SIMILARITIES AND DIFFERENCES IN HEATING SYSTEMS IN BEIJING, XI'AN AND COPENHAGEN

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Foreword

It is my pleasure to write the foreword to this comparison report between Beijing and Copenhagen, as well as the shadow city Xi'an. In so many ways this city-to-city energy efficiency partnership represents the best of what C40 Cities can achieve by working together.

C40 cities is a network of nearly 100 mayors from the world's leading cities, working to deliver the urgent action needed right now to confront the climate crisis and create a future where everyone, everywhere can thrive. The membership of C40 is comprised of many of the world's leading megacities, as well as a grouping of smaller "innovator" cities that provide inspiration to others through their distinctive and pioneering climate leaderships. To see an innovator city, Copenhagen, sharing their expertise and approaches with Beijing and other Chinese megacities in such a tangible manner is a demonstration of the value these cities can bring to the network and furthermore, the critical contribution these cities continue to make in responding to the climate emergency.

Recent years have also seen our Beijing office go from strength to strength, following the success of undertakings such as the C40 China Buildings Programme and the C40 city level China Climate Action Planning programme. It was my pleasure to be in Beijing and share knowledge with a variety of national and city policy leaders back in 2019 at C40's first China Regional Forum. Each time I return to Beijing I'm struck by how quickly the city

has changed, whether this is through using new cycle lanes, enjoying additional green space, or breathing cleaner air whilst noting an ever-greater proportion of electric vehicles on the roads. Keeping this thought in mind, I'm excited to see the progress that will be made in rolling out the findings from this critical comparison study on improving energy efficiency in large buildings linked to district heating – one of the frontier topics for urban climate action in the 2020's.

In the meantime, I want to commend and thank all the city officials and institutional partners who have worked virtually during a global pandemic to share the detailed technical knowledge and expertise contained within this study. This really does exemplify the spirit of friendship, understanding and mutual endeavour which is at the heart of C40.

Mark Watts,
Executive Director, C40 Cities

Foreword

In 2017, Copenhagen had the honor to win a prestigious C40 award for our strategic energy monitoring, management, and renovation programmes in our schools, nurseries, office buildings, and other public buildings. We are the first city in the world to have developed a monitoring system, where we can read the consumption of electricity, water, and heat on an hourly basis and continuously adjust and improve energy consumption in our buildings. This is key to reaching our goal of being a carbon neutral city in 2025.

The energy monitoring system (EMS) developed by Københavns Ejendomme & Indkøb (Copenhagen Properties and Procurement) in collaboration with the city's utility company, HOFOR. The combined with our efforts to streamline building management systems has been instrumental in achieving energy savings in Copenhagen. Our experiences show that these approaches are scalable and efficient. Can these systems be replicated to China? This has been the focus in our close cooperation with Beijing through the Strategic Sector Cooperation project in partnership with C40's China Building Program.

This comparative report shows that the potential for energy and CO2 savings is significant even though there are large differences between Beijing, Xi'an and Copenhagen's heating systems. Based on the solid comparison, pilots mimicking Danish approaches have been implemented both in Beijing and Xi'an. I am delighted to know that remarkable energy-saving results, economic benefits, and better indoor comfort have been achieved as a result of these pilot projects.

I really hope this report will be a great inspiration for other cities around the world.

Last but not the least, I would express my sincere thanks to all our partners and the project staff. Without your commitment and hard work, the report and pilots could not be completed especially during the COVID-19 pandemic period when international travels and physical meetings become impossible in the past 2 years.

Rasmus Vanggaard Knudsen
Director
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Executive summary

This comparison report has been produced as a result of the Strategic Sector Cooperation between Copenhagen and Beijing, as well as with the support of the C40 China Buildings Programme (C40 CBP). It is based on the identified similarities and shared interests of officials from Beijing and Copenhagen relating to the use of district heating and the interaction and control of these systems in large buildings. As such, a study group was formed comprised of staff from C40 Cities Climate Leadership Group, the City of Copenhagen, the Center of Science and Technology of Industrialization Development (CSTID) under the Ministry of Housing and Urban-Rural Development of China (MoHURD), and Beijing Research & Development Center of Building Energy Efficiency. Based on an expression of interest, the city of Xi'an in Shaanxi Province also joined this group as a non-C40 shadow city, notably through the district heating company Raising Group.

Since 2018 Copenhagen and Beijing, joined by Xi'an in 2020, have been working in partnership to identify the key similarities and differences in their heating systems operation. The work undertaken leading up to the publication of this report revealed significant differences between Beijing and Xi'an's heating systems and Copenhagen's. However, despite these differences the comparison research also uncovered the potential for substantial energy and carbon emission savings to be achieved through knowledge sharing and adapting approaches between these cities.

Following numerous technical exchanges, online video screenings, and discussions, three pilot projects were implemented in Beijing and Xi'an – real examples to test previous research findings. These pilot projects had three key focus areas and deliverables to:

1. achieve hydraulic balance in the secondary pipe networks of the district heating system.

2. utilize climate compensation technology at district heating substations.

3. reduce heat supply to public institutions outside working hours.

The results were a clear and a self-evident success: energy savings of up to 25 % were realized with a demonstrable payback period on the investment necessary within 2 years and in some cases even in less than 1 year.

The pilot has made a beneficial exploration, by attempting to change the traditional single supply-side technical adjustment method. And realized the transition from "heat source" adjustment and "heat exchange station" adjustment to "building adjustment" on the user side of the secondary network, and gradually approached the household and room control used in Denmark.

Unsurprisingly, these results have gathered considerable attention amongst the 15 district heating companies under Raising Group in Xi'an. All 15 companies are currently applying for funding to replicate these projects in the coming years.

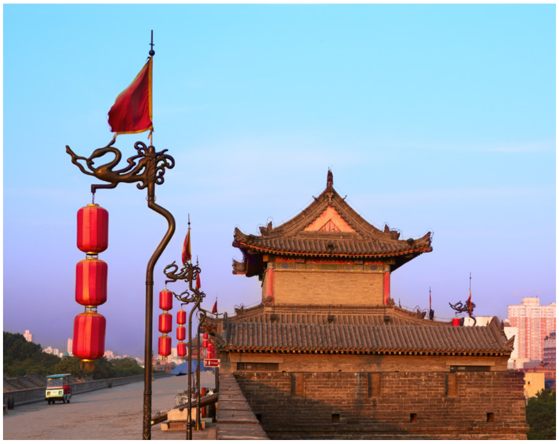
Along with scaling the completed pilot projects, the partner city officials and experts in this collaboration are currently discussing the next phase of the partnership. It is believed that further city-to-city knowledge sharing, discussions, exchanges and pilot projects will lead to further energy savings and carbon emission reductions in new areas of technical practice relating to district heating and large buildings.

1

Study objectives

This comparison report has been produced as a result of the Strategic Sector Cooperation between Copenhagen and Beijing, as well as with the support of the C40 China Buildings Programme (C40 CBP). It is based on the identified similarities and shared interests of officials from Beijing and Copenhagen relating to the use of district heating and the interaction and control of these systems in large buildings. As such, a study group was formed comprised of staff from C40 Cities Climate Leadership Group, the City of Copenhagen, the Center of Science and Technology of Industrialization Development (CSTID) under the Ministry of Housing and Urban-Rural Development of China (MoHURD), and Beijing Research & Development Center of Building Energy Efficiency. Based on an expression of interest, the city of Xi'an in Shaanxi Province also joined this group as a non-C40 shadow city, notably through the district heating company Raising Group.

One of the chief inspirations for this cooperation came in 2017 when Copenhagen won a C40 Cities Bloomberg Philanthropies Award in the Cities4Energy category for the project "Energy Surveillance, Management and Efficient Operation in Public Buildings." This award reflected achieved energy savings of 20% across the city's entire building portfolio, from 2010, and the fact that 5-7% of these energy savings were garnered without significant technical upgrades through low-cost improvements in analytics and control. Following mutual exchanges between Beijing and Copenhagen,



through both the C40 Municipal Building Efficiency Network and the C40 CBP, the objective of conducting a comparison study between Beijing, Copenhagen and Xi'an was settled upon; whereby the lessons and benefits of city approaches to district heating energy efficiency could be shared.

In the initial stages of this cooperation ahead of 2021, two reports were prepared describing the situation in Beijing, Xi'an and Copenhagen - the aim being to review each cities district heating systems, building installations and supporting regulatory framework. This was done to highlight both the similarities and the differences in conditions and ultimately to conclude if knowledge and technology transfers on the ground could be piloting, leading to greater energy efficiency and carbon emission reductions in Beijing and Xi'an.

It is the case that district heating plays a central role both in China and Denmark's overarching heating infrastructure. Following rapid economic growth in recent decades China has developed the world's largest district heating system focused on the cold winter north of the country. In Denmark, the oil crisis of the 1970's spurred the development of cost-effective heat forms and district heating networks were rolled out across the country in urban areas. Whilst district heating can bring efficiencies, these large systems naturally become significant sources of energy consumption within the cities they are implemented. Therefore, discussions and

comparisons on the system efficiency of district heating in Copenhagen and Beijing, particularly in relation to the interface with large buildings, became a common interest between city officials.

Furthermore, in both countries district heating forms an important element in fulfilling societal goals and in the transition to effective and sustainable energy systems. District heating represents a flexible heat form that can allow for the integration of sustainable fuels with high efficiency via co-generation, as well as other clean heat sources. The climate crisis requires for the rapid uptake of large-scale clean energy sources with fluctuating supply – one of the strengths of the district heating sector is that it can provide a balancing role as part of a wider energy system transformation.

However, whilst the potential of district heating systems in the delivery of net zero economies of the future is vast, the purpose of this comparison study was kept purposefully specific:

Firstly, to showcase the ways in which district heating systems and connected buildings can most easily improve their performance according to cost-efficiency and sustainability criteria, taking account of local conditions. This analysis not only concerns pure environmental factors but also social factors such as improved indoor comfort for district heating users.

A particular area of interest in the study was to investigate Building Management System (BMS) controls as well as Energy Monitoring System (EMS) and how these can be used to optimize the monitoring and implementation of energy efficiency in district heating systems.

Secondly, to conduct pilot studies in Beijing and Xi'an, based on the comparison of heating systems and technical exchanges in China and Denmark, in order to better verify and implement advanced technologies and concepts. Following extensive work by Xi'an Raising Group and the support of technical expert teams, pilot projects were implemented in both Beijing and Xi'an, achieving remarkable energy-saving results and economic benefits. Due to limited timeframes and funding, the pilot studies have so far been limited to the regulating technology and control of the hydraulic system of the secondary pipe network, from district heating substation to building entrance. The pilot focus has therefore been on testing static hydraulic balance, climate compensation of heat exchange stations and time-sharing regulation of public/office buildings. In the future, further pilot work will go deeper into controlling heat supply of individual building rooms.

To summarise, the key points of the pilot studies have been:

- Building control scheme, equipment and implementation points;
- Heat and electricity saved by building control technology;
- Room temperature and user feedback after adopting optimized control technology;
- Technical and economic analysis using regulating technology.

2

Point of departure

2.1 State of district heating situation in Beijing and Xian

2.1.1 Main characteristics

The typical technical composition of a Chinese district heating system is that pressurized hot water as the heat medium is produced in a central heat source and distributed to substations (the primary side of the district heating system). Each substation then serves a number of multi-storey or high-rise buildings (the secondary side of the district heating system). District heating in China only provides space heating and does not supply heat for domestic hot water use. Furthermore, the heating period in China is set from November 15th to March 15th.

The China Building Energy Consumption Research report shows that in 2018, the total energy consumption in the building sector account for 46.5% of the total energy consumption of the country, and the total carbon emission is 4.93 billion tCO2, corresponding to 51.3% of the total carbon emissions. Hence the building sector represents a large potential for energy and CO_2 savings.

2.1.2 Energy efficiency advancements

Considering the potential of cost savings and environmental concerns the Chinese Government has done various measures to stimulate energy savings. The 13th Five Year Plan period (2016-2020) proposed that by 2020, the building energy efficiency standards of some areas and key parts such as doors and windows will reach or approach the international advanced level. In new urban buildings, the proportion of green building area is more than 50%, and the proportion of green building materials is more than 40%.

More than 500 million square meters of existing residential buildings and 100 million square meters of public buildings have been completed for energy-saving transformation. The proportion of energy-saving buildings in existing urban residential buildings in China is more than 60%. Moreover, survey shows that many heating companies have a strong awareness of environmental protection and energy saving and has done a lot of management and technical improvement in this area.

2.1.3 Overall development needs

A common overall challenge with Chinese district heating systems is that they supply more heat than the actual heat demand. The reason for this excess heat supply is the general lack of control devices to adjust the indoor temperature and flow in the building heating systems in accordance with the actual heat demand, which results in considerable heat loss.

In terms of temperature control, room temperature regulation and control functions are not available in a large part of the heating area. The national code requires a temperature of at least 18 °C for heat consumers in northern China. The district heating utility usually increases the secondary network's circulation flow rate until at least critical consumers attain this standard. This often result in the systems operating with large volume flow and small temperature differences between the supply and return streams.

When it comes to the flow control in the secondary heating network and at building level, there are usually no automatic flow control devices, which results in an uneven flow distribution in the secondary network of the district heating network. This means that buildings close to the substation tend to receive more flow than needed and become overheated. Buildings located in remote parts of the network receive less flow than required and face difficulties in fulfilling their heating requirements. There is a lack of hydraulic balance.

Inside the buildings and the secondary side of Chinese district heating systems generally operates on a constant flow and pressure basis. The water pressure from the pump is controlled to maintain constant differential pressure at area-substations. In addition, the constant flow operation principle makes the pumps run at constant speed. Although there are some variable-speed pumps, they are mainly used to correct the deviation between the design and operation conditions in terms of the pressure and flow rate. Large volume flow leads to higher than necessary electricity consumption in circulation pumps, small temperature differences, high return temperatures, and network heat losses.

Although the energy-saving consciousness among many district heating companies have become stronger, the implementation of heat metering is poor. Heating companies mostly take "supply guarantee" as a goal, but their role as a market entity is not fully established and they have a strong dependence on government subsidies.

The urban heating price was set for more than 10 years ago, resulting in financial losses for the heating companies. This means that even if heat metering is utilized users will pay the same heating fee as before, but not spend more, thus further increasing the loss of heating companies. The return on heat metering devices alone is low, which is not enough to compensate the investment of heating enterprises, and the profit cannot be guaranteed.

2.2 State of district heating situation in Copenhagen

2.2.1 Main characteristics

The district heating system in the area of Greater Copenhagen is by far the largest system in Denmark supplying 35 PJ of district heating annually and with a distance from the eastern to the western part of the system of approx. 50 km. It consists of several distribution networks interconnected by a transmission grid that over time has developed into one big system. Heat is produced at a variety of different plants including large generation plants (based on biomass), municipal waste plants, surplus heat from industry, and peak load boilers. The total heated floor area which is supplied from the interconnected system is around 75 million. m2 according to the building register and the annual heat sale is 30,000 TJ with an average emission of 65 kgCO2/MWh. In the two largest municipalities Copenhagen and Frederiksberg, 99% of all buildings are supplied with district heating and thus makes this the clear dominant way of heating. In Copenhagen, and Denmark, district heating is used to produce domestic hot water as well. The heating season in HOFOR's area is set from September 15th to May 15th. Outside the heating season costumers are recommended to close their valves to the radiators. In this period district heating is still used to produce domestic hot water.

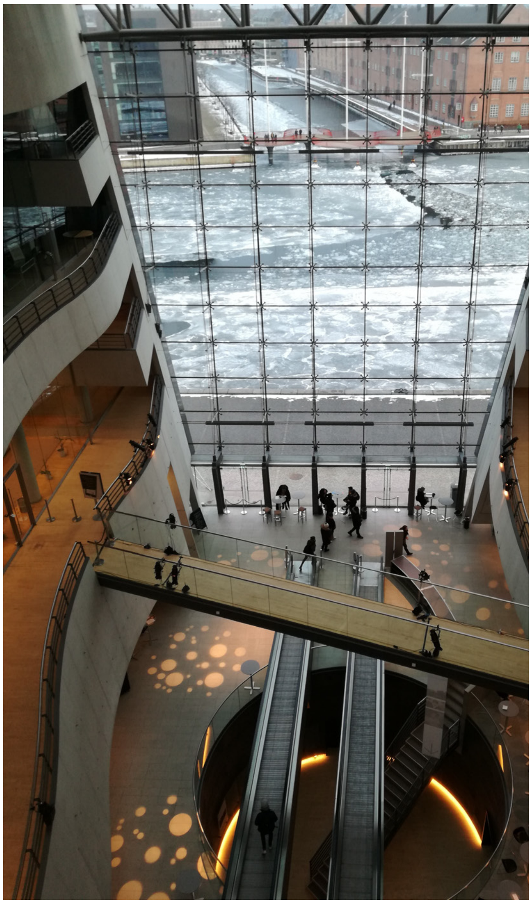
Copenhagen Properties and Procurement (KEID) is the public property administrator of the City of Copenhagen, charged with legal ownership, refurbishment- and overall operational responsibility of the publicly owned buildings in the city. This includes approx. 2,2 million m2 of floor space in around 900 properties and 3,500 buildings. Copenhagen Utilities, HOFOR is a non-profit utility company owned by the Municipality of Copenhagen, HOFOR has the monopoly of supplying district heating to the Copenhagen area.

2.2.2 Energy efficiency advancements

The energy efficiency development is driven by the city of Copenhagen’s ambitious plan of becoming carbon neutral by 2025 including a collection of specific targets and initiatives aiming to pave way for the transition towards carbon neutrality. The Climate Plan has the target of reducing the energy consumption in the municipal buildings of 40% by 2025 compared to the level in 2010, entailing that a majority of municipal buildings will have to undergo energy retrofits.

The Danish building code is a main policy instrument to help achieving the national energy saving targets. For new buildings the code implies strict requirements meaning that the new building stock is constructed with a high energy saving standard that has been tightened in the regular updates of the code. The code also contains regulations regarding the energy performance of building components that are renovated or replaced. Hence the building codes ensure that the existing building stock continuously becomes more energy efficient. It is accompanied by a national scheme for energy labelling of buildings operating since 2006.

KEID is responsible for the maintenance level of the technical installations in each of the public buildings. This has enabled the development of centralized strategies around these types of installations with the aim of implementing energy efficient components and databased tools to assist local operational personnel to secure energy efficient operation and make troubleshooting easier. Part of this has been to put in place an Energy Monitoring System (EMS) and update and streamline Building Management Systems (BMS) as explained under the subsequent section 4.



2.2.3 Overall development needs

The development towards a sustainable energy supply presents a challenge to the district heating system, but socio- and business economic analysis show that district heating plays a critical role in the future energy system. Part of the challenge is to adopt to a lower energy demand due to the stricter building requirements as well as the efforts on energy savings in existing buildings. Another challenge is the increasing share of wind power and other renewables which will decrease the thermal power generation (and consequently also the heating production) at CHP plants, thereby increasing the relative production costs of district heating.

Hence the future development calls for flexible district heating systems that can help balance the fluctuations in the power system and thereby support the integration of renewable energy sources. This can be obtained via technical measures like heat storage, where district heating plants decrease their CHP production when there is sufficient electricity from wind turbines in the system and still be able to supply heating from the thermal storage. Or by using electric boilers and heat pumps, where district heating plants can use excess electricity from wind turbines directly for heat production.

Moreover, low-temperature district heating is a key element in the next generation of district heating. This will allow for a more optimal and efficient use of different energy sources including surplus heat, heat pumps, solar heating, and geothermal energy. The next generation of district heating may also include combined heating and cooling as well as two-way district heating where houses with a possible heat supply during some hours, e.g., from local solar heating, can deliver heat to the network. However, the implementation of low-temperature district heating is challenged because of the relative high supply temperature needed to produce domestic hot water. Also, the need for optimized hydraulic balance is key to enable low-temperature district heating.

Lastly, flexible heat consumption can contribute to the overall efficiency of the district heating network. Currently tests are being conducted in buildings owned by the city of Copenhagen in collaboration with HOFOR. The aim is to heat the test buildings outside of peak hours and decrease the peak load demand. The initial test shows that it is possible to reduce the test buildings peak demand with 22 %. The potential will be further tested in the 2022/2023 heating season in Copenhagen.

Technical comparison and analysis

3

3.1 Beijing/Xi'an and Copenhagen overall system comparison

All heating enterprises in China pursue on-demand heating, that is, by improving the regulation level of the heating system and accurately supplying heat according to the actual needs of users, so as to avoid excessive or insufficient heating. At the same time, heating enterprises also seek to improve the efficiency of the heat source and pipe networks, reducing energy waste in the process of production and transportation.

In Denmark, the regulatory logic of the heating system is dominated by the demand side - a closed-loop system based on end user feedback:

• The key piece of equipment for securing on-demand heating is the radiator thermostatic control valve (TRV), which allows the end user to set room temperature, automatically adjust the heat dissipation of the radiator, make full use of free heat energy such as sunlight, and realize optimum heat/temperature regulation.

• In order to meet the normal working requirements of TRV, the pressure difference of the secondary network (pipe network in the building) is adjusted through the frequency conversion regulation of the water pump or the control valve of the building heat exchange station, and the temperature is adjusted through the climate compensation device of the building heat exchange station;

• Then, the whole primary external network delivers hydraulic balance and other adjustments to meet the needs of a variety of building heat exchange stations.

• At the same time, in order to encourage users to maintain a reasonable and economical demand for heating, Denmark has implemented the household heat metering policy, which encourages users to set the TRV temperature not too high at home and turn down the TRV to the temperature when they are not at home.

In China, the regulatory logic of heating system is dominated by the supply side - the open system in which heating enterprises actively distribute heat to users:

• TRV is generally not installed and users don't have the means to adjust room temperatures. This is all operated by heating enterprises. The feedback for heating enterprises on end user room temperature is delivered through indoor temperature measurement and room temperature sensors (a small number of sensors have been installed in recent years). More feedback is provided via user complaints and the heating enterprises regulate heat through established regulation;

• Public buildings do not adjust to the duty temperature during off-duty hours, especially during weekends or holidays, but continue to heat as residential buildings;

• Building heat exchange stations are generally not used in China. The heating area of common community heat exchange stations is large, usually 100,000 square meters (more than ten buildings and up to dozens of buildings). In order to reasonably distribute heat to each building, some heating enterprises install balance valves (BV) to regulate the hydraulic balance between buildings. Most systems do not have BV and there is hydraulic imbalance in the whole secondary network;

• Unattended automatic control technology is widely used in heat exchange stations. Some automatic control technologies have a climate compensation function, but most automatic control devices have no climate compensation function, or it is the case that these functions are not put into operational use;

• It is difficult to adjust the hydraulic balance of the primary pipe network, and there is hydraulic imbalance in the whole primary network system;

• Because open systems are ubiquitous, heating enterprises- in China maintain the stable operation of the primary network and secondary network system as far as possible during the operation. Only under the condition of user complaints or temperature measurement feedback is the flow distribution of the pipe network locally adjusted to enter a new steady-state operational condition. Most heating enterprises only adjust the supply water temperature at source, according to the outdoor temperature changes. Some advanced enterprises do operate climate compensation automatic adjustment at the heat exchange station.

Chinese and Danish experts identified that the technology gap between the two heating systems is substantial and given these differences, it is would be difficult to replicate approaches completely - there are multiple technologies, policies, practices and habits involved. However, there was agreement that significant results could be gathered through gradual change. To promote heating energy conservation in China, the step-by-step establishment of a closed-loop system dominated by the demand side could be achieved over time with the 'downstream' acting as the main regulator and the 'upstream' as the response. Following intitial comparison study between conditions in China and Denmark it was recommended to gradually implement the pilot work. After each step has achieved energy-saving effects and brought energy-saving benefits, it will bring technology accumulation, confidence, power and capital circulation for the next step:

Step 1: adjust the automatic temperature control of the heat exchange station community;

Step 2: automatic temperature control of public buildings;

Step 3: automatic temperature control of residential buildings;

Step 4: the residential building is automatically temperature controlled a

Therefore, pilot works have so far attempted the first and second steps outlined above, achieving remarkable energy-saving results; The next phase of the pilot will be to look at the third step (residential buildings with floor heating) and the fourth step (residential buildings with radiators).

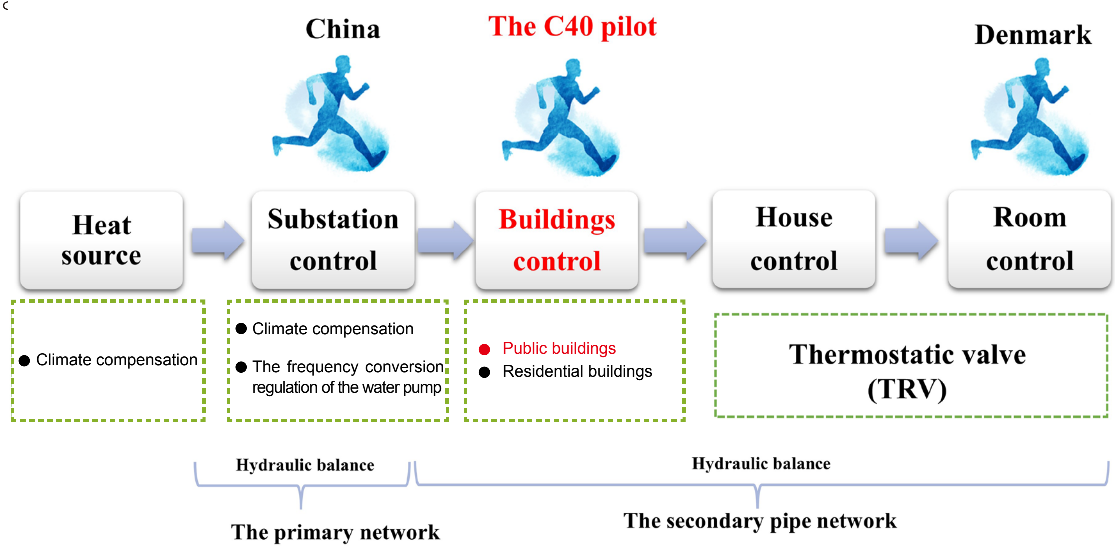
After Sino-Danish expert exchanges, discussion, and initial piloting the key energy-saving technologies that have so far been identified are as follows:

1. Climate compensation technology of heat exchange station;

2. Hydraulic balance technology of pipe network;

3. Building return water temperature control technology.

In addition, the piloting of new approaches will require the dissemination of findings and results as well as updated training and guidelines.



3.2 Climate compensation technology of heat exchange stations

3.2.1 Principle

Climate compensation technology for heat exchange stations takes the heat exchange station as the automatic temperature control object.

Such technology can automatically adjust the water supply temperature of the secondary pipe network by adjusting the primary water flow according to the change in outdoor ambient temperature, so as to realize overall on-demand heating of the secondary network. Climate compensation devices can also collect and analyse indoor temperature changes and optimize heat supply through a powerful self-learning algorithm, such as with Danfoss's LINHEAT system.

This technology can also set variable load demand for different time periods, adjust the temperature curve of the second network for different periods, and realize a comfortable heating level during working hours and on duty heating during the off-duty hours of public buildings, so as to save more energy and reduce consumption.

Climate compensation technology does not conflict with technologies used for temperature control regulation by room, household, or building, and is the basis of in-depth temperature control. For example, it can supplement the effective use of TRV.

3.2.2 Current situation and problems

In Denmark, the application of climate compensation technology has long been popular and it has been optimized and updated with the progress of technology.

In China, only some heating companies, such as KingFore HVAC company, vigorously apply this technology, but most heating enterprises do not apply it. For example, in most heat exchange stations under the control of Xi'an Raising Group, the opening of the electric valve of the primary network or the water supply temperature of the secondary network are mostly issued manually and remotely, whilst the automatic operation function hasn't been adopted.

There are three reasons why most heat exchange stations in China do not adopt climate compensation technology: 1. Defects in automatic control equipment 2. The technical level of personnel and 3. The external network does not adapt to the regulation of heat exchange stations.

To fully realize carbon savings as a product of energy savings a focus on the primary pipe network should be applied. When climate compensation technology is launched in the heat exchange station, the primary pipe network upstream of the heat exchange station needs to be able to adapt to the dynamic conditions of variable flow operation for each heat exchange station. The primary network needs to achieve hydraulic balance and heat source strain flow operation. For the

multi-heat source systems of large pipe networks, energy storage allocation technology needs to be considered to stabilize heat source output conditions.

At the same time, the secondary pipe network of the heat exchange station should first achieve hydraulic balance, otherwise the regulation effect will be affected.

TRV control to adjust room temperature also needs to be carried out under the premise of climate compensation of heat exchange station, otherwise TRV may not work effectively.

3.3 Technical: Hydraulic balancing

3.3.1 Background

As mentioned above and as stated in the Beijing/Xi'an report, a common challenge for pursuing energy efficiency measures in large buildings linked to district heating is customer complaints. Complaints of not meeting the desired comfort level of 18 ℃ can result in the need to increase supply temperatures which increases the risk of overheating and net losses in other areas of the secondary distribution network. Furthermore, initiatives such as the implementation of thermostatic radiator valves in apartments is difficult to implement and utilize without hydraulic balance.

In Copenhagen, hydraulic balancing is achieved by using thermostatic or motor valves and differential pressure controllers and relevant meters (e.g. temperature, flow and pressure) at the building installations before the heat exchanger on the primary side. This enables the system to provide adequate heat for the building, assuming adjustments are correct. Sometimes this is supplemented by valves to regulate flow through the riser pipes in the building. Besides these components, heat distribution to individual apartments (or rooms e.g. an office) is regulated with radiator thermostats.

Even though there are notable differences between the district heating systems in Copenhagen and Beijing/Xi'an, similarities can be identified. In Copenhagen heat exchangers are found at most building/costumer entrances, usually making the secondary network in Copenhagen the central heating network within the buildings. In Beijing/Xi'an the secondary network supplies a number of buildings with large networks between these buildings, supplied by a single large substation. Furthermore, domestic hot water is not generated with district heating in Beijing/Xi'an as it is in Copenhagen. This enables increased flexibility for supply temperatures in Beijing/Xi'an since a constant high temperature for legionella control in hot water tanks is not an issue.

Because of the difference in size of the secondary networks in Copenhagen and Beijing/Xi'an copying the Copenhagen system 1:1 is not an option. However, it is still an option to draw inspiration from the underlying principles.

3.2.2 Balancing advantages

It is recognized by all participating parties that hydraulic balancing should be a priority as an initial energy efficiency measure in large buildings linked to district heating. The Danish expert team have reached this conclusion, and this also reflects the input from the Chinese expert team.

Further efficiency measures may also be considered but they will be more effective if balancing is achieved first. This will lead to multiple future benefits:

Optimal heat distribution in the secondary networks can potentially result in lowering the number of complaints for district heating companies because each building on the secondary network will receive the amount of heat it needs (given that adjustments, heat supply etc is optimised). Lower complaint rates will in turn generate a better financial return for district heating companies because consumers cannot refuse to pay. Overcompensation through increased supply temperatures can be avoided if the number of complaints in the furthest parts of the secondary network is avoided. This can lead to better usage of centralized weather compensation, especially considering there is no need for high supply temperatures for domestic hot water production.

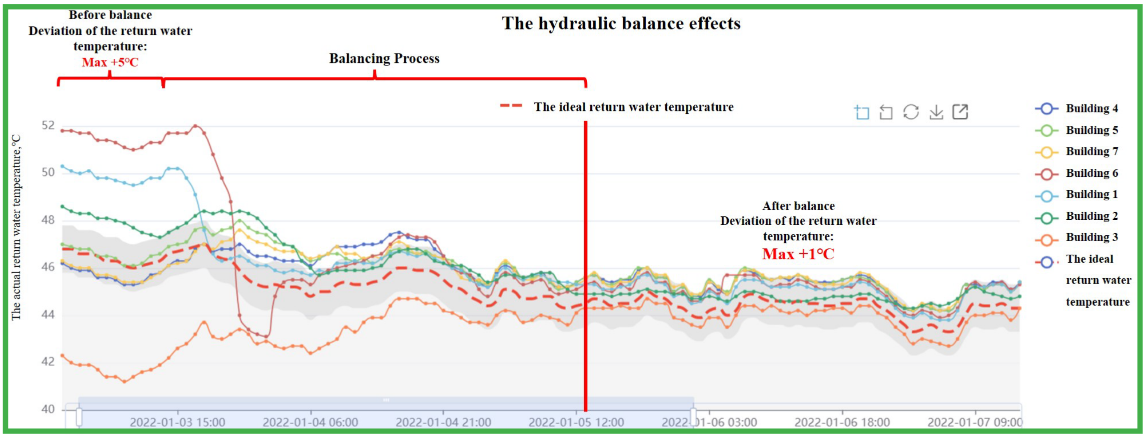
Considering the control principles mentioned in the Beijing/Xi'an country report, balancing the secondary network can lead to expanded options for flow and pressure control at substation level and through this open up the possibility to pursue even more efficient operation.

3.2.3 Balancing suggestions

The primary target for achieving hydraulic balancing is to ensure each building is getting as much heat as it needs to meet the comfort requirements. In Beijing/Xi'an, this can be delivered through relatively few changes to the existing system by installing new components at key areas of the secondary pipe network. This could be differential pressure controllers, motor valves and temperature and pressure meters on the secondary network at building entrances. With these components water flow to the building can be controlled and values can be easily monitored. This can be supported by pressure meters and potentially more pumps on critical points of the secondary network. In sum, the aim is to ensure enough pressure is maintained at the furthest parts of the network and to provide monitoring metrics for the secondary network for better technical troubleshooting.

3.3.4 Pilot application and results

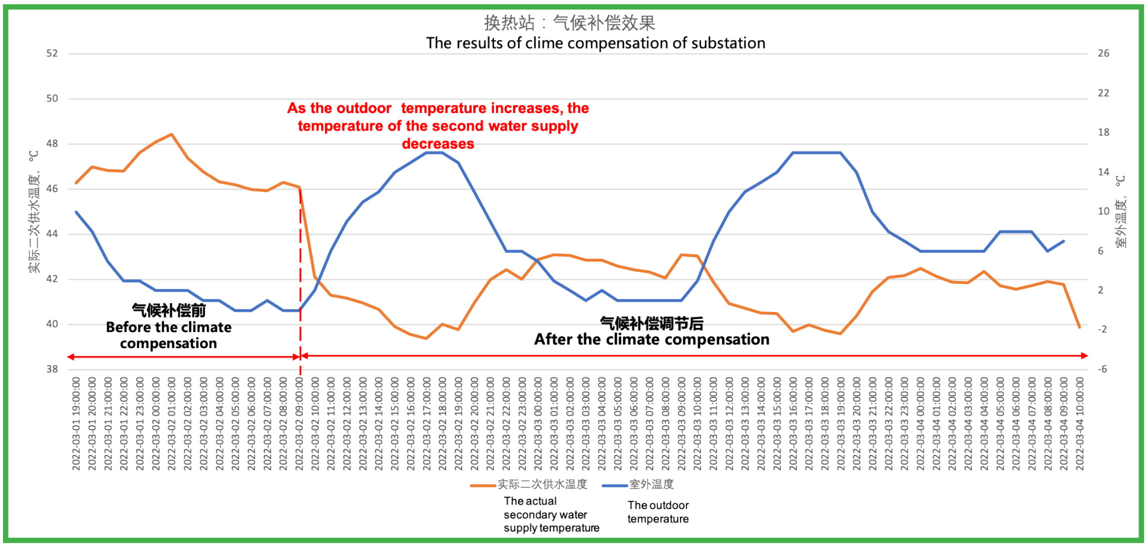
In the pilot work undertaken as part of the Strategic Sector Cooperation between Copenhagen and Beijing and the C40 China Buildings Programme, nineteen buildings of a heat exchange station piloted in Beijing were installed with TIGER's hydraulic balance device, which improved the residential heating quality and saved 3% of electricity. Seven buildings of a heat exchange station were piloted in the heating company affiliated to Xi'an Raising Group, and the hydraulic balance device of TIGER company was installed, which achieved the effect of saving electricity by 13% and heat by 9%. Combined with the climate compensation device, it achieved effective energy savings of 25%.



These pilot experiences highlight that the use of hydraulic balancing technology has great energy-saving potential in Chinese cities with large buildings linked to district heating networks.

Furthermore, two heat exchange stations were piloted in the heating company affiliated to Xi'an Raising Group and the climate compensation devices of Danfoss and Beijing NuanLiu technology company were installed respectively. The former only implemented the climate compensation device and achieved a heat saving effect of 18%. In addition to the climate compensation device, the latter case also utilised building hydraulic balancing technology and achieved an energy-saving effect of 25%.

The pilot practice shows that the use of climate compensation technology also has great energy-saving potential.



3.4 Building temperature control technology

3.4.1 Principle

Building temperature control technology is a technology that takes the building as the automatic temperature control object and adjusts the heat supply to the whole building according to indoor temperature feedback from a range of collection points within the building. It has the following regulating functions and energy-saving effects:

1. Helps achieve hydraulic balance between buildings;

2. Takes into account the free heat of external heat gain (sunlight exposure) and internal heat gain and dynamically adjusts the heat supply in response;

3. When the climate and ambient temperature changes, the system responds quickly and adjust the heat supply in time;

4. When public buildings are not in use, such as at night or on weekends or holidays, required temperatures can be easily changed to an on-duty state, reducing the heat supply.

3.4.2 Current situation and problems

In Denmark, heat exchange stations are generally built in every building, so building regulation has been realized for a long time. Residential buildings realize room temperature control by TRV, which does not need building regulation; TRV with remote regulation is adopted in public buildings, which does not need building regulation, and the energy-saving effect is more effective.

In China, this technology is rarely implemented, but a few pilot projects have achieved good energy-saving results and as such these examples are helping to set the direction of energy-saving technology roll out based on the identified investment benefits.

3.4.3 Pilot application

In this pilot work, building temperature controls for the heating company affiliated to Xi'an Raising Group achieved substantial and practical results. In a public building, on the premise of ensuring that end user room temperature could meet required standards during working hours, the room temperature was lowered during off-duty hours and an energy-saving effect of 11% is achieved.

However, because the other six buildings did not adjust the temperature, the heat saved by the energy-saving building was divided up by other buildings, and there was no energy-saving effect from the overall perspective of the heat exchange station.

Therefore, building temperature control must be carried out on the basis of climate compensation of heat exchange station and constant temperature control of other buildings. Nevertheless, this pilot proved an important principle in terms of controlling out of hours heating demand.

4

Comparison of Energy Monitoring Systems (EMS) and Building Management Systems (BMS)

4.1 EMS in Beijing and Xian

4.1.1 Overall situation in Beijing

There is no standard way of performing energy monitoring in China. As such, each heating company has its own Energy Monitoring System (EMS) and the government carries out statistical analysis by asking for data reports from each company. The performance gap between various company EMS systems is significant. Some are developed by the companies themselves; others are purchased; and the operational functionality varies.

The Beijing Municipal government undertakes the evaluation of energy efficiency performance and gives honorary awards to companies which achieve outstanding energy saving results. However, generally speaking, EMS in China has not reached a level of utilisation and sophistication necessary for the wider scaling of market-oriented energy-saving technologies and energy-saving service companies. Hence the full potential of EMS has failed to be recognised in the implementation of advanced energy efficiency technology, the evaluation and optimization of operational performance, as well as to raise the awareness of heat users for energy conservation via economic incentives.

4.1.2 EMS in Xi'an by Raising Group

The Raising Group operates in Xian and consists of 15 heating companies each with its own EMS. However, in 2020 the group developed and established a central EMS that enabled detailed analysis, evaluation and statistical gathering. The EMS of each subsidiary company of the Raising group has a data acquisition cycle of 1~10 minutes, most of which can communicate local data, remote valve control, and with a few that can automatically control flow temperature and operate climate compensation functions.

The purpose of central EMS in Raising Group is to evaluate its subsidiary companies and promote their energy-saving achievements. At the same time, the system helps analyze and diagnose problems and assists the evaluation of energy-saving projects. Moreover, the results of central EMS analysis represent a key indication for the group on whether to apply further energy-saving retrofitting projects and to evaluate their effectiveness. The system is being completed and the investment is expected to be recovered from energy savings of at least 5%.

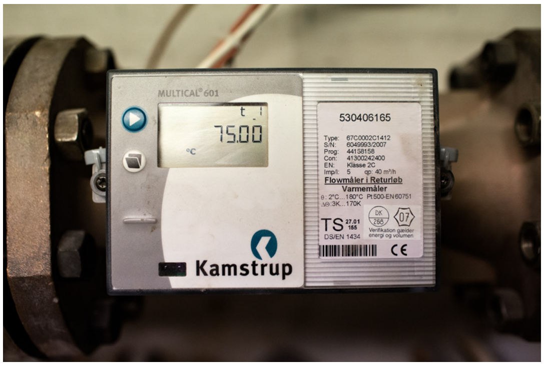
4.2 EMS and BMS in Copenhagen

4.2.1 EMS

The digital energy monitoring programme in KEID began as an energy monitoring project in 2015, following a prior series of energy retrofits and energy efficiency pilot efforts. Through dialogue with industry partners it was identified that actions based on energy monitoring such as balancing and adjusting heat systems would provide a solid basis for achieving reductions in energy consumption.

As a result, the EMS was developed in cooperation with Copenhagen Utilities HOFOR (who act as the software supplier to KEID). Over all, the EMS ensures a host of reliable data points which can be used for a range of purposes such as leakage and error detection, analysis to prioritise energy-saving projects, and acting as a critical aid in documenting and communicating energy consumption patterns. 2300 smart meters are installed in the KEID part of the EMS, making it possible to monitor the heat, electricity and water consumption patterns for over 2 million m2 of floor space in one system. The setup of the EMS follows a strict data governance system structure, whereby buildings, meters, data points etc. follow predefined rules for names and placement in system and hierarchy.

Theoretical energy saving potential was quickly translated into financial savings in Copenhagen with an annual energy cost reduction of 7.5 million DKK has been identified. The financial savings potential made it possible to implement the EMS with a payback time of less than 6 years and the project was approved as a business case, designed to reduce city expenses whilst at the same time saving energy.



4.2.2 BMS

In Copenhagen and Denmark in general, building management systems (BMS) are used to control the central heating installations of larger buildings. The BMS handles weather compensation through supply water temperature control, pumps, and electrical valves. It is usually based on a set of predefined parameters and an outdoor temperature meter. When changes in the ambient temperature are detected the BMS adjusts flow temperature, as well as the operation of engines and valves to most efficiently heat the building based in response to the updated parameters. BMS in buildings in Copenhagen can also control ventilation systems, as well as in some cases lighting and other parts of the building depending on the complexity of fit out.

From the outset the BMS operating in municipal buildings in Copenhagen were hosted on a multitude of different hosting agreements with many different platforms and suppliers, as well as stand-alone systems. In other buildings that did not have BMS installed the operation of heat installations and ventilation systems relied on manual adjustment. This situation was fragmented, lacked and overarching structure and made operational support services hard to realise. It was clear that standardization and streamlining of these systems as well as installing BMS where needed would have a range of benefits.

Between 2017 to 2021 BMS in Copenhagen's public buildings were upgraded, streamlined and connected to the internet where needed. Technical staff can now easily operate installations and utilise options such as weather compensation in heating systems and holiday programs. Furthermore, central technical teams can troubleshoot and assist users more efficiently.

Installing and streamlining BMS was projected to achieve savings of approximately 25 million DKK annually. It is widely recognised that these savings were realized. Alongside these energy and financial savings user comfort has been greatly improved at the same time.

4.3 EMS and BMS conclusions

Energy monitoring and analysis techniques have been implemented in a variety of ways in Beijing and Xi'an, but only in a few cases have they been implemented with commercial success and consistent usage - apart from for mandatory reporting. In Copenhagen and Denmark energy meters have been mandatory for a number of years due to the billing method, and the utility companies roll out of smart meters has accelerated the movement towards dynamic online and digital energy monitoring. As yet, this is not the case in Beijing and Xi'an (and China more generally) and pilots in metering at the building or apartment level have not been an overall success.

However, Raising Group in Xi'an has developed a centralized platform that successfully combines EMS and some BMS metrics across 15 heating companies, 44 heat sources and 480 exchange stations. With this work it is possible for Raising Group to monitor a range of different metrics such as energy use per m2 and the identification of faulty operations. This approach has achieved a 5 % energy consumption reduction with the investment return being realized in less than a year.

These results are similar to those observed by Copenhagen Properties and Procurementin its work with EMS. In Copenhagen a 3% reduction was expected through the establishment and use of EMS and this has been more than achieved.

There are some structural and organizational differences between these examples from Xi'an and Copenhagen. In Xi'an, Raising Group is responsible for the district heating supply whereas Copenhagen Properties and Procurement is responsible for building operation and maintenance. This does not, however, change the fact that centralization and usage of data leads to energy savings.

With these results now documented it is safe to assume that with the correct use of EMS, energy savings can be realized in further Chinese cities.

With regards to BMS some of the control options utilized locally in buildings in Denmark can be achieved from substation level in China. Specifically weather compensation and flow control in the secondary network. Overall, this will help achieve the same effects as were produced in Copenhagen.

With the inclusion of a focus on hydraulic balancing, energy monitoring and management can become even more efficient and pave the way for further energy efficiency measures.

5 Results and conclusions

Since 2018 Copenhagen and Beijing, joined by Xi'an in 2020, have been working in partnership to identify the key similarities and differences in their heating systems operation. The work undertaken leading up to the publication of this report revealed significant differences between Beijing and Xi'an's heating systems and Copenhagen's. However, despite these differences the comparison research also uncovered the potential for substantial energy and carbon emission savings to be achieved through knowledge sharing and adapting approaches between these cities.

Following numerous technical exchanges, online video screenings, and discussions, three pilot projects were implemented in Beijing and Xi'an – real examples to test previous research findings. These pilot projects had three key focus areas and deliverables, to:

1. achieve hydraulic balance in the secondary pipe networks of the district heating system.

2. utilize climate compensation technology at district heating substations.

3. reduce heat supply to public institutions outside working hours.

The results were a clear and a self-evident success: energy savings of up to 25 % were realized with a demonstrable payback period on the investment necessary within 2 years and in some cases even in less than 1 year.

The pilot has made a beneficial exploration, by attempting to change the traditional single supply-side technical adjustment method. And realized the transition from "heat source" adjustment and "heat exchange station" adjustment to "building adjustment" on the user side of the second network, and gradually approached Denmark's household and room control.

Unsurprisingly, these results have gathered considerable attention amongst the 15 district heating companies under Raising Group in Xi'an. All 15 companies are currently applying for funding to replicate these projects in the coming years. Along with scaling the completed pilot projects, the partner city officials and experts in this collaboration are currently discussing the next phase of the partnership. It is believed that further city-to-city knowledge sharing, discussions, exchanges and pilot projects will lead to further energy savings and carbon emission reductions, in new areas of technical practice relating to district heating and large buildings.

Graphic Designer, Jian Shan

Photo credit: Unsplash, the City of Copenhagen