DISTRICT HEATING RESEARCH IN CHINA

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District heating research in China

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PREFACE

District heating is growing rapidly in China as Chinese building areas are expanding fast giving increased heating and cooling demands. This report gives us an overview of the current situation for district heating and the research and development in this sector in China. Possibilities for collaboration between Swedish and Chinese researchers and companies in the field of district heating and cooling are also presented.

The study was performed by Dr Mei Gong and Professor Sven Werner, Halmstad University. A reference group has followed the project and commented the report. The group has consisted of Rickard Frithiof Vattenfall, Henrik Rietz Swep International AB, Henrik Landersjö E.ON Värme, Johan Skarendahl IQ Samhällsbyggnad, Sofia Andersson Energimyndigheten and Jingjing Zhang Lunds universitet.

The project is part of the Fjärrsyn research program which is financed by Swedish District Heating Association and Swedish Energy Agency. The research aims at support the competitiveness for district heating and cooling through increased knowledge about the role of district heating for the sustainable society for example to open for economical feasible solutions and the future's technology.

Carina Bergsten
Chairman of the Business Intelligence Council at Swedish District Heating Association

EXECUTIVE SUMMARY

Background

Sweden has no organised research collaboration with China concerning district heating and cooling, even though Sweden has well-developed district heating and cooling experiences supported by several research programs. The Swedish district heating systems use almost only domestic resources nearly without carbon dioxide emission from fossil fuels. These Swedish experiences and accumulated knowledge about district heating and cooling are unique in the world. China's district heating systems are growing rapidly and Chinese researchers nowadays write more and more articles about district heating and cooling. There should be opportunities for research cooperation between China and Sweden on district heating and cooling.

Aim

This project has five different goals: (1) an overall presentation of the district heating and cooling sector in China, (2) an overview mapping of articles written by Chinese district heating and cooling scientists in international scientific journals, (3) evaluation and summary of the mapping of scientific articles, (4) contacts and meetings with the most active Chinese district heating and cooling researchers, and (5) identification of possibility for a Chinese-Swedish research collaboration on district heating and cooling.

Methods

The Chinese district heating and cooling sector has been analysed by available statistics and published articles. Through the Scopus scientific search engine, the potential research partners have been identified by analysing Chinese publications on district heating and cooling between 1970 and 2013. Based on the number of publications and identified research focuses, four universities were selected for study visits in China, performed between May 27 and June 3, 2014.

Results

With the growth of the Chinese economy and the improvement of living standards, the Chinese building spaces are expanding rapidly, giving higher heating and cooling demands. National energy efficiency building codes in four climate zones and the national heating reform have been developed in order to improve building energy efficiency.

The annual average growth rate of district heated area and pipe lengths increased by 13% and 10% respectively in China during 1997-2012. The national average linear heat density of district heating in China is about two times more than in Sweden, since only large buildings in China are connected to district heating systems. The average relative distribution heat loss in China is 2-3 times higher than in Sweden.

Chinese researchers have achieved an impressive growth of the number of papers published on district heating and cooling during recent years compared to all the papers published internationally. Many Chinese research groups are represented in the literature survey. Tsinghua University is the dominant research group among Chinese district heating and cooling researchers, but Harbin Institute of Technology has expanded their publication rate rapidly during recent years.

Presently, the proportions of heat from boilers and CHPs are almost equal in the Chinese district heating systems. The large Chinese interest in various heat and cold supply methods as CHP, CCHP, and heat pumps can be seen as an introduction to the required transfer from coal-fired CHP plants and boilers to other heat supply options, including using natural gas as fuel. However, no paper on waste incineration with heat recovery was found in the literature analysis. Several Swedish cities use the heat from waste incineration as base load heat supply, since the landfilling of combustible waste and organic waste was prohibited in 2002 and 2005 respectively.

With respect to system functioning, China has an important future challenge of installing customer heat control and flow control in substations in order to eliminate the flow misallocations in the heat distribution networks. New regulation methods are required considering all the important parts: heat sources, heat networks, substations, and heat users. A successful district heating and cooling manager must always minimise both the heat generation costs and the heat distribution costs in order to compete in the heating and cooling market. With the implementation of the 2003 heat reform, the district heating systems in China are transferring welfare systems to more market oriented supply systems; new billing methods based on heat consumption have been suggested in order to replace the building area based method. In Sweden, the district heating systems were commercial from the beginning and have very good market experience.

District heating and cooling researchers at the four visited universities worked with energy policy, technology, design, and community energy planning. Large heat transmission lines have been proposed, the coordinated heat and power district models have also been developed, and several different technologies on pipe-line distribution and meter technology will be used in order to save energy and reduce emissions. Heat pumps are widely used for different sources, and have been applied in the energy planning applications. A large absorption heat pump station was visited in Harbin. The Chinese textbook gives a very detailed view based on calculation and construction methods. The new English/Swedish textbook covers a wider area of district heating and cooling, so a translation of this textbook into Chinese can complement the traditional Chinese textbook.

Conclusions

Our five project conclusions are related to our five project goals:

- China has currently an impressive growth of urban district heating systems, however, these are mainly based on traditional technologies with coal based

CHP plants and boilers. There is a need to use more sustainable heat supply options in these expanding district heating systems.
- Chinese district heating and cooling researchers have become more active in publishing articles during the last few years.
- Chinese publications on district heating and cooling reveal a focus on new heat supply options, as well as on developing the system functioning in heat distribution, especially in the secondary networks.
- Most active Chinese district heating and cooling researchers have been identified at Tsinghua University in Beijing, Harbin Institute of Technology, Harbin Engineering University, and Tongij University in Shanghai. The latter university has mostly an interest in district cooling issues, while the three former universities have a primary interest in district heating issues. Other active universities are Tianjin University, Dalian University of Technology, and Jiangnan University.
- We propose five research collaboration activities such as (1) a general exchange of researchers, PhD students, and master students between China and Sweden; (2) a company program for active district heating engineers in China and Sweden giving the possibility to identify unique district heating and cooling solutions in both countries; (3) identifying possible future research projects; (4) inviting Chinese partners to the international district heating conferences and symposiums held in Europe; and (5) translation of the English/Swedish textbook into Chinese as proposed by the research group at Harbin Institute of Technology and the Chinese District Heating Association.

Our overall conclusion is that knowledge about district heating and cooling can be transferred in both directions between China and Sweden. China has several new ideas of very long transmission pipelines and the use of absorption heat pumps in both CHP plants and in distribution networks, which are not used in Europe today. Sweden has long-term experiences of a highly diversified heat supply and more elaborate system functioning without any flow misallocations. These two subject areas dominate the Chinese district heating research articles nowadays.

SAMMANFATTNING

Bakgrund

Sverige har inget organiserat forskningssamarbete med Kina, trots att Sverige har en mycket väl utvecklad fjärrvärmekompentens i världsklass, som bygger på både driftserfarenheter och forskningsresultat. Sverige har fjärrvärmesystem som nästan helt saknar fossila koldioxidutsläpp och som baseras på nästan enbart inhemska resurser. Kinas fjärrvärmesystem växer i snabb takt och kinesiska forskare skriver alltmer artiklar om fjärrvärme och fjärrkyla. Det borde finnas förutsättningar för ett forskningssamarbete mellan Kina och Sverige kring fjärrvärme och fjärrkyla.

Mål

Detta projekt har haft fem olika mål: (1) en översiktlig kartläggning av fjärrvärmen i Kina, (2) identifiering av artiklar skrivna av kinesiska fjärrvärme- och fjärrkyleforskare, (3) utvärdering och summering av de kinesiska fjärrvärme- och fjärrkylartiklarna, (4) kontakter och möten med de mest aktiva kinesiska fjärrvärme- och fjärrkyleforskarena, samt (5) identifiering av möjliga samarbetsformer för ett kinesiskt-svenskt forskningssamarbete kring fjärrvärme och fjärrkyla.

Metod

Den kinesiska fjärrvärmen har kartlagts genom konventionella analyser av publicerade artiklar och tillgänglig statistik. Potentiella forskningspartners har identifierats genom en litteraturöversikt avseende publikationer om fjärrvärme och fjärrkyla mellan 1970 och 2013 i sökverktyget Scopus. Fyra universitet valdes sedan ut för möten på plats i Kina mellan den 27 maj och 3 juni 2014. Urvalet gjordes utifrån antal publikationer och förmodad forskningsinriktning.

Resultat

En kinesisk ekonomi i stark tillväxt och en ökad levnadsstandard har skapat ett stort behov av nya bostäder. Detta har gett upphov till betydligt högre värme- och kylbehov. Nationella byggregler för fyra olika klimatzoner har utvecklats och en värmereform har genomförts för att öka byggnadernas framtida energieffektivitet.

Fjärrvärmesystemen i Kina har mot denna bakgrund växt mellan 1997 och 2012 med 13 % per år avseende ansluten byggnadsyta och med 10 % per år avseende ledningslängden. Nätens linjetäthet är i snitt dubbelt så hög som i Sverige, då endast stora byggnader ansluts till fjärrvärme. Den årliga procentuella värmeförlusten i näten är 2-3 gånger högre än i svenska system.

Kinesiska fjärrvärmeforskare har uppnått en imponerande tillväxt av publicerade artiklar om fjärrvärme och fjärrkyla under senare år jämfört med övriga världen.

Många kinesiska forskargrupper finns representerade i vår litteraturöversikt. Tsinghua-universitetet i Beijing är dock den dominerande forskargruppen, men Harbins Tekniska Institut har ökat sin publiceringstakt snabbt under senare år.

Andelen värme som kommer från kraftvärmeverk är ungefär lika stor som del andel som kommer från värmepannor. Det stora kinesiska intresset av en mer diversifierad värme- och kyltillförsel som kraftvärme, kombinerade fjärrvärme och fjärrkylelösningar samt stora värmepumpar kan ses som en inledning till en övergång från de traditionella koleldade kraftvärmeverken och värmepannorna till andra tillförselsätt inklusive naturgas som bränsle. Vi hittade dock inga artiklar om avfallsförbränning med värmeåtervinning till fjärrvärme i litteraturanalysen. Många svenska fjärrvärmesystem använder denna metod då deponering av brännbart och organiskt avfall förbjöds 2002 respektive 2005.

Avseende systemfunktionen i de kinesiska fjärrvärmesystemen finns det en framtida utmaning av att installera reglering av värmebehov och flöden i de sekundära fjärrvärmecentralerna. Huvudmotivet för denna reglering är behovet att eliminera den otidsenliga felallokeringen av flöden i de sekundära fjärrvärmenäten. Nya regleringsmetoder finns dock i hela försörjningskedjan: värmetillförsel, värmedistribution, fjärrvärmecentraler och värmeanvändning. En framgångsrik ledare av ett fjärrvärmesystem måste alltid minimera både kostnaderna för värmetillförsel och värmedistribution för att kunna konkurrera på värme- och kylmarknaderna. Detta är speciellt viktigt i Kina där fjärrvärme har övergått från att vara ett välfärdssystem till att vara ett marknadsorienterat energisystem i enlighet med 2003 års värmereform. I Sverige har fjärrvärmen vuxit upp i konkurrens med annan värmetillförsel och har därigenom en god marknadskännedom.

Fjärrvärme- och fjärrkyleforskare vid de fyra besökta universiteten fokuserar på energipolitik, teknik, konstruktion och energiplanering. Långa transmissionsledningar har föreslagits, koordinerade värme- och kraftmodeller används för att hitta sätta för att parera den starkt växande vindkraften och ett flertal tekniklösningar avseende ledningar och mätning analyseras för att reducera värmebehov och tillhörande emissioner. Värmepumpar används för olika värmekällor och integreras in i energiplaneringen. En stor absorptionsvärmepump besöktes i Harbin. Den ledande kinesiska läroboken om fjärrvärme är mycket detaljerad med en inriktning mot beräkningar och anläggningsmetoder. Den nya engelska/svenska läroboken har en vidare ansats på ämnet fjärrvärme och fjärrkyla, så en översättning av denna lärobok skulle kunna komplettera den traditionella kinesiska läroboken.

Slutsatser

Våra fem projektslutsatser relateras till våra fem projektmål:

- Kina har för närvarande en imponerande tillväxt i sina fjärrvärmesystem, men de är i stor utsträckning baserade på traditionell teknik med kolbaserade kraftvärmeverk och värmepannor. Det finns ett behov av att använda en mer uthållig värmetillförsel i dessa expanderande fjärrvärmesystem.
- Kinesiska fjärrvärme- och fjärrkyleforskare har blivit mer aktiva med betydligt fler publiceringar under senare år.
- Kinesiska publikationer om fjärrvärme och fjärrkyla har ett focus på ny värmetillförsel och mer utvecklad systemfunktion i värmedistributionen, speciellt i de sekundära värmenäten.
- De mest aktiva forskarna återfinns på Tsinghua-universitetet i Beijing, Harbins tekniska institut, Harbins ingenjörsuniversitet och Tongij-universitetet i Shanghai. Det senare universitetet intresserar sig mest för fjärrkylefrågor, medan övriga tre universitet har ett primärt intresse av fjärrvärmefrågor. Andra aktiva universitet inom ämnesområdet är Tianjan-universitetet, Dalians tekniska universitet och Jiangnan-universitetet.
- Vi föreslår fem olika samarbetsaktiviteter som (1) ett allmänt utbyte av forskare, forskarstuderande och masterstudenter mellan Kina och Sverige, (2) ett företagsprogram för aktiva fjärrvärmeingenjörer i Kina och Sverige för att få möjligheter att identifiera unika fjärrvärme- och fjärrkylelösningar i respektive land, (3) identifiering av framtida möjliga gemensamma forskningsprojekt, (4) inbjudningar till kinesiska forskare att delta i internationella konferenser och symposier om fjärrvärme och fjärrkyla, samt (5) en översättning av den nya engelska/svenska läroboken om fjärrvärme och fjärrkyla, som också föreslagits av Harbins tekniska institut och den kinesiska fjärrvärmeföreningen.

Vår övergripande slutsats är att kunskap om fjärrvärme och fjärrkyla kan överföras i båda riktningar mellan Kina och Sverige. Det finns i Kina ett flertal nya idéer om långa transmissionsledningar och användning av absorptionsvärmepumpar i såväl kraftvärmeverk som i näten. Detta är metoder som inte används i Europa idag. Sverige har en lång erfarenhet från en väl diversifierad värmetillförsel och en mer utevecklad systemfunktion utan felallokeringar av flöden. Dessa två svenska styrkeområden dominerar idag den kinesiska fjärrvärmeforskningen.

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1 BACKGROUND

There should be some future value for the Swedish district heating sector to undertake a benchmarking against the rapidly growing district heating sector in China. Since many new Chinese district heating systems are being built right now, they have a greater number of degrees of freedom to choose from. In Sweden, we have built many district heating systems over the last 60 years, and we then have fewer degrees of freedom in our existing district heating systems. An important issue for a benchmark is whether the technical choices differ between China and Sweden. One important experience from Sweden is that district heating systems have been developed in a market situation with competition from other heat input and with a wealth of experience from different business models. This experience can be compared to the Chinese experience.

The growth of the Chinese district heating sector has been very rapid during recent years. No other country in the world can exhibit the same rapid growth of the district heating during the last 10-15 years. The heated building area increased by 6 times between 1995 and 2008 according to the Chinese district heating statistics. In many respects, the technology used in China is similar to the technology in Scandinavia, however, the technology in Sweden, Denmark and Finland is characterized by high quality and has been a prerequisite for district heating high market shares.

When it comes to academic activities, the articles on district heating published in international scientific journals from Sweden is still in second place over other countries since 1975 according to the Scopus scientific search engine. The numbers of publications from Germany are still in first place since the journal *Euroheat & Power* (formerly *Fernwärme International*) has published the district articles for more than 40 years in Germany. USA with the *District Energy* journal comes in third place. Soon all three countries will be passed by China; China has enjoyed a strong growth of articles published in recent years. During the years 2010-2012, one third of district heating articles came from Chinese scientists while Swedish researchers accounted for one quarter of all. It means that the Chinese academies are committed to the expansion of the Chinese district heating systems.

To our knowledge, there is no cooperation between China and Sweden for district heating systems and district heating technologies. Notice that projects on environmental technology and environmental innovation are other scopes.

2 GOAL

The goal of the project is to identify the Chinese district heating and cooling research to judge the potential for future collaborative research programs on district heating and cooling systems between Sweden and China. The project has the following five objectives:

- Mapping of the Chinese district heating and cooling system including relevant aspects such as scope, choice of technology, laws and regulations
- Mapping of articles written by Chinese district heating and cooling scientists in international scientific journals and conferences
- Evaluation and summary of the identified Chinese scientific articles about district heating and cooling
- Contacts with relevant district heating and cooling researchers from at least three universities or research institutions through travels to China
- Identify results on technology and knowledge that could be of importance for the prospects of a new technology- and knowledge-sharing research program between China and Sweden concerning district heating and cooling.

3 THE CHINESE ENERGY SECTOR

China has the highest population in the world, 1 354 million at the end of 2012 with an annual growth rate of 0.5%. It is the world's second-largest country by land area, and it covers approximately 9 600 billion m^2, more than 20 times the land area of Sweden. It is also the second largest building energy user in the world, ranked first in residential energy consumption and third in commercial energy consumption (Eom et al., 2012; IEA, 2011).

The structure for the energy system is divided into four basic parts: primary energy supply, final consumption, end use, and local conversion (Frederiksen & Werner, 2013). Figure 3.1 shows the energy balance in four steps for China in order to quantify the current situation of the energy system, four steps are shown in four different stacked bars. The total primary supply of 121.8 EJ (first stacked bar) denotes all energy supplied to satisfy the energy demands. The coal products are the dominant energy supply in China. The total final consumption (second stacked bar) contains all energy commodities used by all community sectors. The difference between these two stacked bars reflects what occurs in the energy transformation sector, including power generation, oil refining, central heat recycling and generation for district heating and cooling systems, as well as the losses in central conversion processes, and in the distribution of electricity and heat. A high proportion of coal is used for generating electricity and heat. Hydropower and nuclear power are used for electricity production. About 40% of all primary energy supplies are lost during the energy transformation due to low conversion efficiencies in the energy sector.

The third stacked bar contains the estimated final end use of heat, electricity, transport and non-energy use. The fourth stacked bar views the conceivable and possible situation if all end use is cut equally by 30% through the implementation of energy efficiency measures. The yellow part at the top of the fourth stacked bar represents the heat losses that are associated with this 30% end use reduction and it is considerably larger than the actual 30% end use reduction itself since the total losses include the central and local conversion losses.

The total final energy consumption in Figure 3.1 is divided into four main sectors shown in Figure 3.2. The four main sectors are industry sector, transport sector, other sectors, and non-energy use. The other sectors include the agricultural, residential, public and commercial sectors. The non-energy use includes plastics, asphalt, lubricants, solvents, and so on.

The huge proportion of heat losses corresponds to more than half of the total primary energy supply. The future energy must reduce these losses by increasing energy efficiency and using renewable energy, thus the carbon dioxide emissions will be reduced, and the security of supply will be increased.

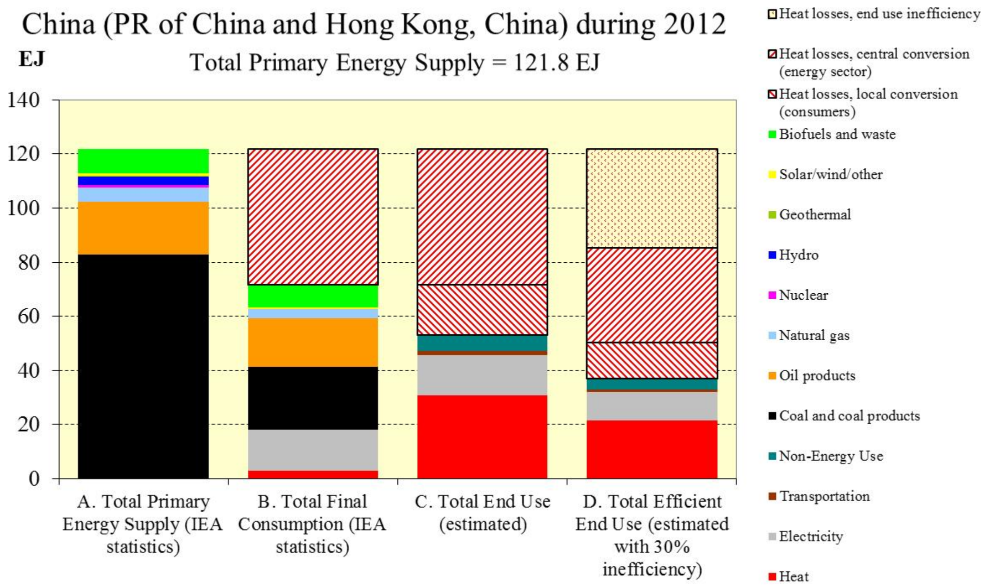


Figure 3.1. Energy balance in four steps for China in 2012. Data source: International Energy Agency (IEA, 2014).

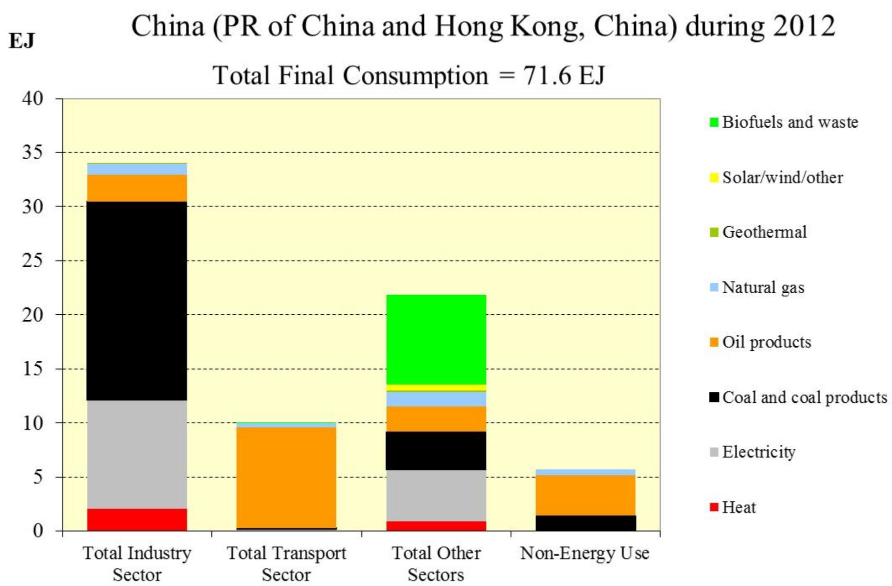


Figure 3.2. Final energy consumption for China in 2012. Data source: International Energy Agency (IEA, 2014).

Carbon dioxide (CO_2) is the main contribution to global warming, the CO_2 emission in China ranks as the highest in the world, about 27% of the world's CO_2 emission (U.S. Energy Information Administration, 2014). Figure 3.3 shows CO_2 emission from 1980 to 2011. After year 2000 the CO_2 emission has increased dramatically. The coal consumption and carbon emissions are very closely related since coal is a dominant part of China's energy mix. The average annual growth rate of CO_2 emission from urban district heating is 10.3%, it was responsible for 4.4% of China's total CO_2 emission in 2009 (L. Wang et al., 2011).

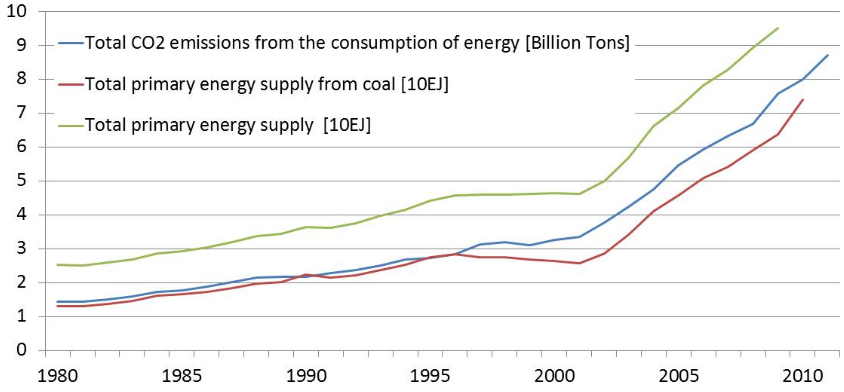


Figure 3.3 Total CO_2 emission from the consumption of energy and primary energy supply from coal and its products in China, 1980-2011. Data source: US Energy Information Administration (U.S. Energy Information Administration, 2014), International Energy Agency (IEA, 2011)

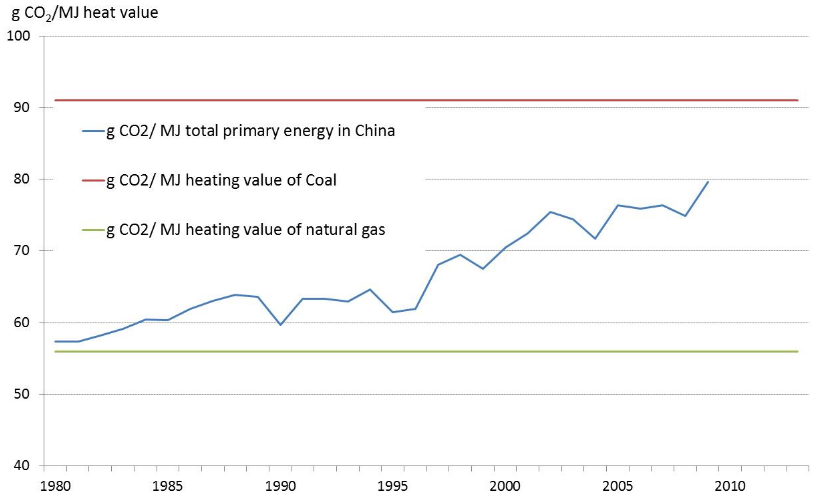


Figure 3.4 Total g CO_2 emission/MJ heating value of fuel in China with the two reference lines of coal and natural gas, 1980-2011. Data source: US Energy Information Administration (U.S. Energy Information Administration, 2014), International Energy Agency (IEA, 2011)

Figure 3.4 shows that the percentage of coal of the total primary energy consumption has increased during recent years. The red and green lines show the specific CO_2 emission per MJ heating values of coal and natural gas respectively. Changing fuel from coal to natural gas will reduce the specific CO_2 emissions.

In China, building energy consumption accounted for 10% of the total energy consumption in 1987, and 27.6% in 2007, it would rise to 40% in the near future (Bao et al., 2012). In 2010 about 92% of the heat demand was produced from coal (IEA, 2011). China is committed to reduce its CO_2 emission 40%-45% from the 2005 levels by 2020 during the United Nations Climate Change Conference in Copenhagen in 2009 (Xia Chen et al., 2013). It is a huge challenge to fulfil the CO_2 reduction target according to present energy usage. The potential to reduce the CO_2 emission from heat supply is very high. New energy efficient technology, shifting energy resources from fossil fuels to renewables, and community energy planning are actions needed to be performed.

4 THE CHINESE BUILDING SECTOR

This chapter gives a short description of the Chinese building sector and related heating and cooling information.

4.1 Chinese buildings

With the improvement of living standards in China, the building space per capita is increasing, so the building spaces are expanding, as shown in Figure 4.1. Over the last several years, the total floor space has increased 1.8-2.0 billion m^2 annually (Yu et al., 2014). The total floor area was 38.9 billion m^2, in which urban residential buildings accounted for 9.6 billion m^2, by the end of 2004 (Zhaojun Wang, 2014). In 2010, the building floor space was about 59 billion m^2, of which 41% was for rural residential buildings and 35% was for urban residential buildings (Yu et al., 2014). The remaining 24% or 14 billion m^2 was used for buildings in the service sector. The total urban heated area was 10.6 billion m^2 during 2012 (Tsinghua University Building Energy Research Center, 2014).

The urban residential floor spaces have increased faster than the rural residential floor spaces due to rapid urbanization, blue colour in Figure 4.1. The urban share of the total Chinese residential floor spaces increased from 22% in 1989 to 50% in 2012. This also causes the strong expansion of centralized heated area from district heating systems, red colour in Figure 4.1, which actually increased even faster. In 2012, 5.2 billion m^2 or 22% of all urban residential building spaces in China were heated by district heating.

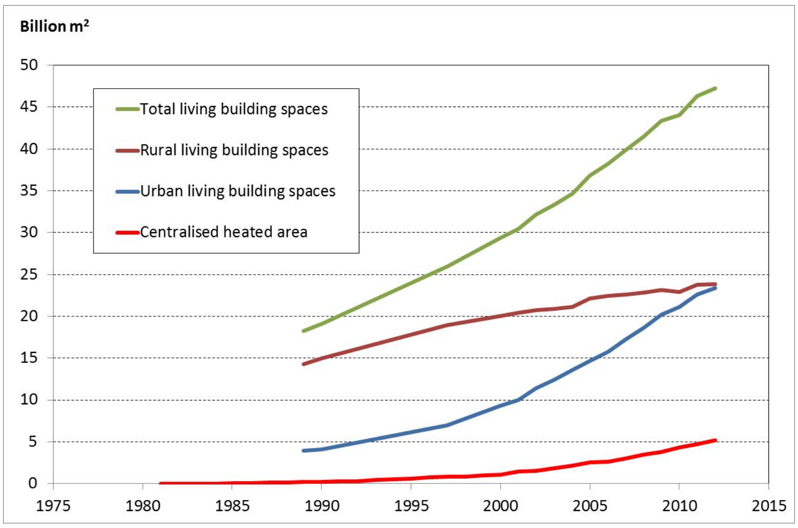


Figure 4.1 The residential floor spaces and centralized heated area in China. Data sources: China statistical yearbook (NBSC, various years)

Picture 1. New residential areas along the Humin Road in Shanghai.

Picture 2. Residential area in the new Qunli district in western Harbin.

4.2 Heating and cooling information

China has a vast variation of landscape from deserts to rainforests, as well as the annual average outdoor temperature changes from -3°C to 24°C, as shown in Figure 4.2. Ministry of Housing and Urban-Rural Development of the People's Republic of China (MOHUD) has divided the country into 5 climate zones (MOHUD, 1993), as shown in Figure 4.3. These five climate zones are defined as follows:

1. The **Severe Cold Zone** has the coldest mean monthly temperatures below -10°C, and more than 145 days for the mean daily temperature below 5°C.
2. The **Cold Zone** has the coldest mean monthly temperatures between -10°C and 0°C, and 90-145 days for the mean daily temperature below 5°C.
3. The **Hot Summer & Cold Winter Zone** has the coldest mean monthly temperatures between 0°C and 10°C, the hottest mean monthly temperature is

25-30°C, 0-90 days for the mean daily temperature below 5°C, and 40-110 days for the mean daily temperature greater than 25°C.

4. The **Hot Summer & Warm Winter Zone** has the coldest mean monthly temperatures warmer than 10°C, the hottest mean monthly temperature is 25-29°C, and 100-200 days for the mean daily temperature warmer than 25°C.
5. The **Temperate Zone** has the coldest mean monthly temperatures between 0°C and 13°C, the hottest mean monthly temperature is 18-25°C, 0-90 days for the mean daily temperature below 5°C.

In the 1950s, the Chinese government decided to use a geographic line between the north and the south divided by Qinling Mountains and the Hua-River, often called the heating north and south lines. This geographic line was originally set in 1908 for other purposes reflecting undeveloped economic and very limited natural resources at that time. The part north of the "line" would build district heating systems, i.e. Huabei, Dongbei and Xibei, see blue colour in Figure 4.3. The main reason was that a minimum of 90 days had the average daily outdoor temperature at or below 5°C annually, following the former Soviet Union standard (Baike, 2014). Usually the heating zone refers to the Severe Cold Zone and the Cold Zone together, i.e. about two-thirds of the Chinese land area, where indoor heating is required by law.

We have estimated that 14% of the Chinese population lived in the very cold zone during 2012. The corresponding proportions were 27% for the Cold Zone, 43% for the Hot Summer & Cold Winter Zone, 12% for the Hot Summer & Warm Winter Zone, and 3% for the Temperate Zone. Hence, 41% of the Chinese population live today in the traditional heating zone.

The first building energy standard for residential buildings was developed in 1986, and then revised in 1995 and 2010 (Bin & Jun, 2012), however it is only for the heating zone in northern China. During the 1990s, limited heating systems were started in the non-heating zone due to poor building insulation and lack of heating equipment. After that, the building energy standard has been developed for the Hot Summer & Cold Winter Zone in 2001 and 2010 and for the Hot Summer & Warm Winter Zone in 2003. The standard for public buildings (non-residential buildings including commercial, educational and governmental buildings) was developed in 2005, further presented in detail in sections 4.3 and 5.4.

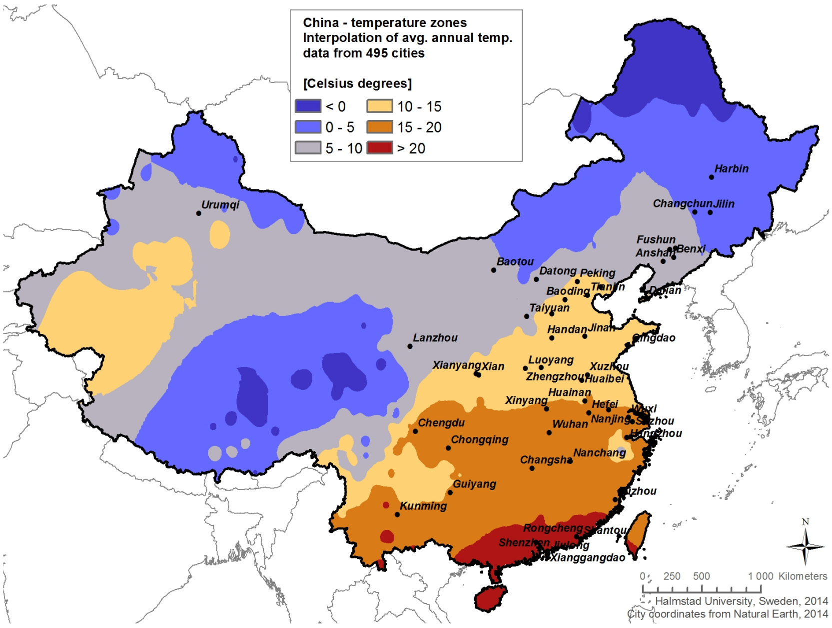


Figure 4.2. Annual average outdoor temperatures for China. Only cities with population over 1 million are displayed. Map is created by Urban Persson, Halmstad University. Data source: (Thematic Database for Human-earth System, 2014).

Figure 4.3. Map showing the various Chinese climate zones defined by the Ministry of Construction. Map from (Draugelis, 2011).

4.3 Heat and cold use in Chinese buildings

City government-owned enterprises control district heating grids in China. Most district heating systems are for space heating which is available only during the winter period, and district hot water preparation is uncommon in Chinese district heating systems. Commonly, there are no control systems to adjust indoor temperature by individual users. This causes unequal room temperatures between users, uncomfortable indoor environment, and waste heat. The heating cost has been calculated by building area until now.

Today half of all the major cities have district heating systems, however, these centralized heating systems are mostly used in northern China. In the rural area of northern China nearly 85% of homes use Chinese Kang as a domestic heating system (Zhuang et al., 2009). The Chinese Kang is a traditional method for cooking, sleeping, domestic heating ventilation which was first developed 2500 years ago. In 2005, the energy consumption in these areas accounted for 39% of the total national energy consumption, 34% of which were based on straw, rice stalks, and firewood (Zhuang et al., 2009).

Due to the former economic situation, the buildings in the Hot Summer & Cold Winter Zone had neither district heating nor district cooling in the past. The indoor environment during summers and winters was very uncomfortable. With the economic development and living standards raising, the demand for both heating and cooling has increased rapidly. The residents often install heating and cooling equipment independently. The heating equipment is electrical heaters, heat pumps (air conditioning equipment), gas heaters, etc. The cooling equipment is mostly air conditioning equipment. Public buildings and factories started to install district heating in areas, such as Shanghai, Jiangsu, Zhejiang and Anhui. MOHUD considers to include this climate zone in the indoor heating zones.

China has become the largest national air conditioning equipment market in the world (Frederiksen & Werner, 2013). According to Figure 4.4, the annual growth rates for urban households have been very high during the last 15-20 years, and for rural households during the last 5 years. Together with USA it represents more than half of the global air conditioning equipment market (Sina News, 2013).

The building energy consumption proportions of different building types were deduced: rural buildings were 39%, buildings in the heating zone were 20%, urban residential buildings outside the heating zone were 20%, and public buildings were 21% in 2010 (B.-J. He et al., 2014). The rural buildings contributed a large part of the total building energy consumption. In 2000, space heating intensity was 31.6 W/(m^2 degree-day) in the heating zone and 17.5 W/(m^2 degree-day) in the Hot Summer & Cold Winter Zone. Heating intensity in rural China was 2.3 W/(m^2 degree-day) in the heating zone and 0.14 W/(m^2 degree-day) in the Hot Summer & Cold Winter Zone (Zhou et al., 2007).

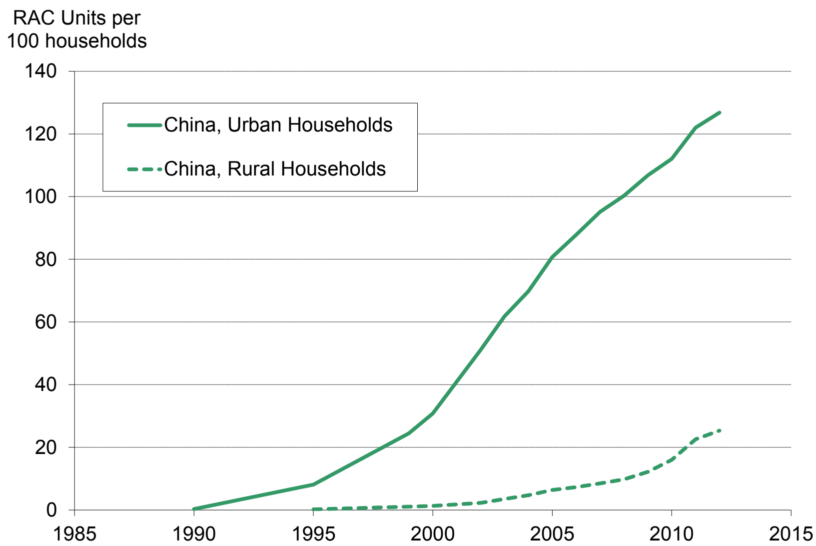


Figure 4.4 Cooling saturation rates for room air-conditioners (RAC) for urban and rural households in China as the number of residential air conditioners installed per 100 households. Data source: China statistical yearbook (NBSC, various years)

Picture 3. The high penetration of room air-conditioners (RAC) in China illustrated by a residential building in central Harbin.

The average indoor temperature is below 18°C in rural areas while 18°C to 22.5°C in cities (information from the study visit at Harbin Institute of Technology, see section 8.2.2). There is large potential to improve building energy efficiency work in China.

Building energy standards and building energy efficiency policies have developed since the 1980s (Bin & Jun, 2012) in order to improve the thermal performance of the building envelope and energy efficiency of Heating, Ventilation, Air-conditioning and Cooling. These standards focused on new construction, additions and retrofits of existing buildings.

An energy design standard for residential buildings in the heating zone started in 1986 aimed at the energy saving rate of 30%, revised in 1995 aiming at the energy saving rate of 50%, compared to the early 1980s' residential buildings (Kong et al., 2012). Energy saving design standards in the Hot Summer & Cold Winter Zone started in 2001 and 2003, both aiming at a 50% reduction of annual energy consumption compared with buildings without measurement of energy saving (Shui et al., 2009). The technical standards for residential buildings in the Hot Summer & Warm Winter Zone (southern provinces) were introduced in order to reduce the space cooling energy consumption in 2003 (J. Li et al., 2009), the purpose of the standard is aimed at reducing 50% of the buildings' annual energy consumption compared to the buildings without measurement of energy saving (Shui et al., 2009).

A national energy-efficiency design standard for public buildings was adopted in 2005 aiming at a 50% annual energy consumption saving compared with buildings from the early 1980s' (Shui et al., 2009).

In 2006 the first green building standard in China (MOHUD, 2006) was released in order to save energy and material, to protect the environment, and to achieve sustainability. Since then, a series of regulations and programs to promote green buildings have been developed.

Even the building standards cover all new construction in China, in 2006 of all the new buildings in the large urban areas, only 60% and 23% met the energy-saving standard during the design stage and the construction stage respectively according to a survey conducted by MOHUD, and in southern China the percentage was just 10% and 8% respectively (Zhou et al., 2011). During the 11^{th} Five-Year Plan (2005-2010), the energy efficiency retrofit task with heat demand control for existing residential buildings of 0.15 billion m^2 was finished successfully in the heating zone. All new buildings are expected to meet the 65% saving target during the 12^{th} Five Year Plan (2011-2015) (Hao, 2009). The 75% saving target was implemented in Beijing and Tianjin in 2013, and will soon be in Hebei province and Shandong province etc. (MOHUD, 2014)

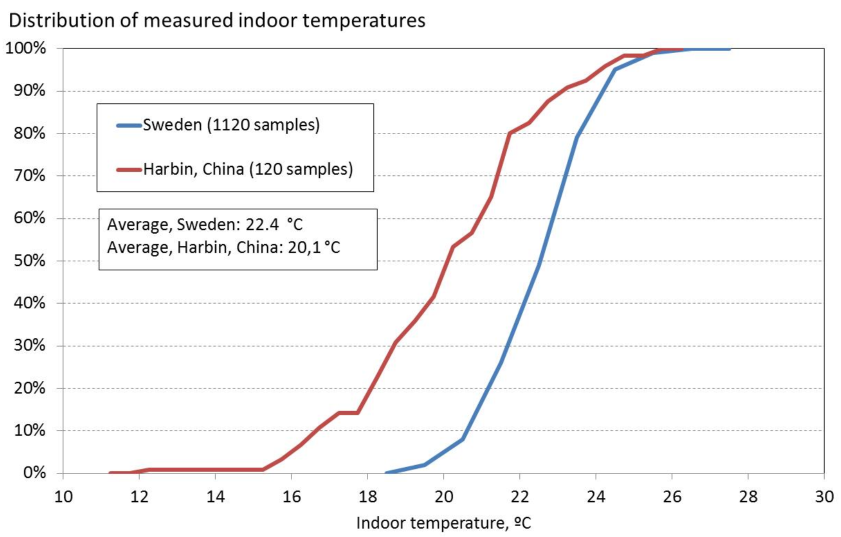


Figure 4.5 The distribution of measured indoor temperatures in Sweden and China. Data sources: (Boverket, 2010) for Sweden and (Zhaojun Wang, 2014) for China

The indoor temperatures are very important for space heating demands as well as for a comfortable indoor environment. Figure 4.5 presents the distribution of measured indoor temperatures with 1120 samples for Sweden, and 120 samples for the city of Harbin, China. The indoor temperature in Harbin has larger variation and lower average temperature than in Sweden. Sweden has better building insulation and more efficient customer control systems for heat demands. According to ASHRAE Standard 55-2004, the comfortable air temperature range is 20.8-26.1°C. More than 92% of the thermal conditions in Sweden satisfy the ASHRAE standard. In Harbin, only 43% fulfil the ASHRAE comfort zone, however, 63% are within the ASHRAE temperature range during the heating season (Z. Wang et al., 2011).

5 THE CHINESE DISTRICT HEATING AND COOLING SECTOR

This chapter describes general district heating information on statistics, energy supply, technology, and policies in China. Most of the data came from available statistics from China and the International Energy Agency.

5.1 Chinese district heating statistics

Since the 1990s, district heating has expanded rapidly, as shown in Figure 5.1. About 400 million m^2 of the centralised heated area and more than 10 000 km of pipe length have been added each year during the past seven years. By 2012 total centralised heated area reached about 5 184 million m^2 which is more than 8 times compare to year 1995 and the total pipe length was 160 080 km which is more than 17 times compared to year 1995 (NBSC, various years). The expansion of pipe length is in the form of hot water pipe rather than steam pipes.

The total pipe length in 1996 increased almost twice compared to the previous year. The reason for this big change of pipe length between 1995 and 1996 was that the statistics was reported only for some cities in 1995 and upgraded to all systems in the provinces in 1996.

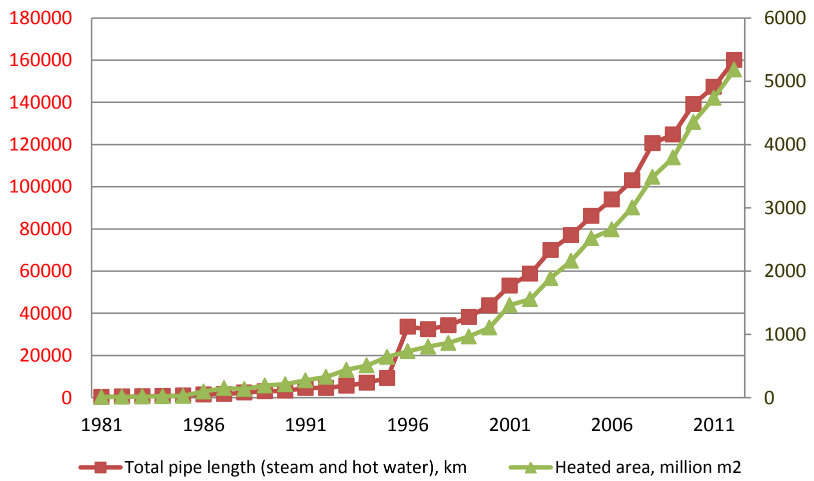


Figure 5.1 Total pipe length and heated area of Chinese district heating system, 1981-2012. Data source: China Statistical Yearbook (MOHUD, various years; NBSC, various years).

Figure 5.2 shows total heat produced and heat demands during 1980-2010 from both the IEA databases and the annual China National Statistical Yearbooks. The discrepancy between the two data sources is less than 10%. Since 1995 the total heat produced has increased rapidly, from about 1 EJ in 1995 to 3 EJ in 2010. The industrial heat demands have grown much faster than the heat demands for non-production purposes.

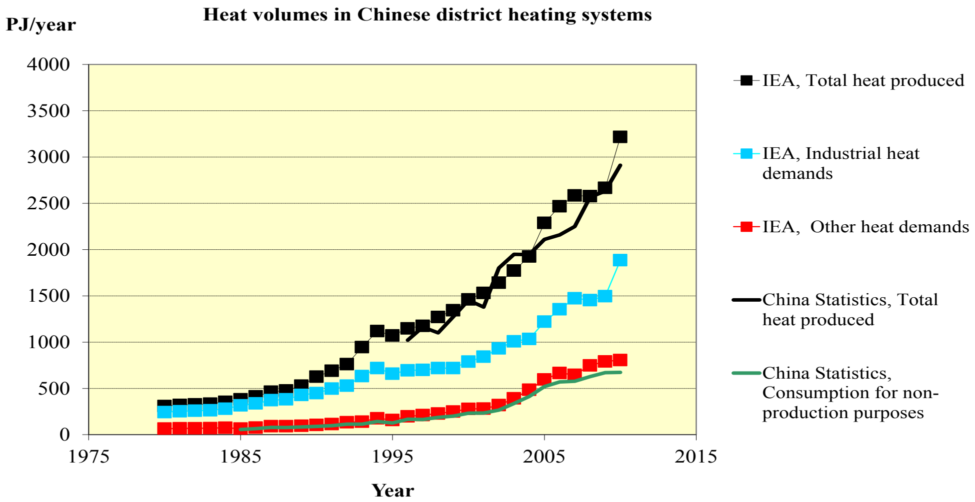


Figure 5.2 Heat volumes in Chinese district heating systems from different data sources, 1980-2010. Data sources: China statistical yearbook (NBSC, various years) and International Energy Agency (IEA, 2011)

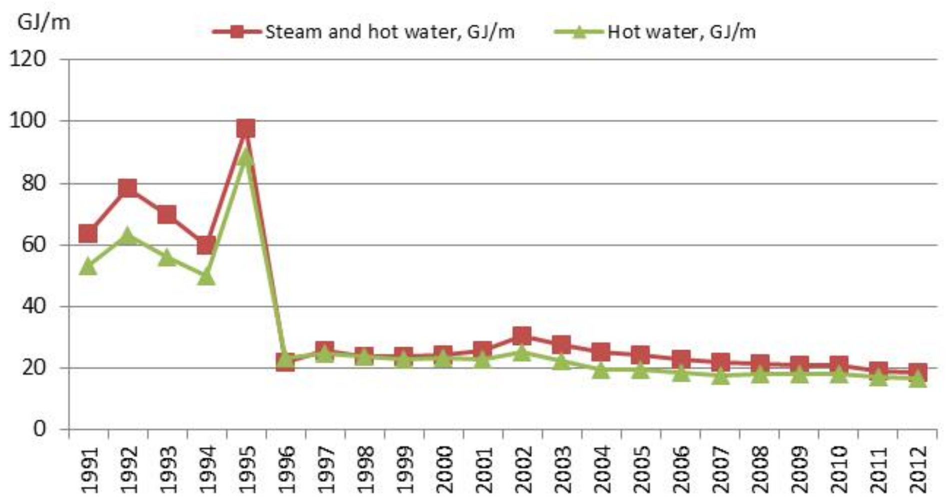


Figure 5.3 Annual average linear heat densities in Chinese district heating systems, 1991-2012. Data source: China statistical yearbook (MOHUD, various years; NBSC, various years).

Figure 5.3 shows the linear heat densities during 1991-2012 from China National Statistical Yearbook. The linear heat density is defined as the annual heat quantity sold to customers per trench length (Frederiksen & Werner, 2013). There are big changes during 1995-1996 due to the change in how the statistics of trench lengths were reported. After 1996, the linear heat density decreases with less concentrated residential areas connected. The linear heat density in China, which is 20-30 GJ/m in recent years, is somewhat higher than the average district heating system of 10-15 GJ/m in Sweden (Frederiksen & Werner, 2013). This is due to the significant proportion of single-family houses connecting to district heating systems in Sweden.

5.2 Energy supply to district heating systems

Coal is the primary energy source in the urban district heating systems, while biomass is used for space heating in rural areas. In 2010, the energy consumption of urban district heating accounted for 3.2% of the total energy consumption (Xia Chen et al., 2013).

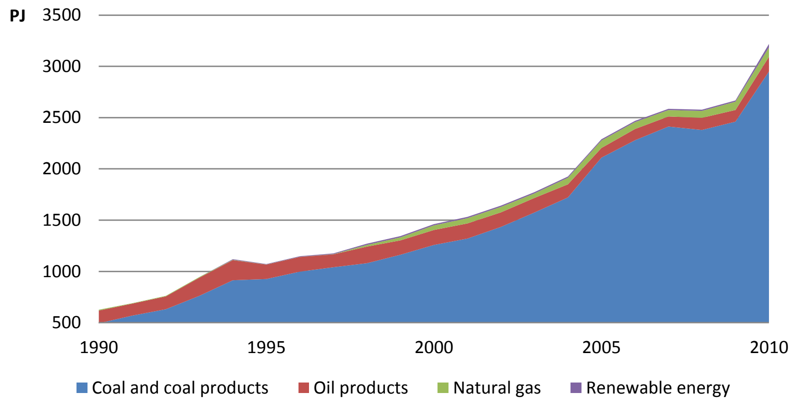


Figure 5.4 Heat produced by fuel source, 1990-2010. Data source: International Energy Agency (IEA, 2011).

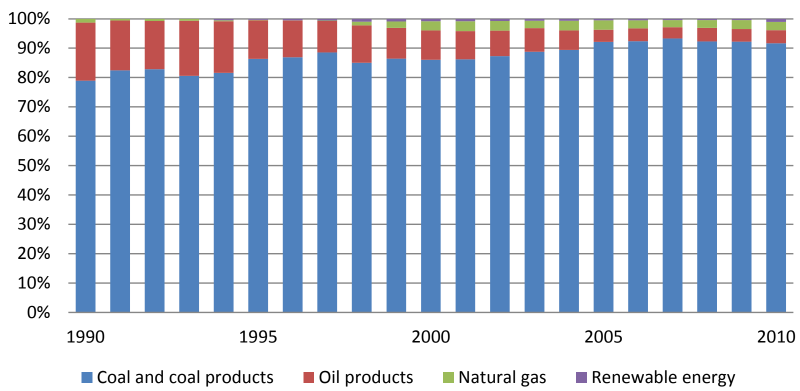


Figure 5.5 Heat produced by source share, 1990-2010. Data source: International Energy Agency (IEA, 2011).

The energy supply for the heating is increasing year by year, while the energy used for district heating in 2010 was five times more than in 1990, shown in Figure 5.4. The dominant fuel in China is coal followed by oil. The oil share is decreasing while the natural gas share is increasing according to IEA statistics as shown in Figure 5.5. Coal and oil present a number of environmental, health and economic challenges. During recent years the smog conditions have become severe from extraordinarily heavy air pollution and PM2.5 aerosols. Most of the air pollution in China is caused by the burning of coal to generate electric power, that is 41% came from coal dust (L. Zhang et al., 2013).

The Chinese government plan to improve air quality and slow down the coal consumption in the Beijing, Shanghai and Guangdong regions. It requires China's most polluted provinces to 'strive to achieve a negative coal increase' in five years. Converting coal based boilers to natural gas boilers will reduce 55% of the CO_2 emissions[1], 60% of the NO_2 emissions and 99.6% of the SO_2 emissions.

The renewable energy in Figure 5.4 and Figure 5.5 are the biofuels and waste mostly, the other renewable energy sources such as solar energy, geothermal energy, etc. are in small percentages. In the future, the fuel source will be changed from coal to natural gas in order to reduce environmental problems even if coal will still dominate for quite a long time. The government encourages heating systems to use CHP/CCHP instead of boilers, as well as using gas instead of coal as fuel, more details in the next section.

5.3 District heating technology

Three generations of district heating technologies have successfully been developed globally. The first generation was based on steam pipes, the second used high temperature hot water, and the third and current one uses medium temperature hot water. In the future, the fourth generation is expected to be based on low temperature water (Lund et al., 2014).

Figure 5.6 shows that district heating is mainly obtained from a combination of CHP plants and boilers in China. During the years 2002 to 2004, heat supplied from CHPs increased, while heat supplied from boilers decreased. After 2004, the heat supply from both CHPs and boilers continues to increase year by year. By the end of 2012, the district heating supply, including steam and hot water was 2.88 EJ, CHPs accounted for 46% and boilers accounted for 51%. The total steam supply was 0.47 EJ, of which CHP accounted for 83% and boilers accounted for 16%. The total hot water supply was 2.44 EJ, of which CHPs accounted for 40% and boilers accounted for 59%. Steam supply is decreasing and hot water supply is increasing year by year. The hot water district heating systems are close to the third district heating technology generation.

[1] Estimation of reduction of carbon dioxide emissions calculated CO_2 by using 90% conversion efficiency and 56 g/MJ for natural gas, and 65% conversion efficiency and 91 g/MJ for coal.

CHP supplied about 30% of the total district heated areas and 83% of industrial steam demands by the end of 2009 (Hong et al., 2013). The remaining heat demands are provided by individual boilers, solar water heating, etc.

China will substitute coal boilers with natural gas boilers with higher efficiencies. The current boiler efficiencies are about 60-65% (Danish Energy Agency, 2013b), and natural gas-fired heating boilers can reach thermal efficiencies of approximately 90%. Approximately one thousand natural gas-based distributed energy projects are expected to be developed as part of China's 12th Five-Year Plan (Wu & Wang, 2014).

China has three types of CHP plants with respect to fuel input: coal-fired CHP plants, natural gas fired CHP plants, and biomass fired CHP plants. China has the largest installed CHP plant capacity in the world. By the end of 2012, the installed capacity greater than 6 MW of cogeneration had reached 221 GW, increased with 16.9 GW compared to the previous year. The annual heat supplied from CHPs was 3.08 GJ, i.e. 3.3% growth compared to year 2011. However, the growth of the installed capacity was greater than the increased heat supply, e.g. 10.8% and 3.3% respectively during 2012 (China Energy Net, 2013).

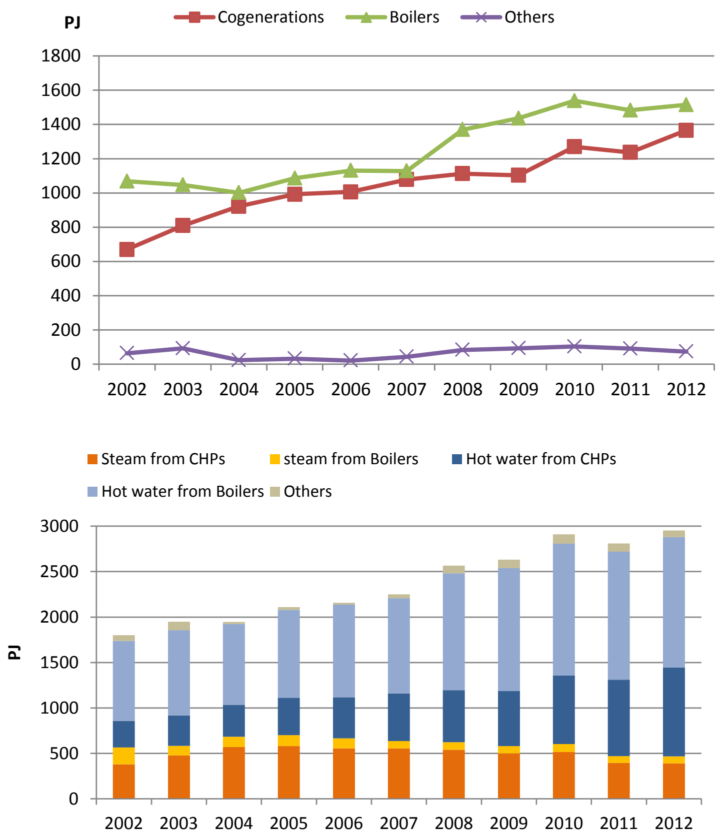


Figure 5.6 District heating (including both steam and hot water) supplied by CHPs, boilers and others, 2002-2012. Data source: China Urban Construction Statistical Yearbook (MOHUD, various years).

Combined Cooling, Heating, and Power (CCHP) technology has been developed recently. CCHP technology fired by natural gas is being developed in some large cities, e.g. Beijing, Shanghai and Guangzhou. In 2004, Beijing Gas Group developed the first pilot CCHP project with two gas engine generators (480 kW + 725 kW) for electricity and two waste heat-fired absorption chiller units (1163 kW + 2326 kW for cooling) provide 7-12°C chilled water in the summer and 50-60°C hot water in the winter to meet the cooling/heating demand at a 32 000 m^2 office building (IEA, 2007). Later on, China's first CCHP technology applied in a district area will be set to run in Shanghai Hongqiao business area (China News, 2013).

The other options for district heating is low temperature nuclear heating system, heat pump, heat storage, solar water heater system, and biomass systems. These technologies from renewable energies will be further developed in the future.

5.4 District heating policies

The environment crisis and energy shortage are among the major problems in China due to its industrialization and disregard of the risk for pollution. The consumption of coal is increasing rapidly, 2.95 EJ of the heat supply during 2010 came from coal, see Figure 5.4. In order to reduce energy consumption and improve the air, a number of policies have been implemented.

China has made Five-Year Plans for national economic and social development since the 1950s. During the 11^{th} Five-Year Plan (2006-2010) it was the first time that China set a target for a 20% reduction in energy intensity and a 10% share of non-fossil fuels in primary energy supply to be reached by 2010 compared to the supply of 2005. This resulted in that the Chinese government, in 2011, reported a total reduction of 19.1% in energy intensity per unit of GDP over this period (Price et al., 2011). For the 12^{th} Five-Year Plan (2011-2015), a continued binding target for 16% energy intensity reductions and 17% carbon intensity reductions, as well as on installed capacities of different renewable energy technologies (The Central People's Government of China, 2011). It continues to focus on increased energy efficiency in buildings, industry and transport with the improvement of energy supply, transformation and energy research, as well as the use of "new" energy, such as nuclear power, hydro power, wind power, solar energy and biofuels. The energy consumption in buildings accounts for approximately 25% of the total energy consumption in China (Zhou et al., 2007), and it will increase to 35% by 2020 due to rapid urbanization and the improvement of living standards (J. Li & Colombier, 2009). It is very important to reduce energy consumption in buildings, so energy codes for buildings and retrofits to existing buildings were implemented, more detail in section 4.3.

Heat reform is an important part of increasing building energy efficiency. In 2000, the Ministry of Construction (called MOHUD now) announced the district heating innovation. In the north, the district heating systems was regarded as a public welfare systems so no heating costs were paid since the 1950s by the consumers who worked in state owned enterprises and governmental organizations. In 2003, the heating systems should turn the public welfare system into a commercialized system, and it addressed the promotion of consumption-based billing and energy saving with respect to both sides in the heat supply and demand relationship. The heat supply market will open to foreign capital in order to improve the quality of the country's heating service (Beijing Time, 2003).

In the district heating systems, the heat has been and is still charged by heated area rather than by measured actual heat consumption. Thus, in 2006, MOHURD published a series of documents to accelerate the progress of implementation of heating meters and consumption-based billing systems in order to encourage building energy efficiency and reduce heat waste. Recently MOHURD required heat supply measurement at local level, heat supply measuring devices installed for new buildings, heat supply measurement and energy efficiency retrofits of existing residential buildings, the improvement of monitoring and regulatory mechanisms for heat supply measurement, as well as the modernization of district heating supply systems. Zhou et al. (Zhou et al., 2013) concluded that these policies could save around 2.93 EJ energy and most of the saving (73%) can be achieved by policies that affect new buildings.

During the 11th Five-Year Plan (2006-2010), 80 cities started to use consumption-based pricing and billing systems, which reach 317 million m^2 of building space, and 182 million m^2 of existing residential building space (MOHUD, 2011). However, the heat billing system with heat metering has been progressing slowly. In 2011, the total building space with heat meters was estimated to be 95 million m^2, but merely 53.6 million m^2 were actually used (Shi, 2014).

12th Five-Year Plan (2011-2015) sets a number of targets for China's district heating sector (Danish Energy Agency, 2013a):

- The capacity share of CHP plants in relation to DH plants shall increase from 36% in 2010 to 43% by 2015.
- A heating reform that covers 400 million m^2 of building area in northern cities by 2015 with strengthened energy saving goals.
- 1 000 natural gas-fired CHP plants planned nationwide
- 1 000 geothermal projects planned with a heating/cooling area of 50 million m^2.
- 100 solar thermal heating projects planned with a heated area of 1 million m^2.

6 COMPARISON: CHINESE AND SWEDISH DISTRICT HEATING SECTORS

This chapter contains a summary of statistical information about China and Sweden concerning heat supply, heat demands, heat deliveries, and heat distribution.

6.1 General information

Table 6.1. General information about the two countries

	China	Sweden
Land area [billion m^2]	9 600	450
Population	1354 million in 2012	9.6 million in 2012
Weather	Large variation between deserts and permafrost	Mild coastal North European climate
Covered by DH	65% of the land area require space heating by law 49% of the urban heated area	100% of the land area require space heating 55% of the national heated area
Heated area [m^2]	10.6 billion	0.6 billion in 2011
Heated area by district heating [m^2]	5.18 billion in 2012	0.33 billion in 2011
First district heating	1950s	1948
First district cooling	2009	1992
Heat billing system	Mostly fixed heating fees according to living area, starting to install heat meters	Fixed fees, often according to heat capacity used, and variable fees based on heat used, according to heat meters
Heating service	From a governmental subsidised welfare system to commercial supply system.	Municipal in the past, nowadays more commercial with private companies as heat providers also.

6.2 Heat supply

Table 6.2. Characteristics concerning heat supply

	China	Sweden
DH source share	Coal (91%) Oil products (4.5%) Natural gas (3%) Renewables (1.5%) in 2010 (IEA, 2011)	Biomass and waste (67%) Large heat pumps (10 %) Industrial heat recovery (8%) Fossil fuel (15%) in 2012
DH supply share in 2012	CHP (46%) Boilers (51%) Others (2%)	CHP (41%) Boilers (41 %) External heat (18%)

6.3 Heat demands

Table 6.3. Characteristics concerning heat demands

	China	Sweden
Total heat demand in buildings [PJ] in 2012	5 000 for urban buildings only	270
Indoor Comfort	Unadjustable indoor temperature, national standards 16-20°C (Wang, HIT), starting to install adjustable control systems	Adjustable indoor temperature, on average 21°C in single-family houses, 22°C in multi-dwelling buildings (Frederiksen & Werner, 2013)
U-value for building envelopes. [W/m² K]	Design standards: 1.16 - 0.82 for walls 3.5 for windows 0.80 - 0.60 for roofs (D. Yan et al., 2011)	Building stock averages: 0.31 - 0.41 for walls, 2.1 - 2.3 for windows, 0.23 – 0.30 for roofs (Boverket, 2010)
Annual average heat use for space heating [kWh/m²]	90-100 (heating zone) (J. Li, 2008)	120-130
Annual average heat use for domestic hot water, [kWh/m²]	Almost no domestic hot water supplied by DH	20-30
Number of heating degree-days	800-7 700 with effective indoor temperature of 18°C (H. Li & Long, 1987)	3 000 in south to 7 000 in the north with effective indoor temperature of 17°C

6.4 Heat deliveries

Table 6.4. Characteristics concerning heat deliveries

	China	Sweden
Total DH deliveries [PJ] in 2012	2 963	188
DH deliveries to industries [PJ] in 2012	2 026	17
DH deliveries to buildings [PJ] in 2012	937	171
DH delivered period	Mostly only during the heating season	All year around
	Mainly for space heating, domestic hot water is uncommon	Integrated for both space heating and domestic hot water
Annual average from/return temperature [°C]	90-130/60	86/47
Heating period	Time depended	Outdoor temperature depended

6.5 Heat distribution

Table 6.5. Characteristics concerning heat distribution

	China	Sweden
Total pipe length [km] in 2011	147 353	22 837
Linear heat density [GJ/m]	20-30	10-15
Relative distribution heating loss	20-25% (IEA, 2007)	6-15%
Heat carrier	Steam and water	Mainly coloured (green) water
Substations	Large, for group of buildings	Small, in almost every customer building

6.6 Main conclusions from the comparison

- China is a very large country, both with respect to land area and population.
- The climate in the Chinese heating zone is similar to the Swedish climate, many of the obstacles and barriers for future development are the same.
- First district heating systems were developed in the 1950s both in Sweden and China.
- Only 65% of land area is covered by district heating, there is almost no district heating in the Hot Summer & Cold Winter Zone. However, district heating is mostly used only for space heating in China, but for both space heating and hot water in Sweden.

- Uncomfortable indoor temperatures due to the heat supply according to date in the heating zone and no district heating supply in the Hot Summer & Cold Winter Zone.
- High energy demands for buildings with poor thermal insulation in China.
- Heat is inefficiently used: due to almost no control devices installed, a lack of knowledge of heat demand control, and low implementation of heat measurements. This poor indoor temperature control causes 20-30% of energy used to be wasted (L. Liu et al., 2011).
- The trench length of district heating pipes increases very rapidly in China.
- High linear heat densities in China show that most Chinese district heating systems are connected to large buildings in urban areas, while half of all district heating is used in multi-dwelling buildings and 14% of the Swedish single-family and two-family detached dwellings are connected (Swedish Energy Agency, 2014).
- High distribution heating losses with hydraulic imbalances and leakages of heat supply network cause great heat losses, which nearly accounted for 30% of the total heat supply (D. Yan et al., 2011). The relative heat distribution heating losses in Sweden are 6-15%.
- China has large substations for groups of buildings, while Sweden has small substations located in almost every customer building.
- The heat sources for Chinese district heating systems are dominated by coal, while Sweden has more than half of the supply from biofuels and waste. This is one of the main reasons for the cause of heavy air pollution problems in Chinese urban areas.

7 PUBLICATION OF DISTRICT HEATING AND COOLING PAPERS

In this chapter, the analysis and corresponding results are based on the Scopus scientific search engine. The chapters in the first international book "District Heating and Cooling" were used as subject classification to analyse papers written by Chinese researchers during 1970-2013. University affiliations were ranked by the number of DHC publications.

7.1 International analyses

When it comes to academic activities, 5 627 international scientific publications were identified for the "district heating" label and 278 for the "district cooling" label according to the Scopus scientific search engine, as shown in Figure 7.1-Figure 7.4.

The numbers of district heating publications from Germany are in the first place since the journal *Euroheat & Power* (formerly *Fernwärme International*) has published district heating articles for more than 40 years in Germany. The district articles from Sweden are still in second place in the world since 1975. USA with the journal *District Energy* comes in third place, and China is in the fourth place. However, China has enjoyed a strong growth of the number of articles published in recent years. During the years 2010-2012 one third of district heating journal articles came from Chinese scientists while Swedish researchers accounted for one quarter of all. It means that the Chinese academies are committed to the expansion of the Chinese district heating systems.

The number of papers published in the Russian *Teploenergetika* journal is in second place among journals, while the English translations of this journal is published in *Thermal Engineering* from Springer. However, a large number of publications in this journal is from at least ten years ago, and Russia is not among the top five countries with the most district energy publications. The number of papers published in *Energy – The international journal* from Elsevier comes in third place among journals. In recent years, district heating papers in *Energy* as well as other energy related journals from Elsevier have increased dramatically.

The numbers of district cooling publications from USA are in first place since the *ASHRAE Transactions* have been published in USA. China was in second place during 1970-2013, followed by Malaysia, Germany and Sweden. This means that the Chinese academic researchers are supporting the expansion of the Chinese district heating and cooling systems by their increased number of publications. Compared to district heating, the research on district cooling needs more attention.

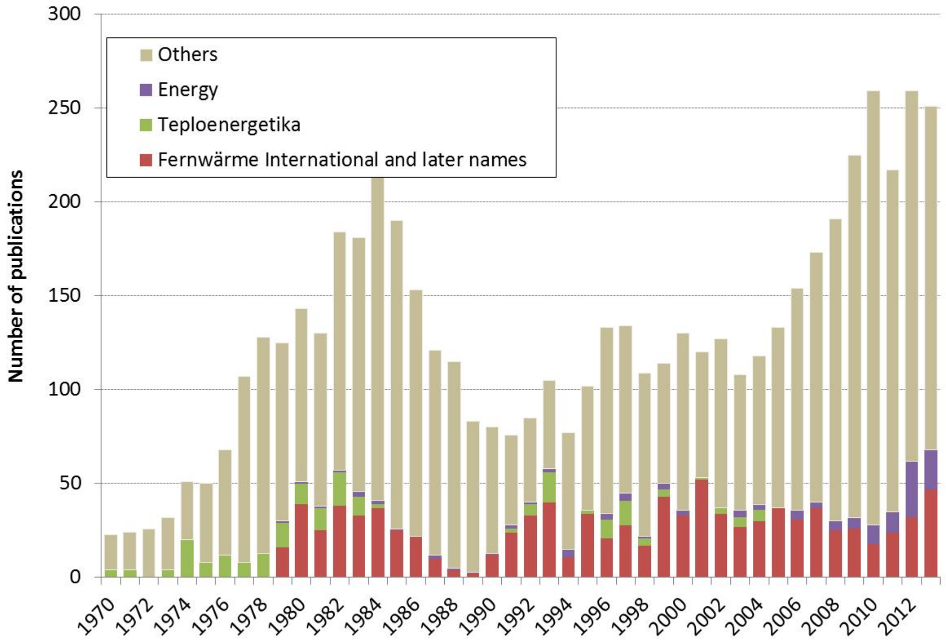


Figure 7.1. Published articles and papers with the "district heating" label 1970-2013 by source. Data source: the Scopus scientific search engine

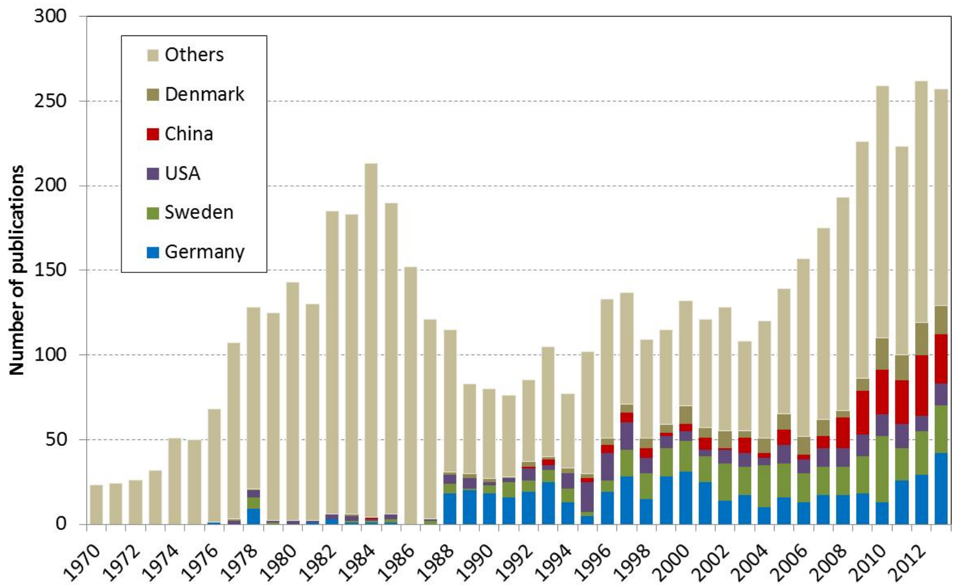


Figure 7.2. Published articles and other papers with the "district heating" label 1970-2013 by country affiliation. Data source: the Scopus scientific search engine.

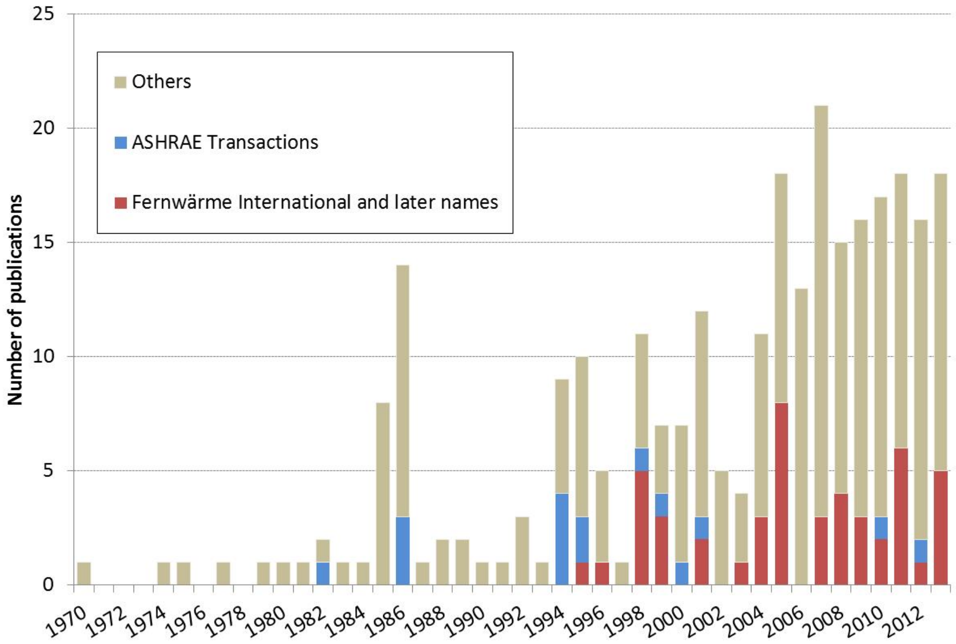


Figure 7.3. Published articles and papers with the “district cooling” label 1970-2013 by source. Data source: the Scopus scientific search engine.

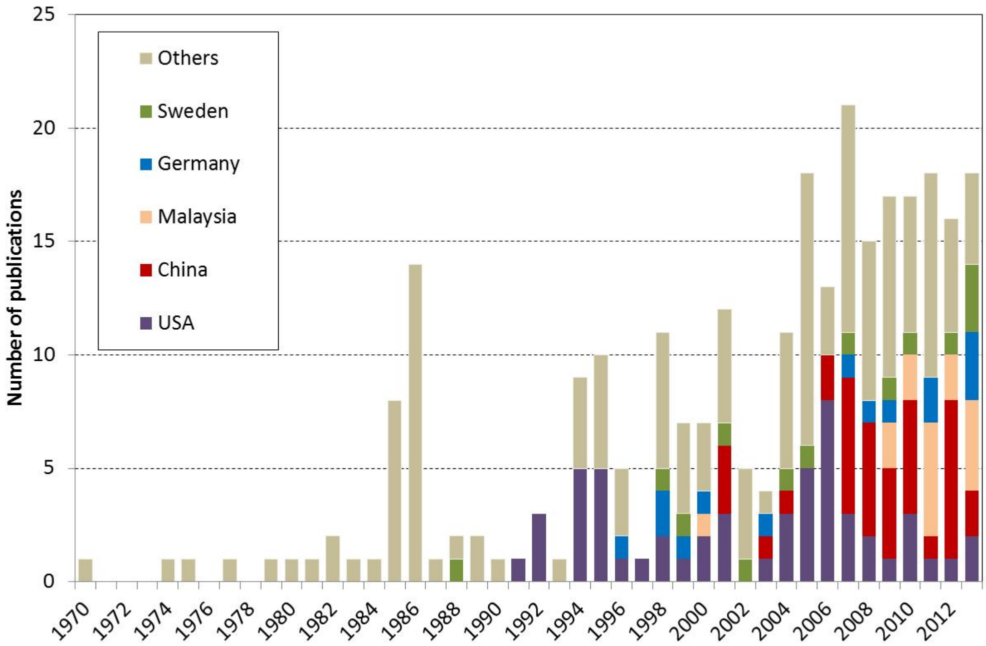


Figure 7.4. Published articles and other papers with the “district cooling” label 1970-2013 by country affiliation. Data source: the Scopus scientific search engine.

7.2 Analysis of Chinese DHC papers

Chinese authors have written 232 of the 5 627 publications on district heating according to the Scopus scientific search engine. However, 16 are non-district heating papers and 11 are only about district cooling, since the Scopus scientific research engine seems to regard the labels ‘heat generation’, ‘heat source’, and ‘heat load’ as ‘district heating’, so the total number of publications becomes 205, as shown in Table 7.1. 28% of district heating papers have been published in conference proceedings and 27% of the international journals in Elsevier, of which 19% of district heating papers are published in the Elsevier journals related to energy, such as Energy, Energy policy, Applied Energy, and so on. Many universities in China have also their own journals, so 20% of district heating papers have been published in these kinds of journals.

Unfortunately, some papers on heating meter reform are excluded in search results. The search results with the search word “heat-meter reform” or “heat reform” are five papers in total, of which three publications are written by Chinese researchers; one of three is already included in the “district heating” search result. The paper written by (L. Liu et al., 2011) presents a new heat bill system method with accumulated on-time and the floor space.

Table 7.1 Publications on district heating by Chinese researchers according to the chapters in the textbook by (Frederiksen & Werner, 2013). (Data source: the Scopus scientific search engine).

Source Title\Chapter	3 Energy, heat, and cold markets	4 Heat & cold demands	5 Heat & cold loads	6 Heat & cold supply	7 Environmen-tal impact & opportunities	8 Heat & cold distribution technology	9 Substations	10 System functioning	11 Economics & planning	Total
China's Journal				5				4	2	11
China's university journal		1	6	17	1		3	12	1	41
Conference	3	4	3	19	5	1	7	11	5	58
Trans Tech. Journal	1	2	1	4	3	2	3	8		24
Elsevier Journal		5		32	5	1	3	8	2	56
Other			1	2	1	1		1		6
Open source Journal				2				1		3
Springer					1		1			2
Wiley Journal								1		1
ASHRAE Journal								3		3
Total	**4**	**12**	**11**	**81**	**16**	**5**	**17**	**49**	**10**	**205**

The first international district heating paper (Yingzhong, 1984) by a Chinese researcher was published in the special workshop issue of The International Journal of Energy in 1984. Eight years later, the second international district heating journal paper (Dazhong et al., 1992) was published. These two papers focused on heat from nuclear energy for district heating.

The Chapters in the textbook “District Heating and Cooling” (Frederiksen & Werner, 2013) have been used as subject classification to analyse these papers, since this book is the first international district heating and cooling textbook published in 2013. In this report, the chapter numbers in the related tables are listed below:

Chapter 3: Energy, heat, and cold markets
Chapter 4: Heat and cold demands
Chapter 5: Heat and cold loads

Chapter 6: Heat and cold supply
Chapter 7: Environmental impact and opportunities
Chapter 8: Heat and cold distribution technology
Chapter 9: Substations
Chapter 10: System functioning
Chapter 11: Economics and planning

The identified papers are dominated by 81 papers on heat and cold supply methods (Chapter 6), since many old, inefficient and high pollution coal-fired boilers need to be replaced, and 49 papers focus on system functioning (Chapter 10) due to the many substations based on the former Soviet Union model, as shown in Table 7.1.

Publications on energy, heat, and cold market (Chapter 3) are very few, since the Chinese district heating systems by tradition have been part of the welfare system without free competition in the heating market. Another low focus research field is on heat and cold distribution technology (Chapter 8); all 5 papers have been published after 2009. The earlier technology was based on the former Soviet Union standards, and this needs to be improved with new enhanced technology. Recently, three papers on heating meter reform have been published, since Chinese district heating systems are expected to turn from public welfare systems into commercialized systems.

Table 7.2 Publications on district cooling by Chinese researchers according to the chapters in (Frederiksen & Werner, 2013). (Data source: the Scopus scientific search engine).

Chapter Year	4 Heat & cold demands	6 Heat & cold supply	7 Environmen-tal impact & opportunities	8 Heat & cold distribution technology	9 Substations	10 System functioning	11 Economics & planning	Total
2001		3						3
2003			1					1
2004						1		1
2006				1	1			2
2007		2			1	1	2	6
2008					1	3	1	5
2009		1		2			1	4
2010	1	2			1	1		5
2011						1		1
2012		2			2	1	1	6
2013						2		2
Total	**1**	**10**	**1**	**3**	**6**	**10**	**5**	**36**

According to the Scopus scientific search engine, 37 of 278 publications on district cooling were written by Chinese researchers, one of them was a non-district cooling paper, so the total number of papers by Chinese researchers came to 36, as shown in Table 7.2. The number of papers on heat and cold supply method (Chapter 6) and system functioning (Chapter 10) are equal, about 28% each, together they account for more than half of the publications. The publications on substations (Chapter 9) and planning (Chapter 11) are in third and fourth places.

7.2.1 Heat supply method

Table 7.3 summarises papers on heat supply methods during 1984-2013. Early papers on heat and cold supply were mostly related to nuclear energy; later research focuses more on renewable energy sources, such as geothermal and solar heat. Waste heat from thermal power plants (combined heat and power) and industrial processes are recently being focused on. Boilers generate about half of all heat supply in district heating systems, but there was only one paper (Cong et al., 2011) published, analysing 472 heating boilers in Tianjin. The statistics from these boilers showed very low energy efficiency. Heat pumps and CHPs are the main direction of the development, as well as CCHP. The recently published papers on heat supply methods align with most of the five current, suitable, strategic local heat and fuel resources for district heating. These five strategies are (Frederiksen & Werner, 2013):

- CHP plants (usable upgraded excess heat from thermal power stations),
- waste-to-energy plants (usable heat obtained from waste incineration),
- usable excess heat from industrial processes and fuel refineries,
- fuels that are difficult and bulky to handle and manage in small boilers,
- natural geothermal heat sources.

Table 7.3 Heat supply methods during 1984-2013

Heat supply	1984	1992	1993	1995	1996	1997	1998	1999	2000	2001	2003	2004	2006	2007	2008	2009	2010	2011	2012	2013	Total
absorption							1														**1**
bioenergy																	1		1		**2**
boiler																		1			**1**
CCHP									1	1										1	**3**
CHP			1						1						2	2	2	2	2	1	**13**
flue gas condensation															1						**1**
geothermal					1	2	2	1			2	1	1		2		1		1		**14**
heat pump											2		1	2		4	8	3	4	1	**25**
industrial waste heat																		1		1	**2**
mulitiple heat sources											1								1		**2**
nuclear	1	1	1	2	2	2	2			2	1					1				1	**16**
solar																				1	**1**
Total	**1**	**1**	**2**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**6**	**1**	**2**	**2**	**5**	**7**	**12**	**7**	**9**	**6**	**81**

The publications in recent years on heat pumps are the number one topic among the heat supply methods. (Y. Li et al., 2011) proposed a district heating system based on distributed absorption heat pumps in order to supply the low-grade renewable energy in the substation. It can save primary energy supply by 23-46% compared to a conventional district heating system. (Ying & Yufeng, 2012) described the dilatancy technology of a district heating system with a high-temperature heat pump to enhance the capacity of the district heating system, to increase the temperature difference, to reduce the diameters and the initial investment of primary side network, and to save the operation consumption of circulating pumps.

(B. Zhang et al., 2013) proposed an ejector heat pump-boosted district heating system with CHP in order to recover waste heat from circulating cooling water in the CHP plant and to improve the heating capacity of existing district heating systems with CHP. (Sun et al., 2012) developed a new waste heat district heating system with CHP based on absorption heat exchange cycles in order to increase the heating capacity of CHP through waste heat recovery and reduced district heating costs.

A number of heat pump district heating systems using renewable/free energy sources have been analysed, such as geothermal (Qiu et al., 2012; Z. Wang et al., 2010; Zhao et al., 2003), seawater (Haiwen et al., 2010a, 2010b; X. l. Li et al., 2010; H. Shu et al., 2010; Shu et al., 2009; H. W. Shu et al., 2010), lake water (Xiao Chen et al., 2006), ground water and sewage (X. Chen et al., 2012).

(Xia Chen et al., 2013) proposed that heat pump heating serves as a replacement for urban district heating, as a result replacing the coal-based urban district heating with heat pump heating decreases energy consumption and CO_2 emission by 43% in the heating sector, however, there was no explanation on how to calculate CO_2 emissions in this paper.

Geothermal heat is one of the important research topics of the heat supply method. Six earlier publications on geothermal heat were related to indirect geothermal district heating systems and plate heat exchangers. Later, (Lei & Valdimarsson, 2006) used a dynamic simulation model to optimize geothermal heat supply with temperatures between 70 and 90°C for district heating system in Tianjin. The large-scale ground-source/coupled heat pump to access geothermal heat for a district heating and cooling system was applied in Shanghai (Gao et al., 2008a; Gao et al., 2008b). (Zheng et al., 2012) proposed a comprehensive and systematic operation strategy for a geothermal step utilization heating system in order to utilize geothermal energy efficiently.

Two papers on industrial waste heat were related to low temperature industrial waste heat sources. The universal design approach to industrial-waste-heat based district heating was proposed by (Fang et al., 2013) with a case study. No paper was found with the search words “waste incineration” and “district heating” by Chinese researchers according to the Scopus scientific search engine.

7.2.2 System functioning

First international paper on system functioning (Jiang et al., 1996) was published on water leakage and blockage detection in 1996.

The heritage of the Russian principle with calculated balancing of heat distribution networks is still a major problem in China, giving misallocations of heat deliveries to customers. Some buildings are overheated, solved by using open windows, while other buildings are underheated giving low indoor temperatures and critical customer viewpoints. These problems must be solved if payments for heat deliveries should be based on actual heat use using heat meter readers. The number of articles about system functioning can be tracked to these major flow allocation problems in the Chinese district heating systems.

Some papers focused on analysis and optimization of networks, such as (W. Q. Liu et al., 2004; Xuzhong Qin & Jiang, 1999; X. Qin et al., 2001; Zou et al., 2005). Some models on pipeline network with multiple heat sources were proposed, e.g. a hydraulic model of looped pipeline network (Na et al., 2012; Pengfei et al., 2011), and an object oriented-based method (H. Wang et al., 2012).

The traditional regulation methods included quality regulation, quantity regulation, and intermittent regulation, etc. These are all static regulation methods without considering the thermal inertia of the heating systems and buildings. (Jie et al., 2012) proposed a new regulation method called quantitative regulation based on the heat requirements of the users.

By tradition, Chinese district heat deliveries have been invoiced by the connected building spaces. Due to the heat meter reform, Chinese district heating systems are introducing heat meters and customer control systems in the buildings.

The application of thermostatic radiator valves has become popular. Yan et al. (J.-j. Yan et al., 2005) investigated consumer behaviour including the regulation of thermostatic radiator valves and the opening of windows and its influences on the hydraulic performance and energy consumption of individuals and the whole system. They concluded that a 30% deduction of the pump consumption with a 10% deduction of the flow rate and 10% energy savings with the heat metering billing systems.

Liu et al. (L. Liu et al., 2011) compared the pros and cons of several metering methods, these methods charge fees according to heat-allocation meters on radiators, heated areas (traditional way), hot water meters in each household (volumetric meter), calorimeters in each household, and room temperature. After comparison, they proposed a new method that the total heating fee of a building is allocated according to the accumulated on-time (on/off valves) as well as the floor space of each household.

7.3 Most productive Chinese researchers

However, the Chinese researchers working on district heating and cooling systems are split into many affiliations. During the recent four years the total publications from the top five universities are almost equal to the rest of the universities. Figure 7.5 and Figure 7.6 show the top five most published district heating and cooling university affiliation in China respectively during 1990-2013.

District heating researchers at Tsinghua University are the leaders in this field, accounting for 28% of the sum total of Chinese district heating publications. They were dominant five years ago. However, during the recent five years, the publications at other universities have expanded faster, especially at Harbin Institute of Technology. The total number of publications at Harbin institute of technology has grown from third place during all the years to the second place during 2010-2013.

The total publications on district cooling are low compared to on district heating. The university with the most publications is Tongji University, followed by Tsinghua University.

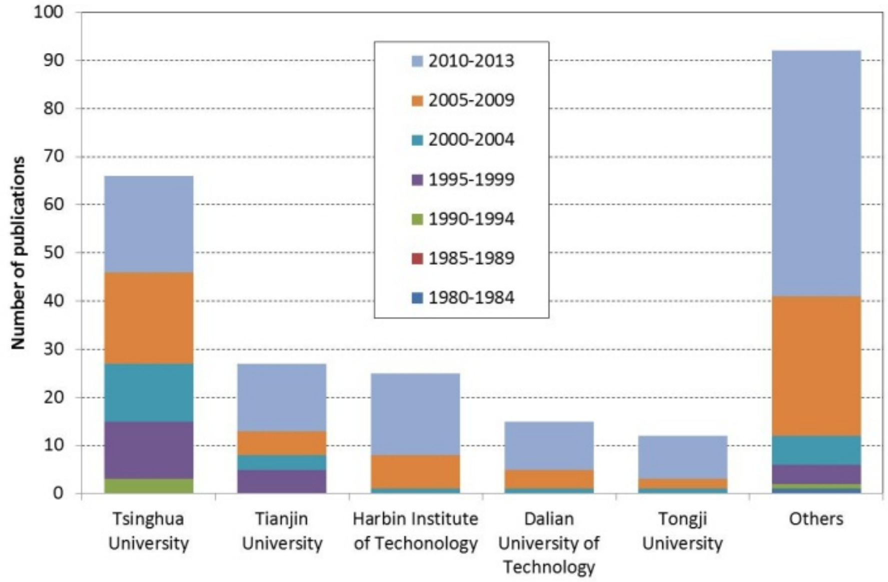


Figure 7.5 Published articles and other papers with the “district heating” label 1970-2013 by University affiliation. Data source: the Scopus scientific search engine.

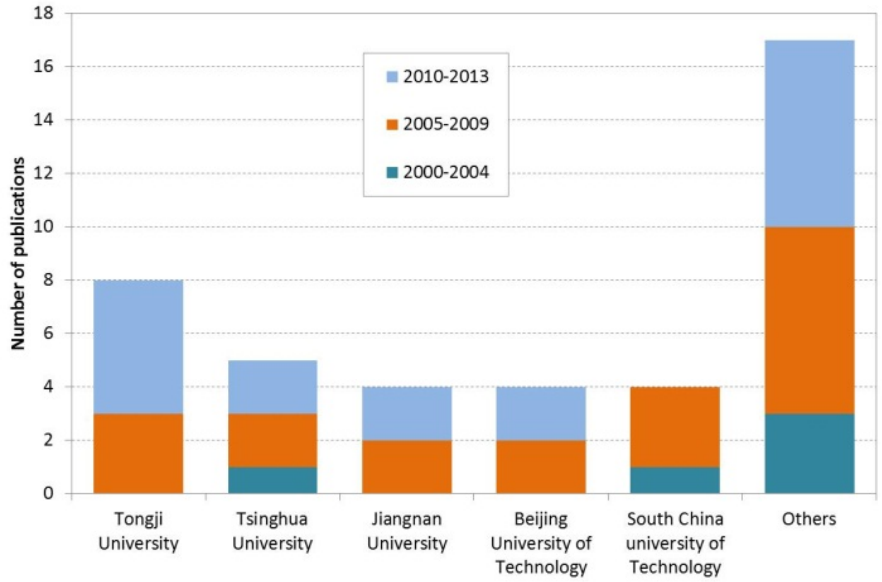


Figure 7.6 Published articles and other papers with the “district cooling” label 1970-2013 by affiliation. Data source: the Scopus scientific search engine.

7.4 Main conclusions from the literature review

Chinese researchers have achieved an impressive growth of the number of papers published on district heating and cooling during recent years compared to all papers published internationally.

Many Chinese research groups are represented in the literature survey. Tsinghua University is the dominant research group among Chinese district heating and cooling researchers, but Harbin Institute of Technology has expanded their publications rapidly during recent years.

The large Chinese interest in various heat and cold supply methods as CHP, CCHP, and heat pumps can be seen as an introduction to the required transfer from coal-fired CHP plants and boilers to other heat supply options, including using natural gas as fuel. However, no paper on waste incineration with heat recovery and only two papers on industrial heat recovery were identified in the literature analysis.

With respect to system functioning, China has an important future challenge of installing heat and flow controls in connected buildings in order to eliminate the flow misallocations in the secondary heat distribution networks. New regulation methods are required considering all important parts: heat sources, heat networks, substations, and heat users.

Sweden has long-term experiences from these two main directions of Chinese district heating research. The heat supply to Swedish district heating systems is highly diversified with heat supply from waste incineration, industrial processes, biomass CHP, large heat pumps, and supporting peak boiler plants since many years. System functioning is based on four independent control systems: heat and flow control in customer substations and differential pressure and supply temperature control at the heat supply plants. Hereby, flow misallocations do not appear in the Swedish district heating systems.

A successful district heating and cooling manager must always minimise both the heat generation costs and the heat distribution costs in order to compete in the heating and cooling market. Earlier, the district heating systems in China were welfare systems, now with the implementation of the heat reform in 2003, new methods of heating fees have been suggested.

8 VISITED UNIVERSITIES

Four universities were chosen to be visited in China. This chapter describes the chosen reasons and the meetings at the four universities.

8.1 First University: Tsinghua University

Address:
北京市海淀区清华大学
Department of Building Science and Technology
School of Architecture
Tsinghua University
Beijing 100084，China

8.1.1 Publications on district heating and cooling

Tsinghua University has the first place on district heating publications and the second place on district cooling publications.

Table 8.1 lists all publications on district heating at Tsinghua University. Their research focuses on heat supply methods. Out of 64 papers totally, 39 papers were related to heat and cold supply (Chapter 6), 9 papers on system functioning (Chapter 10), and 7 papers on substations (Chapter 9). Many departments contribute to the district heating and cooling research, the department with the highest activity is the Department of Building Science.

Table 8.1 Publications on district heating from Tsinghua University according to the chapters in (Frederiksen & Werner, 2013). (Data source: the Scopus scientific search engine).

Year	3 Energy, heat, and cold markets	4 Heat & cold demands	5 Heat & cold loads	6 Heat & cold supply	7 Environmental impact&opportunities	9 Substations	10 System functioning	11 Economics & planning	Total
1992				1					1
1993	1			1					2
1995				2					2
1996				2			1		3
1997				2			2		4
1998				2					2
1999							1		1
2000				1			1		2
2001				3			1	2	6
2003		1		3					4
2005			1						1
2007		1		1					2
2008			1	1		1			3
2009				7		2	2		11
2010				7					7
2011				3		1			4
2012		1		1		3			5
2013				2	1		1		4
Total	**1**	**3**	**2**	**39**	**1**	**7**	**9**	**2**	**64**

Compared to district heating publications, the publications on district cooling were few, as listed in Table 8.2. Heat and cold supply (Chapter 6) is the subject area with the highest focus.

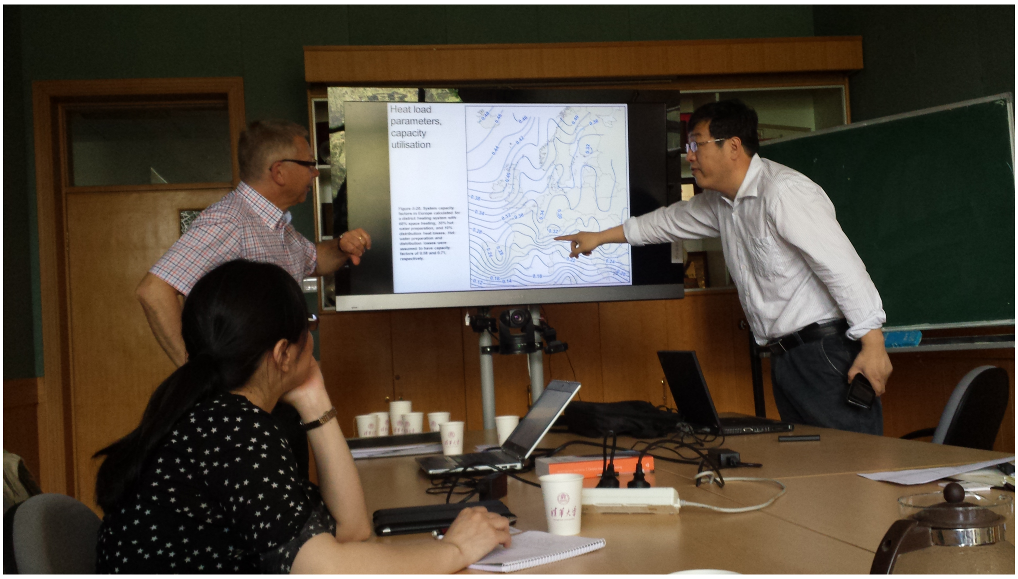
Table 8.2 Publications on district cooling from Tsinghua University according to the chapters in (Frederiksen & Werner, 2013). (Data source: the Scopus scientific search engine).

Year	6 Heat & cold supply	10 System functioning	11 Economics & planning	Total
2001	1			1
2007	1		1	2
2010	1			1
2013		1		1
Total	**3**	**1**	**1**	**5**

8.1.2 Visit on 27th May 2014

Local participants: Professor Lin Fu, Dr. Weixing Yuan, Dr. Jian Sun, Dr. Xiao Wang, Dr. Xiling Zhao, Jingyi Wang, Yanting Wu, and several PhD and master students

Main topic: Policy concerning heat supply



Picture 4. Professors Fu and Werner discussing the levels of capacity utilization in European district heating systems.

Presentations:

- The relationship between haze and winter heating in Beijing, Tianjin and Hebei (BTH) region (presented by Jingyi Wang):
    - The total energy level increased significantly in winter because of heating.

- Coal utilization is the main emission source of NOx. Heating is the most dominant emission source of NOx in winter in Beijing.
- The main emission source of total suspending PM in Beijing is coal, petrol and diesel, and the most dominant emission source of total suspending PM in Hebei is coal.
- The high level of PM2.5 in winter is due to the burning of a large quantity of coal for the heat demand. So the heating plays an important role in the winter haze day's formation.
- Developing low-emission heating technologies and systems could greatly help the treatment of haze pollution in winter in the BTH region.

- A new CHP system based on absorption cycles (presented by Dr. Jian Sun):
  - The current situation: heating from CHPs and large boilers almost equally, long distance between large heating source and users, and low energy efficiency.
  - Example of using absorption heat pumps to recover heat in first CHP plant in Datong:
  1. Increased heat capacity: By using absorption heat exchangers, the temperature of water that returns to CHP plant decreases from 60ºC to 35ºC, so the heating capacity of heating network is enlarged by 38%; by using exhausted heat recovering units, capacity of heat supply increases by 50%, cost of heat supply is decreased sharply.
  2. Energy saving: About 1.9 PJ of low grade heat could be recovered each heating season, which is equal to 80 000 tons of standard coal.
  3. Environment protection: This project could reduce dust by 538 tons, SO_2 by 1 266 tons, NO_x by 410 tons, and CO_2 by 200 000 tons.
- "Coordinated heat and power" district heating model (presented by Yanting Wu):
  - In Yichang city, about half the heat comes from coal boilers with high energy consumption and high pollution, 13% from centralised gas boilers, 10% from small gas boilers, and 22% from CHP plants. These coal boilers need to be changed to CHP plants by either constructing new CHP plans or transforming current power generation to CHPs.
  - Electricity boilers with thermal storage are used in wind power in highly developed regions with low electricity prices; unfortunately, the boilers have low energy efficiency.
  - Two thermal storages: the low temperature tank is for storing low temperature water produced during valley hours, and the high temperature tank is for storing high temperature water during valley hours. These storages in the district heating system are used to replace boiler peak load, to load full with CHP.
  - Advantage with this model: low CHP output at valley hours with stable heat output, if fully used the potential heat capacity of sources, the energy efficiency of the system is high.

- The suggested large heat supply net in the area of BTH region (presented by Jingyi Wang): to decrease distribution costs of long-distance transport (>200 km) with the large temperature difference technology, large pipe diameter, and high flow speed.

The challenges of Chinese district heating systems are, firstly air pollution; secondly, relations between the district heating and cooling systems and the environment.

8.2 Second University: Harbin Institute of Technology

Address:
哈尔滨市南岗区西大直街 92 号哈尔滨工业大学
Department of Building Thermal Engineering
School of Municipal and Environmental Engineering
Harbin Institute of Technology
Harbin, Heilongjiang, China

8.2.1 Publications on district heating

Harbin Institute of Technology has expanded their publications on district heating rapidly, from third place during all the years to the second place during 2010-2013. Table 8.3 lists all the publications on district heating at Harbin Institute of Technology. Their research focuses on system functioning. Out of 24 papers totally, 10 papers were related to system functioning (Chapter 10), and 7 papers on heat and cold supply (Chapter 6).

Table 8.3 Publications on district heating from Harbin institute of technology according to the chapters in (Frederiksen & Werner, 2013). (Data source: the Scopus scientific search engine).

Year	4 Heat & cold demands	5 Heat & cold loads	6 Heat & cold supply	7 Environmental impact&opportunities	9 Substations	10 System functioning	11 Economics & planning	Total
2002							1	1
2005		1	1		1	2		5
2007			1					1
2009						1		1
2010		1				3		4
2011	1		2			2		5
2012			1			1		2
2013		1	2	1		1		5
Total	**1**	**3**	**7**	**1**	**1**	**10**	**1**	**24**

8.2.2 Visit on 29th May 2014

Local participants: Professor Yiqiang Jiang, Professor Pinghua Zou, Professor Xiumu Fang, Professor Zhaojun Wang, and several PhD and master students

Main topic: Policy and Technology

Picture 5. Professors Werner, Jiang, and Zou exchange gifts.

Picture 6. The seminar room at the department of Building Thermal Engineering with professors, associate professors, and PhD and master students.

Presentations:

- Summary of Research (Presented in Chinese): The presentation showed their research activity within the field of district heating systems, e.g. high efficiency energy saving technology, pipe-line distribution technology, evaluation of the heat net reliability, decision-making of intelligent heat net, heat meter technology, heat pump with solar energy/waste heat, residential building energy consumption, and thermal comfort in the heating zone.

- Residential Building Energy Consumption and Environment in Cold Climate Regions of China (Presented by Professor Zhaojun Wang):
    - The total number of civil buildings increased annually by 1.6 to 2.0 billion m^2. With urban residential buildings and public buildings increasing by 400-500 million m^2 each, and rural houses by 700-800 million m^2. The percentage of building energy consumption to total energy consumption increased from 10% in 1978 to 27.50% in 2008.
    - In rural areas, 94% of the houses are without any insulation which causes large heat loss in the buildings. The average indoor temperature is below 18ºC. In Heilongjiang province the heat sources are coal (32%), firewood (3.8%), straw (56.2%), LPG (2%) and electricity (5%).
    - 70% of the heating energy consumption in urban residential buildings come from centralized heating systems, 15% is from coal-fired boilers, 10% is from wall-mounted gas boilers, and 5% is from heat pumps. Within centralized systems, 45% of the heat is from coal-fired boilers, 5% from gas-fired boilers, 35% from heat and power plants, and 15% from boiler plants.
    - The heated area is expanding from north to south, and from the heating zone to the Hot Summer & Cold Winter Zone. The air-conditioning area is expanding from south to north. The proportion of the building energy consumption will continue to rise due to the accelerated urbanization process and continuous improvement of people's living standards.

8.3 Third University: Harbin Engineering University

Address:
哈尔滨市南岗区南通大街 145 号哈尔滨工程大学
College of aerospace and civil engineering
Harbin Engineering University

8.3.1 Chinese Textbook *Heat supply engineering*

The 4th edition Chinese university textbook on district heating was published in 2009 (P. He et al., 2009). This textbook is concentrated on heat supply and system function as it is the most interesting field for Chinese researchers and has sold about 40 000 copies until now. This textbook contains more detailed calculations compared to the English textbook by two Swedish researchers (Frederiksen & Werner, 2013). One of the co-authors Gang Sun, who works at Harbin Engineering University, was chosen to visit.

8.3.2 Visit on 30th May 2014

Local participants: Professor Gang Sun, Professor Fei Wang (Taiyuan Institute of Technology), Design institute, and several PhD and master students.

Main topics: Technology, design, and operation.

Study Visit: Heilongjiang Long Tang Power Investment Co., Ltd Qunli Heat Supply Branch Company, see Appendix 1.

Picture 7. Professors Gang Sun and Sven Werner exchanging their own textbooks on district heating.

8.4 Fourth University: Tongji University

Address: Sino-German College of Applied Sciences
Tongji University
67 Chifeng Road
Shanghai 200092, China P.R.

8.4.1 Publications on district heating and cooling

The most published papers are the fifth place on district heating and the first place on district cooling at Tongji University. Table 8.4 and Table 8.5 list all the publications on district heating and district cooling respectively. The most focus in the district heating publications is given to heat and cold demands (Chapter 4), system functioning (Chapter 10) and heat and cold supply (Chapter 6).

Professor Weiding Long, who is active at the International Institute of Refrigeration (IIR) in Paris and vice president of the committee of HVAC in China, took part in all eight publications on district cooling at Tongji University. Most of these publications are related to the optimization of pipe network (Chapter 10) and community energy planning (Chapter 11). A district cooling and heating system named regional distributed heat pump energy bus system was introduced by (Long, 2014; P. Wang & Long, 2012) in order to achieve maximum urban energy efficiency, and to use clean energy, renewable energy sources and end-use energy saving.

Table 8.4 Publications on district heating from Tongji University according to the chapters in (Frederiksen & Werner, 2013). (Data source: the Scopus scientific search engine).

Year	3 Energy, heat, and cold markets	4 Heat & cold demands	6 Heat & cold supply	9 Substations	10 System functioning	Cooling	Total
2003	1						1
2008			1	1			2
2010			1			1	2
2011		1				1	2
2012		1			1		2
2013		1			2		3
Total	**1**	**3**	**2**	**1**	**3**	**2**	**12**

Table 8.5 Publications on district cooling from Tongji University according to the chapters in (Frederiksen & Werner, 2013). (Data source: the Scopus scientific search engine).

Year	4 Heat & cold demands	6 Heat & cold supply	10 System functioning	11 Economics & planning	Total
2008			2		2
2009				1	1
2010	1		1		2
2011			1		1
2012		1		1	2
Total	**1**	**1**	**4**	**2**	**8**

8.4.2 Visit on 3rd June 2014

Local participants: Professor Weiding Long, Professor Hang Yu, Professor Yiqun Pan, Dr. Yutong Li, Dr. Gaijing Zhang, Dr. Beihong Zhang, and several PhD and master students

Main topic: Energy planning

Presentation:

- Urbanization trends and community energy planning in China (Presented by Professor Weiding Long):
  - More than one percent increase of the urbanization ratio every year in the past.
  - The main sector of energy consumption in almost all cities is the manufacturing industry, the high carbon endowments of energy structure with coal as the main resource.
  - A car-oriented planning concept caused a huge increase in traffic energy consumptions, and no position of the community energy planning in the urban planning.
  - General level of building energy consumption is not so much higher, but there are signs of a correlation between low energy consumption

and poor indoor environmental quality, energy waste and energy poverty, and big waste and small savings.
    - Huge demand of urban life energy in the future, and very difficult to use renewable energy sources in cities with compact and higher density urban forms.
    - Urban industries, transportation and buildings, three major energy-consuming sectors, need horizontal interrelation and vertical coordination.
    - Community energy planning is necessary to reduce energy and carbon emission.
- Method and tools for community energy planning, a review (presented by Zishuo Huang):
    - Challenges in energy planning: cascade energy use and heat recovery; integrated use of renewable energy and land ownership; distributed generation and electricity regulations; population suburbanization separation of workplace and residence, extension of commute time; higher residential vacancy rate, lower efficiency of DHC in residential community; coordination of city resources; air pollution and social security; and livelihood issues.
    - Advantages of micro energy grids: integrated application of low grade heat source and renewable energy; maximizing energy efficiency and economic benefits; and the important support of smart grids.
- The Research of Urban Energy Planning for Low Carbon and Eco-city (presented by Dr. Yutong Li)
    - Community energy planning is secondary energy planning at demand side, further planning of traditional primary energy planning and focus on secondary energy.
    - A framework to analyse the community energy system sketched with energy/exergy flow based on secondary energy commodity costs and distribution costs. These costs not only mean monetary expenses, but can also be fossil energy consumption ratios or environmental costs.
- The General Research and Adaptation Analysis of Present Energy System Utilization of Buildings (presented by Dr. Gaijing Zhang)
    - The current electricity consumptions of the public buildings accounts for 22-24% of the total power generation capacity. It will keep increasing due to the urbanization of China.
    - To implement 100 of the “National Green Ecological Demonstration City” and to complete more than one billion square meters of new green buildings during the “Twelfth Five-Year Plan”.
    - The technology of district energy systems: 1. gas CCHP based on the stepped utilisation of energy to improve gas efficiency from 35% to 80%; 2. heat pump system with renewable energy utilization with better efficiency compared to boilers/chillers; 3. district cooling system with energy storage at night in order to improve the efficiency

    - of the system. The key technologies of district energy systems are heat pump technology and energy storage.
    - The cold source of buildings uses mostly the conventional electric refrigeration unit, and the heat source of northern and southern buildings mostly uses the municipal heating network and the gas hot water boiler respectively.
- Research on district thermal load prediction model and community morphology for energy efficiency (presented by Professor Yiqun Pan)
    - Project 1: Methodology for optimally sized district energy systems.
    - Project 2: Community morphology and microclimate based on energy consumption: the aim is to assess and compare how residential morphology and microclimate can affect the energy consumption on the neighbourhood scale in Shanghai.

8.5 Main conclusions from these study visits

Our main impressions and the directions of research identified are summarised in Table 8.6.

Table 8.6 Summary overview of the four universities visited.

University	Tsinghua University, Beijing	Harbin Institute of Technology	Harbin Engineering University	Tongji University, Shanghai
Main subjects in research activities	Policy with heat supply	Policy and technology	Technology and design	Energy planning & green buildings
Highlights during the meetings	Strong focus on policy issues and policy implications	Strong focus on technology of pipeline as well as heat meter	Good knowledge of existing systems and operating experiences	Strong research on method and tools for energy planning, and district energy

9 RESULTS AND SUGGESTIONS

9.1 Energy system with district heating and cooling

With the growth of the Chinese economy and the improvement of living standards, the living building spaces are expanding with 1.8-2.0 billion m^2 annually. The urban living building spaces are increasing much faster than the rural living buildings due to rapid urbanization. More urban heating systems are needed. At the same time, carbon dioxide emission has increased dramatically after year 2000 with the increase of coal consumption, which also causes severe air pollution recently from local emissions of coal dust. Heat production mostly comes from coal and its products, then oil products. It is very important to reduce CO_2 from heat production in order to reduce the CO_2 level according to United Nations Climate Change Conference in 2009. There are several ways to reduce heat production in China.

First, it is to improve the thermal performance and energy efficiency of the buildings by developing building energy standards and building energy efficiency policies with 30-50% energy savings. All new buildings are expected to meet the 65% saving target during the 12th Five Year Plan (2011-2015).

Secondly, it is to introduce the heating reform by implementing heat meters and consumption-based billing systems.

Thirdly, it is to transfer coal boilers to higher efficiency natural gas boilers, to turn off inefficient small coal boilers gradually, to develop CCHP technology and the other options for district heating. These options are low temperature nuclear heating system, heat pump, heat storage, solar water heating system, and biomass systems.

China has large substations for groups of buildings while Sweden has small substations close to customers. The linear heat density in China is twice as high as in Sweden, since the Chinese district heating system is connected to large buildings while 14% of Swedish single-family and two-family detached dwellings are connected to district heating systems. Relative annual distribution heat losses in China (20-25%) is higher than in Sweden (6-15%).

9.2 Mapping Chinese DHC publications

According to Scopus search engine, the numbers of district heating and cooling publications from Chinese research are in the fourth and second place respectively. A Chinese researcher published the first district heating paper in an international journal in 1984, eight years afterwards there was the second district heating paper in an international journal. During 2010-2012 one third of the international district heating journal articles came from Chinese scientists.

Out of a total of 205 identified district heating papers, 81 papers on heat and cold supply methods is dominating, then 49 papers focusing on system functioning. Only four or five papers were related to energy, heat and cold market, and distribution technology.

Out of a total 37 district cooling papers, both heat and cold supply methods and system functioning are dominating, 10 papers each. No paper was focusing on market conditions or cold loads.

9.3 Evaluation of publication contents

Almost no paper on boilers has been published even though about half the heating comes from boilers. A large part of the research interest is concerned about various heat and cold methods, such as CHP, CCHP, and heat pumps from different sources, this can be seen as a step to achieve the targets for China's district heating sector during the 12th Five-Year Plan (2011-2015). No paper on waste incineration with heat recovery and only two papers on industrial heat recovery were identified in the literature analysis. Several Swedish cities use the heat from waste incineration as a base load heat supply, since dumping combustible waste and organic waste was prohibited in 2002 and 2005, respectively.

The second area which receives the most research interest is system functioning. Many Chinese researchers focus on analysing, modelling and optimising pipeline networks. Recently Chinese researchers pay more attention to heat metering and customer control systems in order to reduce the heat demand and to implement heat reform. The district heating systems in China will substitute welfare systems with commercial systems. In Sweden, the district heating systems were commercial from the beginning and have very good market experience.

9.4 Identified research institutions

Four universities in China were chosen to be visited according to publications from the literature survey and the Chinese textbook on district heating. During the journey in China, district heating was the dominant discussion subject at three of the universities located in the heating zone, only one university outside the heating zone focused on local district energy solutions, but almost no discussion related to district heating and cooling technologies.

At Tsinghua University, the numbers of publications are in first place on district heating and second place on district cooling. The study visit shows that they focus on heat supply policies. A large heat supply net has been suggested in the region of Beijing, Tianjin and Hebei. A new CHP system based on absorption cycles and coordinated heat and power district models are being run in the systems in Datong and Yichang respectively in accordance with energy saving and environment protection. The air pollution and its relation with the district heating and cooling systems are the biggest challenge for Chinese district heating systems. Developing low-emission heating technologies and systems can help to reduce pollution in the heating zone.

At Harbin Institute of Technology, district heating publications have increased rapidly during 2010-2013. The study visit shows that they focus on policy and technology. Researchers at this university presented their research, which includes high efficiency energy saving technology, pipe-line distribution technology, evaluation of the heat network reliability, decision-making of intelligent heat networks, heat meter technology, heat pumps with solar energy/waste heat, and so on. Residential building energy consumption and thermal comfort in the heating zone was also presented.

One of the authors of the Chinese textbook *Heat Supply Engineering* works at Harbin Engineering University. The study visit shows that they focus on technology and design. In Harbin city, 41% of the building space is heated by large local coal boilers, 29% by CHP plants, and 30% by individual heating options. A new residential area in western Harbin was visited, the thermal length (NTU) of heat exchanges in the substation is only 2.6 while it is 4.0 in individual substations for each building in Sweden. There are large district heating systems, e.g. the one visited in Harbin is about twice as big as the largest semi-integrated district heating system within the European Union.

At Tongji University, the numbers of publications are in first place on district cooling and fifth place on district heating. The study visit shows that they focus on energy planning and green buildings. Community energy planning is a tool focused on secondary energy in order to reduce energy and carbon emission, and to build up an eco-city. The technology of the district energy system includes gas CCHP, heat pump systems with renewable energy, and district cooling systems with energy storage.

9.5 Possible research collaboration

Our suggestion for a research and knowledge cooperation program between China and Sweden contains four parts:

- **Research mobility:** a general research exchange program for researchers, PhD students, and master students active at universities with established district heating and cooling research in China and Sweden.
- **Company program:** A seminar program for active district heating and cooling employees and researchers for exchanging ideas in order to improve the current district heating systems. This program can contain identification of existing unique district heating and cooling solutions in both countries as
    - regional district heating systems
    - long heat transmission pipes
    - CCHP solutions
    - large absorption heat pumps in CHP plants
    - large absorption heat pumps in heat distribution networks
    - large compressor heat pumps
    - heat recovery from industrial processes
    - heat recovery from waste incineration
    - heat recovery from computer centres
    - flue gas condensation
    - heat storages
    - coordination between CHP and wind power

  - natural cold resources
  - carbon dioxide reductions
  - big data assessments etc..
- **Future research projects:** Working groups for identifying possible collaboration concerning future research projects based on the findings from the discussions in the company program.
- **International conferences and symposiums:** inviting Chinese researchers to the international district heating conferences and symposiums held in Europe, with the possibility to locate international conferences and symposiums in China in the near future.
- **Textbook:** translation of the new English/Swedish textbook into Chinese as proposed by the research group at Harbin Institute of Technology and the Chinese District Heating Association.

This kind of program can be operated during about five years with an annual budget of 1-2 million euros in both countries together. The financing of the program should be discussed with suitable research boards in each country.

10 CONCLUSIONS

First, our five project conclusions are related to our five project goals:

- China has currently a very impressive growth of urban district heating systems, both with respect to connected heated areas and distribution pipes. However, this expansion is based on traditional technologies with coal based CHP plants and boilers. Final heat deliveries are not based on local heat demand control giving severe flow misallocations in the secondary networks. There is a need to use more sustainable heat supply options in these expanding district heating systems. China has a unique opportunity to implement more new district heating technology, for example applying absorption heat pumps.
- Chinese district heating and cooling researchers have become considerably more active in publishing more articles in international energy journals during the last few years.
- Chinese publications on district heating and cooling reveal a focus on new heat supply options and on the development of the system functioning in heat distribution.
- The most active Chinese district heating and cooling researchers have been identified at Tsinghua University in Beijing, Harbin Institute of Technology, Harbin Engineering University, and Tongji University in Shanghai. The latter university has an interest in district cooling issues, while the three former universities have a primary interest in district heating issues.
- We propose five different research collaboration activities as a general exchange of researchers, PhD students, and master students between China and Sweden; a company program for active district heating engineers in China and Sweden which gives the possibility to identify unique district heating and cooling solutions in both countries; identifying possible future research projects; inviting Chinese partners to the international district heating conferences and symposiums held in Europe; and translation of the English/Swedish textbook into Chinese as proposed both by the research group at Harbin Institute of Technology and the Chinese District Heating Association.

Second, the overall conclusion is that knowledge of district heating and cooling can be transferred in both directions between China and Sweden. China has several new ideas of very long transmission pipelines and the use of absorption heat pumps in both CHP plants and in distribution networks, which are not used in Europe today. Sweden has long-term experiences of diversified heat supply and more elaborate system functioning without any flow misallocations. These two subject areas dominate the Chinese district heating research articles nowadays.

11 REFERENCES

Within this reference list, we use the following three abbreviations:
MOHUD (Ministry of Housing and Urban-Rural Development of the People's Republic of China)
NBSC (National Bureau of Statistics of the People's Republic of China)
IEA (International Energy Agency)

Baike: "*District heating*" 2014, from http://www.baike.com/wiki/%E9%9B%86%E4%B8%AD%E4%BE%9B%E6%9A%96, Accessed on 20140327

Bao, L. et al.: "*Analysis and proposal of implementation effects of heat metering and energy efficiency retrofit of existing residential buildings in northern heating areas of China in "the 11th Five-Year Plan" period*" Energy Policy, Vol. 45, No. 0, pp. 521-528, 2012

Beijing Time: "*China's Heating Reform to Offer Huge Business Opportunities"* 2003, from http://english.peopledaily.com.cn/200308/16/eng20030816_122425.shtml, Accessed on 20140228

Bin, S., & Jun, L.: "*Building Energy Efficiency Policies in China"* Global Buildings Performance Network, 2012

Boverket: "*Teknisk status i den svenska bebyggelsen-resultat från projektet BETSI*", 2010

Chen, X. et al. (2012) Performance and benefits evaluation of two water-source heat pump systems for district heating. *2012 International Conference on Civil, Architectural and Hydraulic Engineering, ICCAHE 2012: Vol. 204-208* (pp. 4225-4228). Zhangjiajie.

Chen, X. et al.: "*Energy saving and emission reduction of China's urban district heating*" Energy Policy, Vol. 55, No. 0, pp. 677-682, 2013

Chen, X. et al.: "*The performance of an open-loop lake water heat pump system in south China*" Applied Thermal Engineering, Vol. 26, No. 17–18, pp. 2255-2261, 2006

China Energy Net: "*我国热电联产应由《热电大国》发展为《热电强国》(CHP plan should be developed from big to strong in China)"* 2013, from http://www.china5e.com/index.php?m=content&c=index&a=show&catid=73&id=856188, Accessed on 20140228

China News: "*中国首个区域冷热电三联供项目试运行 (China's first CCHP in a district area set to run)"* 2013, from http://www.chinanews.com/sh/2013/10-17/5393030.shtml, Accessed on 20140307

Cong, L. et al.: "*Energy efficiency research and analysis on district heating boiler in Tianjin*" In Inner Mongolia, 2011

Danish Energy Agency: "*District heating-Danish and Chinese experience"* Danish Energy Agency, 2013a

Danish Energy Agency: "*District heating and combined heat and power in China"* Danish Energy Agency, 2013b

Dazhong, W. et al.: "*Chinese nuclear heating test reactor and demonstration plant*" Nuclear Engineering and Design, Vol. 136, No. 1-2, pp. 91-98, 1992

Draugelis, G. J.: "*Drivers, trends, barriers for DHC in China*" In 35th Euroheat & Power Congress, Paris, France, 2011

Eom, J. et al.: "*China's building energy demand: Long-term implications from a detailed assessment*" Energy, Vol. 46, No. 1, pp. 405-419, 2012

Fang, H. et al.: "*Industrial waste heat utilization for low temperature district heating*" Energy Policy, Vol. 62, No. 0, pp. 236-246, 2013

Frederiksen, S., & Werner, S.: "*District heating and cooling"* Studentlitteratur AB, Lund, Sweden, 2013

Gao, J. et al.: "*Numerical and experimental assessment of thermal performance of vertical energy piles: An application*" Applied Energy, Vol. 85, No. 10, pp. 901-910, 2008a

Gao, J. et al.: "*Thermal performance and ground temperature of vertical pile-foundation heat exchangers: A case study*" Applied Thermal Engineering, Vol. 28, No. 17-18, pp. 2295-2304, 2008b

Haiwen, S. et al.: "*Energy-saving judgment of electric-driven seawater source heat pump district heating system over boiler house district heating system*" Energy and Buildings, Vol. 42, No. 6, pp. 889-895, 2010a

Haiwen, S. et al.: "*Quasi-dynamic energy-saving judgment of electric-driven seawater source heat pump district heating system over boiler house district heating system*" Energy and Buildings, Vol. 42, No. 12, pp. 2424-2430, 2010b

Hao, B.: "*Building energy efficiency evaluation and labeling (BEEEL)*" In European council for an energy efficient economy 2009 summer study proceedings, Nice, Frence, 2009

He, B.-J. et al.: "*Building energy efficiency in China rural areas: Situation, drawbacks, challenges, corresponding measures and policies*" Sustainable Cities and Society, Vol. 11, No. 0, pp. 7-15, 2014

He, P. et al.: "*供热工程 (Supply Heat Engineering) (4rd ed.)"* Chinese Architecture Industry Publisher, Beijing, China, 2009

Hong, L. et al.: "*Assessment of China's renewable energy contribution during the 12th Five Year Plan*" Energy Policy, Vol. 62, No. 0, pp. 1533-1543, 2013

IEA: "*The international CHP/DHC collaborative-Advancing near-term low carbon technologies"* International energy angency, 2007

IEA. "*Energy Balances of OECD/non-OECD Countries 2011*", 2011

IEA. "*Energy balances for non-OECD countries*", 2014

Jiang, Y. et al.: "*Leakage and blockage detection in water network of district heating system*" ASHRAE Transactions, Vol. 102, No. 1, pp. 291-296, 1996

Jie, P. et al. (2012) Optimization of regulation methods in district heating systems. *2nd International Conference on Mechatronics and Intelligent Materials 2012, MIM 2012: Vol. 490-495* (pp. 1475-1480). GuiLin.

Kong, X. et al.: "*A review of building energy efficiency in China during "Eleventh Five-Year Plan" period*" Energy Policy, Vol. 41, No. 0, pp. 624-635, 2012

Lei, H., & Valdimarsson, P.: "*Simulation of district heating in Tianjin, China*" In San Diego, CA, 2006

Li, H., & Long, S.: "*度日计算方法及其分布特征 (The calculation method and districution of Degree day)*" HVAC (Building Techonology Communications), Vol. 1, No., pp. 4-10, 1987

Li, J.: "*Towards a low-carbon future in China's building sector—A review of energy and climate models forecast*" Energy Policy, Vol. 36, No. 5, pp. 1736-1747, 2008

Li, J., & Colombier, M.: "*Managing carbon emissions in China through building energy efficiency*" Journal of Environmental Management, Vol. 90, No. 8, pp. 2436-2447, 2009

Li, J. et al.: "*Decision on optimal building energy efficiency standard in China—The case for Tianjin*" Energy Policy, Vol. 37, No. 7, pp. 2546-2559, 2009

Li, X. l. et al.: "*Optimal design of district heating and cooling pipe network of seawater-source heat pump*" Energy and Buildings, Vol. 42, No. 1, pp. 100-104, 2010

Li, Y. et al.: "*A new type of district heating system based on distributed absorption heat pumps*" Energy, Vol. 36, No. 7, pp. 4570-4576, 2011

Liu, L. et al.: "*Major issues and solutions in the heat-metering reform in China*" Renewable and Sustainable Energy Reviews, Vol. 15, No. 1, pp. 673-680, 2011

Liu, W. Q. et al.: "*Intelligent control method on district heating network*" Dalian Ligong Daxue Xuebao/Journal of Dalian University of Technology, Vol. 44, No. 3, pp. 464-468, 2004

Long, W.: "*Smart Micro Energy Network for Eco-Communities*" REHAV Journal, Vol. 51, No. 2, pp. 12-17, 2014

Lund, H. et al.: "*4th Generation District Heating (4GDH): Integrating smart thermal grids into future sustainable energy systems*" Energy, Vol. 68, No. 0, pp. 1-11, 2014

MOHUD: "*民用建筑热工设计规范 (Thermal design code for civil building) GB 50176-93*" Beijing, China, 1993

MOHUD: "*□色建筑□价□准 (Evaluation standard for green building) GB/T 50378-2006*", 2006

MOHUD: "*□□□能减排精神 落实供热计量收费 (Implement energy saving and emission reduction, and heat cost with heat metering system)*" 2011, from http://www.mohurd.gov.cn/bldjgzyhd/201109/t20110930_206469.html, Accessed on 20140107

MOHUD: "*住房城乡建设部办公厅关于 2013 年全国住房城乡建设领域节能减排专项监督检查建筑节能检查情况的通报*" 2014, from http://www.mohurd.gov.cn/zcfg/jsbwj_0/jsbwjjskj/201404/t20140416_217682.html, Accessed on 20140922

MOHUD: "*China Urban Construction Statistical Yearbook*" China Planning Press, Beijing, various years

Na, W. et al. (2012) A hydraulic modeling of loop pipeline network with multiple heat sources based on graph theory. *4th International Conference on Technology of Architecture and Structure, ICTAS 2011: Vol. 374-377* (pp. 740-744). Xi'an.

NBSC: "*China Statistical Yearbook*" China Statistics Press, Beijing, various years

Pengfei, J. et al.: "*Establishment and solution of the model for loop pipeline network with multiple heat sources*" Energy, Vol. 36, No. 9, pp. 5547-5555, 2011

Price, L. et al.: "*Assessment of China's energy-saving and emission-reduction accomplishments and opportunities during the 11th Five Year Plan*" Energy Policy, Vol. 39, No. 4, pp. 2165-2178, 2011

Qin, X., & Jiang, Y.: "*Accessibility analysis of district heating loop-networks based on genetic algorithms*" Qinghua Daxue Xuebao/Journal of Tsinghua University, Vol. 39, No. 6, pp. 90-94, 1999

Qin, X. et al.: "*Optimization of Hydraulic Conditions in District Heating Networks*" In Atlanta, GA, 2001

Qiu, Z. et al.: "*Performance study of absorption/compression heat pump (ACHP) system by low-temperature geothermal tail water*" Taiyangneng Xuebao/Acta Energiae Solaris Sinica, Vol. 33, No. 4, pp. 653-657, 2012

Shi, S. Y.: "*China calls for a new plan for district heating*" EuroHeat&Power, Vol. 11, No. II, pp. 19-21, 2014

Shu, H. et al.: "*Study on the decision-making of district cooling and heating systems by means of value engineering*" Renewable Energy, Vol. 35, No. 9, pp. 1929-1939, 2010

Shu, H. W. et al.: "*Energy-saving criterion of seawater source heat pump district heating system*" Xi'an Jianzhu Keji Daxue Xuebao/Journal of Xi'an University of Architecture and Technology, Vol. 41, No. 4, pp. 561-565, 2009

Shu, H. W. et al.: "*Critical COP value of heat pump unit for energy-saving in the seawater-source heat pump district heating system and the analysis of its impact factors*" Harbin Gongye Daxue Xuebao/Journal of Harbin Institute of Technology, Vol. 42, No. 12, pp. 1995-1998, 2010

Shui, B. et al.: "*Country Report on Building Energy Codes in China"* Pacific Northwest National Laboratory, 2009

Sina News: "*2013 冷年，全球空调市场回顾与展 (The review of the global air conditioning equipment market for the cold year 2013)"* 2013, from http://news.dichan.sina.com.cn/2013/08/20/839762.html, Accessed on 20140217

Sun, F. et al.: "*New waste heat district heating system with combined heat and power based on absorption heat exchange cycle in China*" Applied Thermal Engineering, Vol. 37, No. 0, pp. 136-144, 2012

Swedish Energy Agency: "*Energy in Sweden 2013"* Swedish Energy Agency, Eskilstuna, Sweden, 2014

The Central People's Government of China: "*国民经济和社会发展第十二个五年规划纲 (The 12th Five-Year Plan)"* 2011, from http://www.gov.cn/2011lh/content_1825838.htm, Accessed on 20140228

Thematic Database for Human-earth System. "*累年各月平均气温及年较差(分台站)数据库(The monthly mean temperature and annual range (sub stations) database)*", 2014

Tsinghua University Building Energy Research Center: "*中国建筑节能年度发展研究报告 2014 (2014 Annual Report on China Building Energy Efficiency)"* China Architecture & Building Press, Beijing, China, 2014

U.S. Energy Information Administration: "*International Energy Statistics"* 2014, from http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm, Accessed on 20150505

Wang, H. et al.: "*Analysis of multi-sources looped-pipe network based on object-oriented methodology*" Zhejiang Daxue Xuebao (Gongxue Ban)/Journal of Zhejiang University (Engineering Science), Vol. 46, No. 10, pp. 1990-1909, 2012

Wang, L. et al.: "*Contribution from Urban Heating to China's 2020 Goal of Emission Reduction*" Environmental Science & Technology, Vol. 45, No., pp. 4676-4681, 2011

Wang, P., & Long, W. (2012) Research on energy consumption of regional distributed heat pump energy bus system. *4th International Conference on Technology of Architecture and Structure, ICTAS 2011: Vol. 374-377* (pp. 425-429). Xi'an.

Wang, Z. (2014). [Personal communication].

Wang, Z. et al.: "*Analysis of geothermal water sustainability for district heating in Xianyang City*" In Chengdu, 2010

Wang, Z. et al.: "*Thermal responses to different residential environments in Harbin*" Building and Environment, Vol. 46, No. 11, pp. 2170-2178, 2011

Wu, B., & Wang, L.: "*Energy and exergy analysis on China's nagural gas urban district heating systems for replacing coal: a case study of Beijing*" Distributed Generation & Alternative Energy Journal, Vol. 29, No. 1, pp. 29-48, 2014

Yan, D. et al.: "*Achievements and suggestions of heat metering and energy efficiency retrofit for existing residential buildings in northern heating regions of China*" Energy Policy, Vol. 39, No. 9, pp. 4675-4682, 2011

Yan, J.-j. et al.: "*Experiment and analysis on performance of steam-driven jet injector for district-heating system*" Applied Thermal Engineering, Vol. 25, No. 8–9, pp. 1153-1167, 2005

Ying, W., & Yufeng, Z.: "*Analysis of the dilatancy technology of district heating system with high-temperature heat pump*" Energy and Buildings, Vol. 47, No. 0, pp. 230-236, 2012

Yingzhong, L.: "*The important roles of nuclear energy in the future energy system of China*" Energy, Vol. 9, No. 9–10, pp. 761-771, 1984

Yu, S. et al.: "*Scenarios of building energy demand for China with a detailed regional representation*" Energy, Vol. 67, No. 0, pp. 284-297, 2014

Zhang, B. et al.: "*Study of an innovative ejector heat pump-boosted district heating system*" Applied Thermal Engineering, Vol. 58, No. 1-2, pp. 98-107, 2013

Zhang, L. et al.: "*Comparison of District Heating Systems Used in China and Denmark*" EuroHeat&Power, Vol. 10, No. IV/2013, pp. 12-19, 2013

Zhao, P. C. et al.: "*Temperature matching method of selecting working fluids for geothermal heat pumps*" Applied Thermal Engineering, Vol. 23, No. 2, pp. 179-195, 2003

Zheng, G. et al.: "*Operation strategy analysis of a geothermal step utilization heating system*" Energy, Vol. 44, No. 1, pp. 458-468, 2012

Zhou, N. et al.: "*Quantifying the potential impact of energy efficiency and low carbon policies for China*" In The European Council for an Energy-Efficient Economy's 2013 Summer Study on Energy Efficiency, Toulon, France, 2013

Zhou, N. et al.: "*Energy Use in China: Sectoral Trends and Future Outlook"* Lawrence Berkeley National Laboratory, 2007

Zhou, N. et al.: "*Assessment of building energy-saving polices and programs in China during the 11th Five Year Plan"* Lawrence Berkeley National Laboratory, 2011

Zhuang, Z. et al.: "*Chinese kang as a domestic heating system in rural northern China—A review*" Energy and Buildings, Vol. 41, No. 1, pp. 111-119, 2009

Zou, P. H. et al.: "*Hydraulic simulation and analysis of heating loop network with multi-heat source in faulty condition*" Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/Journal of Tianjin University Science and Technology, Vol. 38, No. SUPPL., pp. 1-4, 2005

Appendix 1: Harbin study visit

This appendix contains some short notes from a visit to some district heating facilities in Harbin that was performed together with Professor Gang Sun, Harbin Engineering University, in conjunction with our May 30, 2014 meeting.

District heating in the Harbin city area

Harbin is the regional capital city in the Heilongjiang province and has about 5 million inhabitants. The total building space in the city is estimated to 200 million m^2, including both residential and service sector buildings, with the approximate proportions of two thirds and one third, respectively.

Annual average heat delivery is about 550 MJ/m^2 in Harbin, giving a total heat demand of 110 PJ/year for space heating. Domestic hot water is not normally prepared by district heating, but from individual electric water heaters. Since domestic hot water is not provided, the heat distribution networks are closed down during the summer. Design outdoor temperature for district heating is -26ºC. New buildings have 20-30% lower heat demands than existing buildings.

About 70% of the space heating demand is provided by district heating, corresponding to a building space of about 140 million m^2. With a specific heat use of 550 MJ/m^2, the total heat supply from district heating can be estimated to 77 PJ/year. This is about twice as much as the largest semi-integrated district heating system within the European Union, which is Warsaw.

Table 11.1. Overview of the district heating activities in Harbin.

Area of Harbin	**Connected building space, million m^2**	**Estimated heat delivery, PJ/year**	**Heat sources**
North	20	11	Large CHP plant of 600 MWe, heat transmitted by a 27 km transmission pipeline to the northern parts of the city
South	4-5	2.5	Small CHP
Northeast	4	2	Small CHP
Central	4-5	2.5	Small CHP
West	Now supplying 9, but designed and built for 32	5	CHP plant 300 MWe and 700 MWth with 320 MW boilers for peak load, giving a total heating capacity of 1020 MW.
East	15	8	CHP plant 300 MWe
Non-CHP district heating	About 80	45	Large local coal boilers

Six providers of district heating deliver heat from various CHP plants in Harbin. District heating is also provided by about 100 large local boilers in local networks. A rough estimation of the proportions is provided in Table 11.1. Hereby, several different district heating providers operate in the city as separate entities. Some networks are connected to each other, but only for backup reasons. A future challenge is to consolidate this fragmented heat supply situation by replacing many local coal boilers with heat recovered from CHP plants.

The remaining 30% of the city building space is heated by individual heating options like small coal and gas boilers or heat pumps.

Residential area in Western Harbin

We visited some district heating facilities in a new residential area in western Harbin, operated by the Qunli heat supply branch company. This branch is a subsidiary of a state-owned company (Heilongjiang Longtang Power investment Co. Ltd) working with CHP and heat distribution to 900 million m^2 of building space in the whole of China.

The construction of the residential buildings started in 2009 for a planned total building space of 2 million m^2. The area will be constructed during ten years, so 2 million m^2 are connected to district heating each year. Currently, 9 million m^2 of building space are connected to the western district heating system in Harbin.

The initial part of the area is supplied by a DN1200 pipeline from the CHP plant in western Harbin. The second and last part of the new residential area will be connected to another DN1200 pipeline.

Picture 8. Professor Gang Sun in the company meeting room with two company representatives on each side.

Control room

This control room supervises 58 substations today, but more substations will be added as the residential area will be extended with more buildings. The substations transfer heat from the primary network from the CHP plant to the secondary networks supplying heat to the connected buildings. Each substation supplies heat to a building space ranging between 0.1 and 0.2 million m^2.

The substation heat exchangers are designed for 130-70ºC on the primary side and 85-60ºC on the secondary side, when the whole residential area is finalised. This gives a very short thermal length (NTU) for the heat exchangers of only 2.6. In Sweden, we use longer heat exchangers with thermal lengths of 4 in individual substations for each building.

Some buildings are equipped with underfloor heating systems, giving somewhat lower design temperatures of 50-45ºC for the secondary side.

Picture 9. Intense discussion in the control room.

Pumping station

In the middle of the primary network, a boosting pumping station was installed with 4 parallel units, each with one pump for the supply pipe and one pump for the return pipe. This pumping station is located in the basement of the local office of the heating branch, containing the control room. Within the network, the pumping station was installed in association to a DN1000 pipeline.

The pumping station also contained a small substation for the local heat branch office.

Picture 10. Pumps and valves installed in the pumping station.

First substation in the new residential area

We also visited the first substation established in 2009. It supplies heat to 0.2 million m^2 of residential buildings. One heat meter was installed for heat supplied from the primary network. This substation delivered heat to three different areas, one substation each with heat exchangers and flow control valves for the primary flow. The secondary flow was measured for each of the three areas, but without any temperature sensors.

Picture 11. Mei Gong checking the installed heat and flow meters in the substation.

Picture 12. Substation view with heat exchangers for one residential area and the flow meter installed in the pipe above.

Picture 13. Part of the new residential area connected to the visited substation.

CHP plant in Western Harbin

The CHP plant is equipped with a new large absorption heat pump station, commissioned in 2013. In total, it contains 225 MW of heat supply capacity in six units of about 38 MW each. The purpose with these large heat pumps is to recover heat from the cold condensers in the CHP plant. The evaporators are used to cool the cooling circuit to the cooling towers from 25 to 15ºC. The absorbers and the condensers increase the temperature in the incoming return flow from the heat distribution network from 55 to 75ºC. The generators (or desorbers) are fed by the extracted steam from the steam turbines. In order to understand and explain the benefits with this hybrid between a CHP plant and a heat pump station, a thermodynamic analysis is required in conjunction with other prevailing conditions.

The heat balance is that one unit of heat from the extracted steam gives 1.7 units of heat to the return flow, since 0.7 units are obtained from the cooling circuit.

Picture 14. Interior picture from the heat pump station containing six large absorption heat pumps with a total capacity of 225 MW.

Conclusions from these technical study visits

An overall conclusion from these technical study visits was that the extension of the district heating in Harbin was performed with one coal-based CHP and traditional Chinese heat distribution technology with secondary heat networks without heat demand and flow control in connected buildings. The use of a large absorption heat pump station in the CHP plant was, however, an interesting exception from this overall conclusion. This innovative application has not been implemented in Europe.

DISTRICT HEATING RESEARCH IN CHINA

District heating is growing rapidly in China as Chinese building areas are expanding fast giving increased heating and cooling demands. This report gives an overview of the current situation for district heating and the research and development in this sector in China.

The study shows that China has an impressive growth of urban district heating systems that are mainly based on traditional technologies with coal based combined heat and power plants and boilers. It is obvious that there is a need to use more sustainable options for heat supply in these expanding district heating systems.

Chinese publications on district heating and cooling focus on new options for heat supply. The literature also focuses on developing the system functioning in heat distribution, especially in the secondary networks.

The overall conclusion is that knowledge of district heating and cooling can be transferred in both directions between China and Sweden. China has several new ideas of very long transmission pipelines and the use of absorption heat pumps in combined heat and power plants as well as in distribution networks, which are not used in Europe today. Sweden has long-term experiences of diversified heat supply and more elaborate system functioning without any flow misallocations.

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