cost		80.28%		58.43%		
Substations cost		19.72%		38.33%		
Total		100%		96.76%		

2.3.2. China

There is a real case in Weihai city in Shandong province of China (Danfoss A/S, 2004), where a total of 343,139 m² heating areas are split into 8 heating zones. Moreover, two scenarios are compared: 8 large substations (Scenario 1) versus 86 building-level substations (Scenario 2), see Table 5. The comparison includes the investment needed for the

substations and primary and secondary pipes. This investment calculation does not include the cost of civil works to any extent, nor the cost of electrical facilities (transformers, cubicles, etc.), network valves, or the power connection needed for the group substations. If these expenses were included, it would increase the total investment of Scenario 1 and make Scenario 2 even more

favorable. The contrast clearly shows that the investment would be lower when using building-level substations, although the total cost of small substations is double compared to that of large substations. Pipeline routing in the primary side can be done more efficiently and with a greater temperature difference, thus reducing the pipe diameter. From a technical perspective, small pipe size and a high differential temperature are helpful for reducing the heat loss of DH pipelines. In addition, Scenario 2 also gives other additional technical benefits, which remarkably influence the long-term operational costs and the total lifetime of the heating system. These benefits could include, but are not limited to, the following:

- an uncomplicated hydraulic system;
- a reduction of pump operation costs;
- Improvement of heat user comfort level;
- Modular design;
- reduced space requirements;
- The possibility to combine DHW system;
- Ability to charge the heating fee based on actual consumption;
- Flexible and smart control.

According to China's industry standard JGJ173-2009 (Ministry of Housing and Urban-Rural Development P.R.China, 2009), the building-level substation is recommended in 4.2.5 because of obvious technical superiorities, which are mentioned above.

Against the background of the heat reform in China, there is an opportunity to upgrade the DH system of China. Small substations can be in line with current DH industry developments. There is great potential for employing this application in the future.

2.4. End Consumer

Heat reforms are ongoing in China. In July 2003, eight central government ministries and commissions jointly issued a Government Circular calling for each of the 16 Northern provinces (in cold and severe cold climate zones) to implement heating system reforms in several pilot municipalities, according to the specified guidelines in the document "Heat Reform Guidelines." The principles of these Guidelines are the commercialization of urban heating, the promotion of technical innovation in heating systems, the application of energy-saving building construction, and the improvement of living standards. In the section on heat consumers, establishing a heat metering and billing mechanism based on actual consumption and improving building energy efficiency are two main tasks.

2.4.1. Heat Metering and Billing

There are some fundamental differences between DH systems in Denmark and China when it comes to the consumers. Two of the differences are heating billing and metering measurement.

Generally, China uses a fixed heating price based on square meters when charging the heating bill. Heat unit price

depends on different factors, such as the type of heat generation (DH plants or HOBs), the type of thermal media (water or steam), building type (residential or commercial). Generally, internal building heating systems follow the constant flow principle, due to the lack of control devices at the end user. The statutory indoor temperature of residential buildings in the heating season is 18 °C. If the temperature is lower than this standard, the customers can refuse to pay the heating fee; if it is higher than this, the heating fee is charged as normal. Under this condition, heat consumers have no incentive to consciously save energy. For this reason, the heat reform aims to install regulation devices at the end of internal building heating systems, thereby making the room temperature adjustable; the heating fee will be charged according to the actual energy consumption. To reach this goal, several technical heat-metering measures have been invented and applied in China. In (Liu et al., 2011), the technical heat metering measures are presented and analyzed according to China's current DH situation. Currently, the heating area in China in 2012 was 4.92 billion m²; the retrofitted area for heat metering was 0.805 billion m² in northern China, which accounted for approximately 66.7% of the total retrofitted area of heat metering devices installed (Ministry of Housing and Urban-Rural Development of China, 2012).

Table 6 lists two households' heating bills from Denmark and China. This seeks to illustrate the differences of heat billing between these two countries, not the price level. As this comparison is not based on the same benchmark, the heating bill of Denmark includes the DHW and SH throughout the year, while the Chinese heating bill contains only the SH fee during the heating season. In Denmark, the cost of DH is split into fixed and variable costs. The fixed cost covers the cost of the distribution network and the variable cost is metered according to actual energy consumption.

In Denmark, regulation devices are mounted at the end of internal heating systems to adjust the thermal flow rate into air heat units, thereby, the heat consumer can take measures to reduce heat consumption, such as closing the thermostatic valve instead of opening the window. In fact, the consumer can have a strong influence over their energy consumption by setting the desired room temperature. Additionally, consumers decide for themselves when their heating season starts or ends. The installation of heat meters and other regulation devices do not, in themselves, save energy. Rather, the energy savings are initiated by the consumers' own awareness. This way of heat billing has shown an average of 20-35% energy savings by the consumers (Drysdale, 2002). Further, modern energy meters are provided with facilities for remote reading. This is not only convenient for the DH companies to monitor the entire heating system, but also facilitates heat users tracking their energy consumption online.

Table 6. Comparison of heating bill between Denmark and China*

Heating bill for a 154 m ² one-family house in Denmark for the whole year (365 days)						
variable cost		Heat meter records		Unit price (exl.tax)	DKK	€
	start	end	consumption			
	258.99 GJ	356.75 GJ	97.76 GJ	80 kr./GJ	7820.8	1048.4
fixed cost	effect contribution	heating area 154m ²		15 kr./m ² /year	2310	309.7
subscription fee					550	73.7
Tax	25%				2670.2	357.9
total					13351	1789.7
Heating bill for a 154m ² apartment in a multi-storey building in Beijing for the heating season (125 days)						
fixed cost	Heating generation types		heating area	Unit price (incl.tax)	Total (Yuan)	€
	Gas-fired boiler		154m ²	30 Yuan/m2	4620	474.8

*1Euro=8.48 Yuan=7.46 kr.

Table 7. Residential building energy requirements in Denmark

Standard	Building class	Kwh/m ² /year	conditions
BR08	Building class 2008	70+2200/HFS*	Minimum requirement in 2006-2010 year
	Low-energy building class 1	35+1100/HFS	Low-energy building class
	Low-energy building class 2	50+1600/HFS	Low-energy building class
BR10	Building class 2010	52.5+1650/HFS	Minimum requirement in 2012 year
	Building class 2015	30+1000/HFS	Low-energy building class
	Building class 2020	20	Low-energy building class

*HFS is the building's heated floor space in m²

2.4.2. Building Energy Efficiency

Building energy efficiency is a key factor influencing the heat load of space heating. Since space heating typically represents a significant share of total building energy consumption, the most beneficial way to implement energy savings is to increase the energy efficiency of stock of houses.

Since the 1970s energy crisis, energy efficiency policies have been implemented in Danish buildings, which is has driven significantly less consumption than is experienced in most other European countries with similar climates (Danish Energy Agency, 2012). Furthermore, Danish authorities' strategy includes announcing future energy efficiency requirements many years in advance. Local municipalities have the power to require new construction to comply with future building requirements. Table 7 lists Danish residential building energy regulations and corresponding heat requirements.

The Chinese residential building sector accounts for approximately 30% of the country's final energy consumption (Richerzhagen *et al.*, 2008). In 2008, heating energy consumption in northern Chinese towns accounted for 23% of total building energy consumption (Tsinghua University building energy research center, 2011). In an effort to reduce heating energy consumption, China began to enforce "Building Energy Efficiency Codes" in 2005 by implementing a three-step approach (Ministry of Housing and Urban-Rural Development of China, 2013).

- Step 1: Residential buildings built in 1991-1999 are

required to achieve 30% energy savings compared to average residential buildings built before 1991.

- Step 2: Residential buildings built in 2000-2004 are required to achieve 50% energy savings compared to average residential buildings built before 1991.
- Step 3: Residential buildings built after 2005 are required to achieve 65% energy savings compared to average residential buildings built before 1991 in that location.

Since China's legal heating areas cover different climate zones, building heat consumption index levels vary from case to case. For Beijing, in the 1980s, standard coal consumption per square meter per heating season was 25.2kg. According to the 3-step energy saving approach, this consumption should be reduced to 17.64kg (30%), 12.4kg (50%), and 8.28kg (65%) respectively. In order to reach those levels, the efficiency of the DH distribution pipeline and the efficiency of the boiler are improved accordingly, as well as the building's envelop insulation performance. Consequently, building heat consumption per square meter per heating season is decreasing; see Table 8, with calculations based on equation (2).

$$q_c = 24 * Z * q_H / (H_c * \eta_1 * \eta_2) \quad (2)$$

The heating season in Beijing (Z) is 125 days and H_c stands for the calorific value of the standard coal equivalent, 8140wh/kg. Table 7 and 8 contain building energy-consumption requirements in Denmark and in China. However, it is illogical to make a simple comparison, since

Danish regulations try to promote long-term thinking concerning energy-efficiency investments. For instance, Danish regulations include requirements for overall building energy demand: SH, ventilation, cooling, DHW, and non-residential lighting. This has encouraged innovation towards more comfortable buildings that have lower overall energy demands. In the case of China, building energy efficiency exclusively focuses on the energy consumption of SH. After the third step energy savings are achieved, the heat consumption of Beijing residential buildings are 43.5kwh/m²/year; this is slightly higher than 40kwh/m²/year in BR10 Building class 2015 (if floor area is 100m²). One

could say that Danish buildings have higher energy efficiency than those of China, since overall energy consumption of buildings includes factors others than SH.

The high energy-efficiency of Danish building stock is the result of a consistent effort over many years, relying on strict requirements and standards, an experience that could be an inspiration to China. For China, enhancing energy efficiency could be an effective way to ease the pressure of energy supply security, reduce CO₂ emissions, mitigate the pollution issue, improve the thermal comfort level of building, and so on. There is a significant series of advantages (Richerzhagen et al., 2008).

Table 8. Building energy efficiency codes in China combined with the 3-step approach

	Year and design standard	q_c :Standard coal ¹ consumption (kg/m ²)	Energy saving ratio	q_H :Building heat consumption index (w/m ²)	η_1 :Efficiency of distribution network	η_2 :Efficiency of boiler
Datum	1980 Year	25.2	100%	27.4	0.8	0.5
Step 1	1986: JGJ26-86	17.64	30%	22.4	0.85	0.55
Step 2	1995: JGJ26-95	12.4	50%	20.6	0.9	0.68
Step 3	2010: JGJ26-2010	8.28	65%	14.5	0.92	0.7

Table 9. The overview of comparison DH systems used in China and Denmark

Items	Denmark	China	Potentials for China
DH season	Whole year	Winter Only	
DH system	SH and DHW integrated.	DH is mainly for SH.	DHW generation from DH has great potential to expand the market share.
Heat generation	Efficient and flexible heat production system, optimizing the combination of heat generation technologies and mix of fuels.	Coal is dominate DH fuel.	
	Boilers (biomass, fossil fuel).	Large-scale, high-capacity CHP plants are encouraged mostly.	
	Heat pump/electric heat boilers.		
	Solar heat.	Fossil fuel CHP.	Renewable energy, waste energy, clean energy technologies.
Distribution network	Biomass CHP & geothermal DH plants, Gas CHP.		
	Waste incineration heat/CHP.	Fossil fuel heat-only boilers.	
	Surplus heat from industry.		
	Development tendency is LTDH, from 70/40°C ~55/25°C.	High DH supply temperature (130/70°C).	
DH network control	Reduced heat loss of distribution pipeline based on multiple techniques: directly buried, pre-insulated steel pipe, optimized geometry of service pipes, applied low DH supply, and high temperature differential operation.	Large dimension of distribution pipes due to high heat density.	Improve the efficiency of DH system by achieving the overall hydraulic balance.
	Building level substation or flat station for each apartment. Single family house and multi-storey buildings are typical.	Small temperature difference, hydraulic imbalance and the lack of intelligent control comprise the efficient of DH system.	
	Adjustable indoor temperature due to regulation devices at end of internal building heating system.	Large substation for a group of buildings. High-rise and multi-storey buildings are typical.	Building level sub-station, or even flat station concept
	Heat bill is based on actual consumed energy. Government regulates building energy consumption and supervises implementation.	Non-adjustable indoor temperature is min.18°C legally.	
End users		Heat bill is fixed and charged by floor heating areas.	Retrofit for heat metering and temperature-adjustable heating systems.
		Building efficiency can be improved through reduced consumption of heat.	

¹ China typically converts all its energy statistics into "metric tons of standard coal equivalent" (tce), a unit that bears little relation to the heating value of coals actually in use in China. One tce equal 29.31 GJ (low heat) equivalent to 31.52 GJ/tce (high heat).

3. Results

Table 9 gives an overview of comparison of DH systems used in China and Denmark, also states the potentials of the Chinese DH system.

4. Discussion

Energy efficiency permeates the main aspects of the Danish DH system. The fundamental idea of DH, “utilizing local energy otherwise wasted,” has been well fulfilled. The idea of heat production is to carry out a wide range of CHP technologies, define according to the corresponding scale, in accordance with local conditions—larger for major cities and smaller for suburban areas. Meanwhile, a diverse range of DH fuels are available, especially renewables, such as biomass, geothermal, and solar energy. Moreover, waste energy is also a well-utilized resource within Denmark’s DH system. This utilizes low quality energy in the DH sector, thus reducing the consumption of primary energy. In addition, all kinds of heat storage facilities can adjust the heat supplied from storage systems or heat production units, depending on the price of electricity in different periods, ensuring the economical operation of the DH system. As such, Danish DH systems establish an efficient and flexible heat production system by optimizing the combination of heat generation technologies and a mix of fuels.

As for the distribution network, innovative methods have been explored and utilized, these technologies not only reduce the heat loss of the distribution network, also keep DH competitive in low-heat-density areas. In addition, sophisticated control systems have been implemented, wherein a powerful programmable controller is usually set, with weather compensation and segmentation control. Control valves, working together with sensors, ensure the extract differential pressure in individual branch that the DH system operates under hydraulic balance. Customer substations are even closer to heat users to gain better network control. Additionally, the installation of heat meters and regulation devices at the ends of the heating system enable a heat metering and billing mechanism based on actual consumption. This motivates the heat user to consider means for saving energy. Wide ranging, energy-saving measures and mandatory building energy requirements have improved the energy efficiency of Danish buildings. These facts, together, will accelerate the transition process of Danish DH from 3rd to 4th generation and, as a result, DH will contribute towards realizing the ambitious energy targets.

China has a substantial DH market with large heating areas and high linear heat density. It is full of potential and possibilities. Environmental issues will force China to adjust its energy consumption structure, with less fossil fuel and more sustainable energy as a safer model. Surplus heat from industrial processes presents a valuable resource, which is expected to be utilized properly by combining appropriate

technologies. In addition, the reduction of heat loss and the improvement of hydraulic issues can also greatly enhance the efficiency of DH networks. Applying building-level substations rather than large-scale ones, will allow DH systems to be more flexible and efficient. Heat reform opens the door for establishing wise heat metering and billing mechanisms, and will encourage the heat consumers to consciously save energy. Other focuses of the heat reform are to improve the thermal properties of building envelopes and to upgrade heating systems; these create a platform for applying advanced technologies. One could say that China is in a transition stage of upgrading DH systems and can benefit from the successful experience of other countries. In fact, collaboration and idea exchanges in the DH field between China and Denmark have already started. This does not mean, however, that China should directly copy the experience of other countries. Rather, with sensitivity to national conditions and in compliance with relevant regulations, China can selectively absorb, adopt, and implement best practices in the context of its own heating reforms.

5. Conclusion and Policy Implications

This paper has analyzed the current situation of the DH industry in these two countries. Based on the comparison of the main elements of DH systems used in China and Denmark, it is clear that China can take inspiration from the Danish DH system development and selectively adopt the relevant technologies, based on the real situation.

One experience from Denmark is to establish smart heat production in DH systems by combining different heat generation technologies and a mixture of fuels, as well as the utilization of thermal storage to make the system flexible.

The fundamental idea of DH in Scandinavian countries, “using local energy otherwise wasted,” should be propagated in China’s DH field. For China, the existing valuable resource could be surplus heat from industrial processes, which is readily available around high-density urban areas, where the DH pipeline infrastructure is available, since DH has developed in these areas for some years.

Improvement of the efficiency of DH networks by enhancing automatic control level into hydraulic balance and achieving higher building energy efficiency would be shortcuts for China’s DH system to reach energy-saving and emission-reduction targets.

For China, supply security, pollution, and GHG emissions could be the most important current challenges. Meanwhile, efficiency improvement and modernizing DH with clean energy technologies have the maximum synergy between energy supply security and air pollution abatement. These challenges could also represent other opportunities. Updating DH systems in a sustainable way definitely benefits China in terms of long-term development.

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