Think Denmark

White papers for a green transition

DISTRICT ENERGY

Energy efficiency for urban areas

INSIDE THIS WHITE PAPER

State of Green
Connect. Inspire. Share. Think Denmark

DISTRICT ENERGY
Energy Efficiency for Urban Areas
Version 2.0
March 2018

Front page photo
Cover photo showing Viborg Combined Heat and Power Plant
Architecture: Kjelgaard & Pedersen
Photo: Kontraframe

Editor in Chief
State of Green

Editorial Committee

Danish Energy Agency	Patrizia Yvonne Renoth, pyr@ens.dk
DBDH	Morten Jordt Duedahl, md@dbdh.dk
Danish Energy Industries Federation	Hans Peter Slente, hps@di.dk

Contributors to White Paper

Aalborg University	Dr. Brian Vad Mathiesen, bvm@plan.aau.dk
ABB Denmark	Martin B. Petersen, martin.b.petersen@dk.abb.com
Arcon-Sunmark	Knud Erik Nielsen, ken@arcon-sunmark.com
Babcock & Wilcox Vølund	Ole Hedegaard Madsen, ohm@volund.dk
COWI	Theodor Møller Moos, tmm@cowi.dk
Danfoss	Jonna Senger, senger@danfoss.com
Funen District Heating	Jan Strømvig, js@fjernvarmefyn.dk
Grundfos	Anders Nielsen, anders@grundfos.com
HOFOR	Henrik Lorentsen Bøgeskov, hbog@hofor.dk
Høje Taastrup District Heating	Uffe Schleiss, uffe.schleiss@htf.dk
Islington Council	Stephen Mirkovic, stephen.mirkovic@islington.gov.uk
Kamstrup	Steen Schelle Jensen, ssj@kamstrup.com
Logstor	Peter Jorsal, pjo@logstor.com
Logstor	Jørgen Ægidius, jae@logstor.com
Ramboll	Anders Dyrelund, ad@ramboll.com
Ramboll	Flemming Ulbjerg, fu@ramboll.com
Silkeborg District Heating	Jens Østergaard Jørgensen, jj@silkeborgforsyning.dk

For more information
To order copies of this white paper or receive information about other related publications, please contact State of Green at info@stateofgreen.com

DISTRICT ENERGY KEY TO EFFICIENCY AND COMPETITIVENESS

District energy is a well proven concept, which can spur green growth and will be a central part of the flexible energy system.

Lars Chr. Lilleholt, Danish Minister of Energy, Utilities and Climate

An efficient and flexible foundation - ready for the future

A competitive economy uses its limited resources in the most efficient way. Denmark is one of the most energy efficient countries in the world. A pivotal part of this is that 63% of Danish homes get their heat and hot tap water from district heating. Furthermore, around 60% of our electricity comes from combined heat and power production with efficiency rates of up to 92%. This makes district heating essential to the Danish heat and power supply. Because of the high efficiency and flexibility in the district heating and combined heat and power system, it is a key element of Denmark's vision of being fossil fuel independent by 2050.

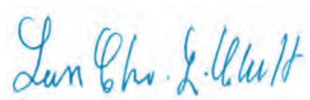
Sharing lessons learned and solutions based on four decades of experiences

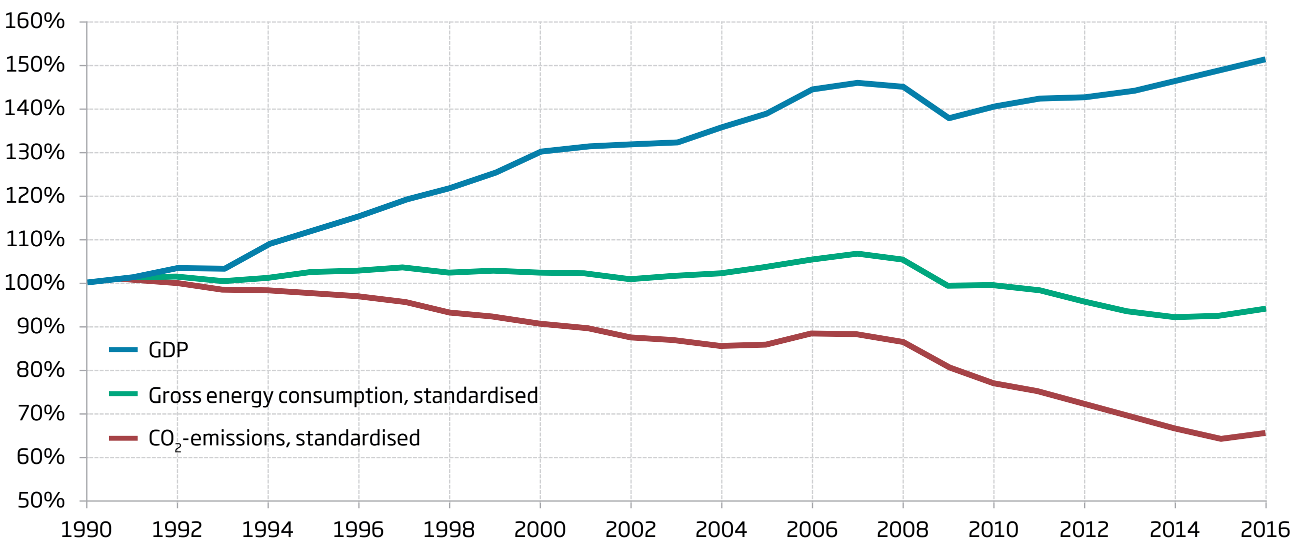
Denmark's strong drive towards district heating was a result of the oil crisis in the 1970s, which hit Denmark's economy hard. Comprehensive analysis of alternative heat supply options clearly showed that district heating in many areas was the best solution. Therefore, Denmark passed its first heat supply law in 1979. Based on this law, Danish stakeholders have developed a political framework to implement district heating successfully across Denmark and gained valuable experience over the past four decades. This has also spurred the growth of numerous companies, who deliver state-of-the-art technologies and know-how within all parts of the value chain of district energy systems.

A well proven and evolving concept - ready for the world

This White Paper is published at a time of strong international demand for energy-efficient solutions. Energy-efficient district heating is of strategic importance to the European Union member states and has great potential in the rest of the world. Denmark co-operates with a number of countries to share our lessons learned and further develop district energy. Even though district energy is a well proven concept, it is evolving and innovative technologies are still being developed, creating new opportunities. I am pleased to share this White Paper with you. This is the first White Paper that describes the policy framework, provides insight on key elements supported by best case examples, as well as shows the future of district energy through development of e.g. low temperature heating and district cooling.

I hope you will be inspired.





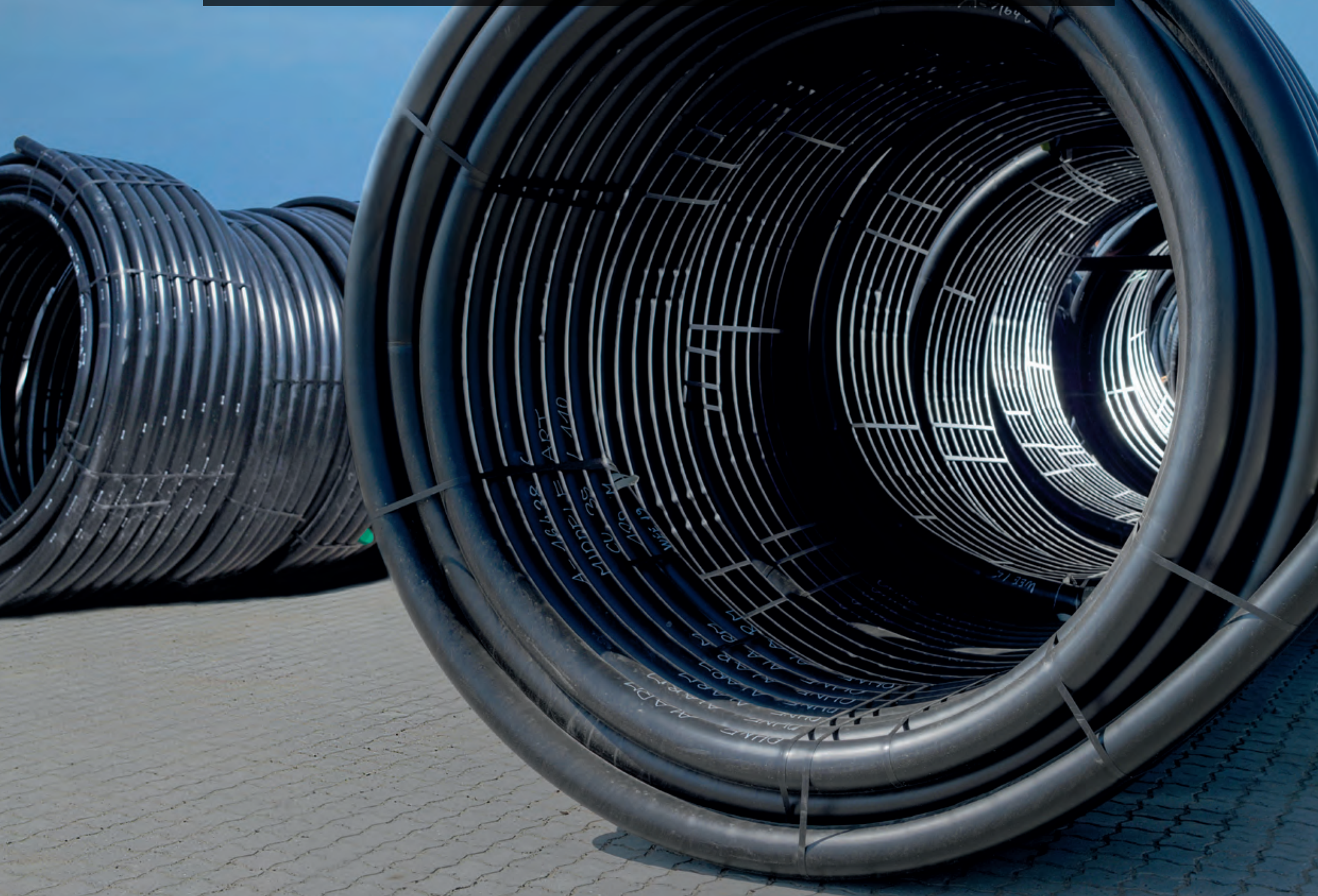
In 2016 67% of district heating in Denmark was produced by combined heat and power (CHP) units. The widespread use of district heating combined with the large share of cogeneration with electricity is one of the reasons that it has been possible to increase energy efficiency, decouple the development in energy consumption from economic growth (GDP), and reduce carbon emissions over several decades.

ABOUT THIS WHITE PAPER

District energy is how value is created by supplying heating and cooling collectively instead of individually and at the same time helping in reaching our climate goals. Heat (or cold) that has no – or very little – value in one place, becomes highly valuable by being transported to a place where it is needed. District energy is the system that takes care of this value creation. Heated or chilled water is used as a carrier. Put simply, district energy is about moving energy in water, with a valuable temperature, from a place of production to the place of consumption.

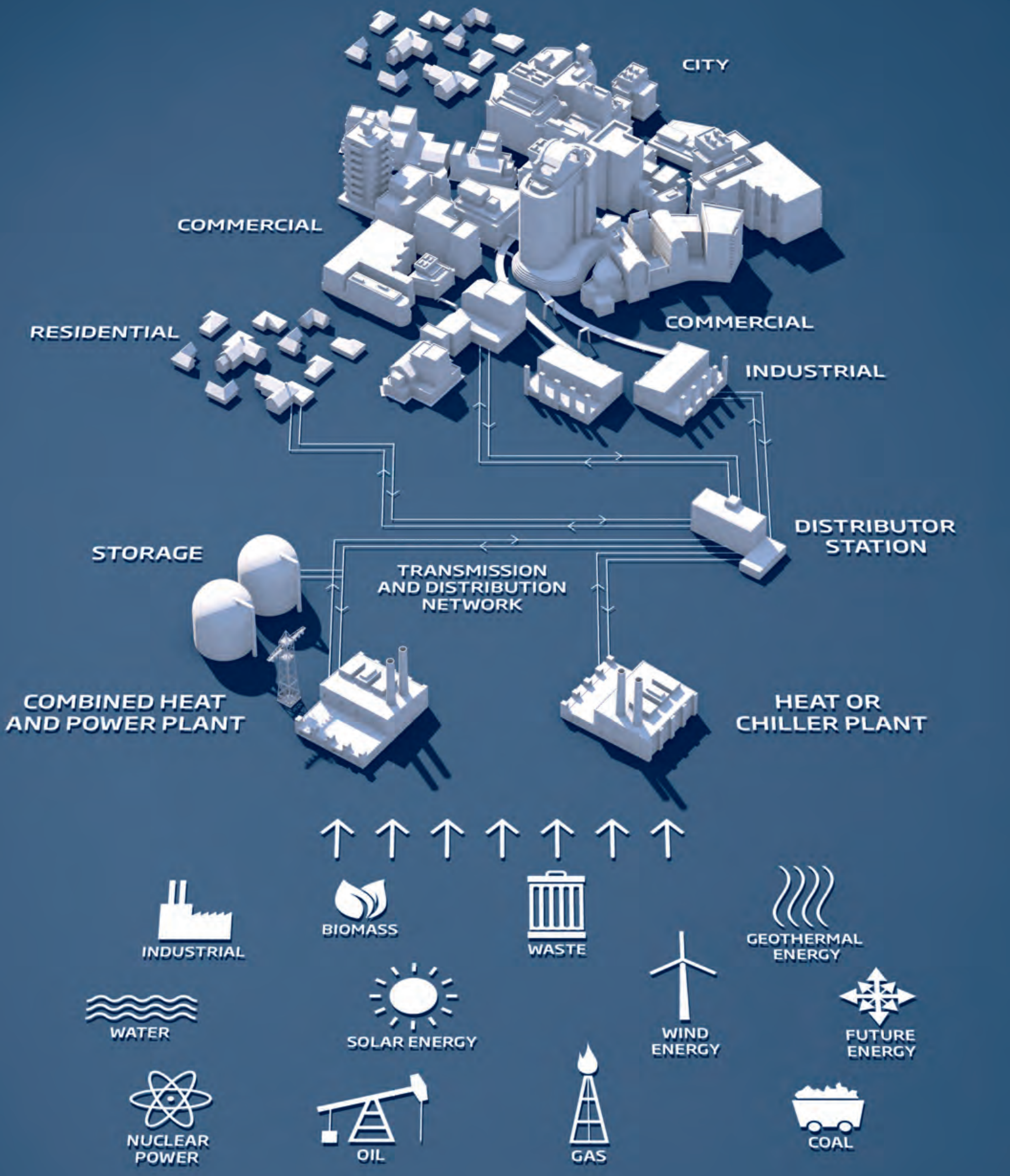
District energy is feasible many places where there is a concentrated need for heating or cooling, e.g. in industrial zones or densely populated areas both in larger and smaller cities. A large part of the initial investment in district energy is creating the infrastructure by laying pipes in the ground. Using high quality pre-insulated pipes ensures that this investment will last for decades and over time becomes a small part of the overall cost of operating the district energy system. Proper installation, metering and heat regulation on the consumer end leads to hassle-free use and payment, as well as a highly improved indoor climate.

This White Paper draws on competencies built up through more than 100 years of experience with district energy in Denmark and around the world. It highlights some of the main learnings to consider when wanting to expand the use of district energy, such as the system, regulatory framework, planning, efficiency and flexibility of energy source, storage and future perspectives, by including relevant cases from around the world. Since district heating is still dominant and most of the technology for district heating and cooling is the same, the term "district heating" will be used for both.



INDEX

OVERVIEW OF A DISTRICT HEATING SYSTEM



Overview of a district heating system
Heat is either produced or collected as surplus heat from many sources (bottom part of illustration), then pumped through highly effective district heating pipes to the end users. Through the storage facility, it is possible to decouple production over short or longer periods of time - even months.

With several production facilities, the economy of the district heating system can be optimised continuously. The end user will enjoy heat delivered from the best available source and not be stuck with just one fuel option.

DISTRICT ENERGY AT ITS CORE

Fuel flexibility and secure supply

District heating is extremely resilient. Its usage dates back to over 100 years ago. Today it is a vital element in the development of sustainable cities.

Jan Strømvig, Managing Director, Fjernvarme Fyn and Chairman of DBDH

Essentially, district heating systems make use of heat produced in central locations and distribute it through pipelines to a large number of end users. In this way heat, that has no or very low value in one place, e.g. industrial surplus heat, can be transformed to high value, in places where there is a high demand for heat, such as small towns or large urban communities.

Advantages of district energy compared to individual solutions

Individual heating solutions only allow one specific type of fuel, e.g. coal, oil or natural gas. For the end user, this means that their heating bill is fully financially exposed to price increases of a specific fuel. With district heating, it is possible to take advantage of market forces driving price changes on different types of fuels. District heating also makes it possible to achieve other societal preferences and political goals, e.g. independence from fuel imports and CO_2 targets. In short, it is much simpler to change fuel from, e.g. natural gas originating from one central place, than it is to change boilers in thousands of individual houses. Today, even electricity is used to produce heat, when prices reach virtually zero due to excess capacity from e.g. wind turbines.

Flexibility is one of the key advantages

Production of district heating or cooling at central units gives access to several fuel types. This makes district heating production very flexible. In turn, this increases both the security of supply and production efficiency. Should one unit break down, there are alternatives available, where at any given time the district energy company can choose the cheapest fuel. Establishing a district heating network also permits the usage of low-quality heat in society. This could be surplus heat from industry and waste incineration, and heat from combined heat and power (CHP) production.

100 years old technology – and still as vibrant as the first day

The world needs to increase focus on exploiting all available sustainable energy resources in the most optimal way. This means that advantage must be taken of surplus heat from any source, replacement of fossil fuels with renewable energy, such as solar and biomass, as well as ensuring systems integration between electricity and heat.

The future will also increase the possibility to store heat from summer to winter in the form of large-scale seasonal storage. District heating provides an answer to these challenges and should therefore be considered as the backbone of tomorrow's urban communities and smart cities. The establishment of district heating can start on a small scale and over time gradually cover the entire urban community. Copenhagen is a good example. Here it all started with one small local system in 1903 and now 98% of the city is supplied by district heating.

MODERN DISTRICT HEATING PIPE SYSTEMS - THE MOST EFFICIENT WAY TO SAVE ENERGY

Total cost of ownership is crucial for future district heating projects

Design of and choice of system for district heating networks have a major influence on performance in terms of energy efficiency, CO_2 emissions and operating costs.

Jørgen Ægidius, Sales Director, District Energy & Peter Jorsal, Product Manager, LOGSTOR

Financial results and environmental impact are influenced by the piping system

The pipe systems for transmission and distribution of district heating are capital goods for society and the district heating company. The pipe system is a way to provide customers with heat and by extension, comfort and convenience.

The functionality of the district heating network has a major influence on how the district heating company performs in relation to energy efficiency, CO_2 emissions and operating and maintenance costs. The technical life span for today's pre-insulated pipe systems is over 30 years. Therefore, it becomes important to review and optimize the long term Total Cost of Ownership (TCO) and thereby ensure the functionality and improve the energy efficiency of the pipe systems and the district heating operations over time. In that way, a modern pipe system safeguards the considerable investments related to transmission and distribution of district heating.

Total cost of ownership is the key to choosing an optimal pipe system

The long technical service life of a pipe system means that choosing a high quality solution far outweighs the initial higher cost. Calculations, tests and experience prove that the major part of the TCO stems from heat losses from the pipe systems. Thus, minimizing heat loss during the entire operating period of the system will significantly improve efficiency and thereby lower the operating costs of the network. This is also illustrated by the example from Hillerød in Denmark.

Low Total Cost of Ownership in the City of Hillerød

The TCO was applied in the selection of the pre-insulated pipe system installed in the Danish city of Hillerød.

Project details:

- 14 km of trench primarily in DN80 - DN150
- Operating conditions, Tf/Tr:/Ta 80/40/8 °C
- Energy costs: 27 EUR/MWh

Required system: TwinPipe

The different solutions considered by LOGSTOR:

- TwinPipe insulation series 1, 2 or 3

The chosen solution:

The basis for evaluation of the incoming tenders included, in addition to the direct capital costs, operating costs related to the heat loss from the transmission system during a 30-year period, which makes up for approx. 40% of the total capital costs. The technical value of the proposed products and solutions was also included in the evaluation.

The project owner decided to install a pipe system based on TwinPipes in insulation series 2 offered by LOGSTOR. This system provided the lowest TCO taking into consideration the investment cost and the heat loss cost over 30 years.

Benefits:

An energy efficient system with approx. 20% energy savings in comparison to a solution based on Twin pipe series 1 and +40% savings in heat loss in comparison to a traditional pair of single pipes in insulation series 2.

The key issues in optimization of a pipe system.

Total Costs of Ownership is influenced by several parameters:

The design of the pipe system must be based on the real operating assumptions in a way that secure the minimum expected life span of more than 30 years. This is secured by using the guidelines in the European standard EN 13941 resulting in simplifying the system and reducing the number of compensators, U-loops etc.

The components must be chosen so that they fulfill the functional requirements for the pipe system. This goes for the pipes, T'ees, valves etc. but especially for the jointing system, where the lifespan relies not only on the product itself but also on a proper installation.

The greatest contributor to the TCO is the heat loss from the pipe system. Therefore, it is essential to choose pipe systems with the optimal insulation properties. In addition, heat loss can be reduced by choosing TwinPipe systems instead of a single pipe system, using higher insulation thickness and choosing pipe systems with a diffusion barrier between the outer PE casing and the PUR foam. The diffusion barrier secures that the initial low heat loss remains unchanged during the life span.

In order to monitor the pipe system continuously over its lifespan, the system should be designed with a surveillance system that can detect at any time if there is a defect in the system and moisture is coming into the foam. If this happens, an alarm will be given immediately and repair can be arranged in good time. This ensures the expected long lifespan.

INTELLIGENT DISTRICT HEATING

Using meter data as the basis for increased efficiency

The heating utility of Denmark's second largest city expects to halve the payback period on its EUR 33 million investment with optimisations based on frequent meter data.

Steen Schelle Jensen, Head of Product Management, Kamstrup

New possibilities with smart metering
In 2012, when faced with replacing two thirds of their worn out heat meters, AffaldVarme Aarhus (AVA) decided they might as well make the changeover in the most intelligent way possible. This meant replacing all 56,000 meters with hourly remotely read meters as well as introducing leakage surveillance and enhancing consumer involvement as part of a smart metering solution from Kamstrup. The increased amount of data has enabled a whole new level of analysis, troubleshooting and improvement options.

"We did a business case for the project, but already now the results have exceeded our expectations. If we continue to see these kinds of results, I expect us to recoup the investment in just half of the meters' expected 16-year lifetime," says Erik Brender, project manager at AVA.

Real-time decisions require real-time data
Increasing demands on district heating utilities to optimise operations and energy efficiency mean that AVA and others must continuously manage and improve their production and distribution network.

The necessary basis for making these optimisations is frequent and accurate meter data. Combined with visualisation tools and analytics, they provide a detailed network overview and allow utilities to adapt all aspects of their business accordingly, which also ensures they maximise the full value of their data.

Data-based optimisation
With intelligent district heating, the administration involved in collecting and handling meter data is reduced and expenses for rectifying missing or incorrect readings are virtually eliminated. More frequent data directly from the network also allows utilities to make more precise production forecasts, shape peak demands and run their production closer to the limit.

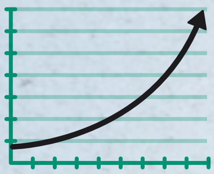
At the same time, knowing the actual state of the distribution network based on hourly values on flow, temperature levels and pressure allows utilities to minimise losses and target their efforts and investments. They gain detailed insight into the performance of specific zones and individual buildings in their supply area, including substation efficiency and building envelope performance. In this way, they can identify the potential for optimising the existing building stock.

Finally, more frequent meter data also benefits the end user by allowing utilities to provide more targeted customer service, offer online energy management services, such as eButler, or introduce new billing schemes. Ultimately, the more data a utility has, the more value it can create.

Improved consumer involvement with eButler
eButler is Kamstrup's online solution for visualising meter data. The solution stands out by being a practical tool that can produce tangible results for end users. A study by the Danish Technological Institute based on interviews of approximately 1,200 customers shows that, out of those who tried using eButler, 73% have used it again. They are generally very satisfied and have achieved substantial savings as a result of reducing their heat consumption based on the information in eButler.

HISTORICAL OVERVIEW OF DISTRICT ENERGY IN DENMARK

FOCUS ON ENERGY EFFICIENCY AND SECURITY OF SUPPLY

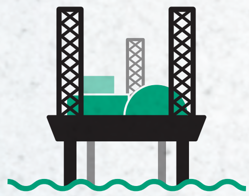


1973-74. The high energy prices caused by the international energy crisis increased the Danish focus on fuel independence and motivated improvements in energy efficiency.

1976-79. Denmark's first overall energy plan lays the basis for a long-term energy policy and the Danish Energy Agency is established. The first law on heat supply starts a new era in public heat planning which still exists today.

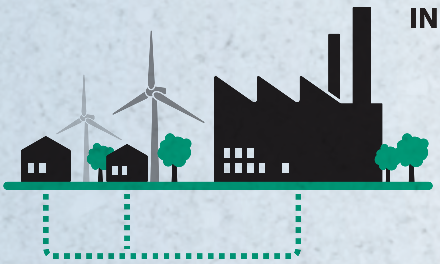
1981-82. National heat planning takes place throughout the country. The heat plans include "zoning" with the purpose of establishing efficient, low-emission energy systems.

INCREASED FOCUS ON DOMESTIC FUELS



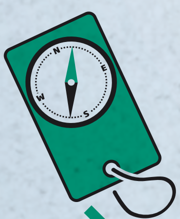
1984. The Danish North Sea natural gas production begins. The Ministry of Energy directs power plants to establish natural gas installations.

1985-86. Parliamentary decision on public energy planning without nuclear power. Coal was excluded from heat planning. Energy taxes are increased due to a drop in oil prices. The co-generation agreement emphasizes small-scale CHP plants as a major energy policy priority.



1990. Political agreement on increased use of both natural gas-fired CHPs and biomass for heat in district heating. Furthermore, the agreement increased installation of wind power.

CHANGE FROM NATIONAL PLANNING TO PROJECT APPROACH



1990. Revision to law on heat supply introduces a new planning system. Planning directives and guidelines for fuel choice and CHP is provided to all local authorities/municipalities.

1992. A range of subsidies were introduced in order to support energy savings, CHP and renewable energy sources.

1993-2000. Political agreement on the use of biomass in power production. Revision to law on heat supply. A political majority in the Danish Parliament decides to improve conditions for 250 small and medium-sized CHP plants outside the major cities.

THE KEY TO SUCCESS IN DISTRICT ENERGY

A peek into four decades of lessons learned in Denmark

The widespread use of district heating and combined heat and power is one of the main reasons why it has been possible to increase energy efficiency and reduce carbon emissions over the past decades.

Morten Bæk, Director General, Danish Energy Agency

District heating - a cornerstone in Denmark's green transition
The very first combined heat and power plant in Denmark was built in 1903. It was a waste incineration plant, which made it possible to handle waste and provide electricity and heat to a nearby hospital, thereby delivering two services simultaneously.

During the 1920s and 1930s, a collective district heating system was developed, based on excess heat from local electricity production. From here on, district heating from combined heat and power (CHP) expanded, and by the 1970s, around 30% of all homes were heated by district heating systems.

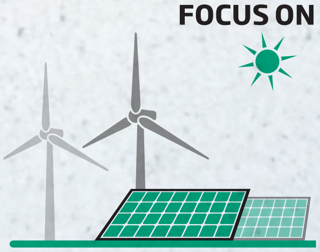
Decreasing energy dependency and consumer costs
The energy crisis in 1973/74 made it evident that saving energy was critical both to decrease the dependency of imported fuels and to reduce consumer heating costs. Therefore, a decision was made to expand the fuel-efficient CHP systems to a number of cities in Denmark.

First heat supply law in 1979
Prior to 1979 there was no law regulating the heat supply in Denmark. Most heat consumers had small oil-fired boilers or other forms of individual heating. In order to fulfil its policy goals, Denmark passed its first heat supply law in 1979. The law contained regulations regarding the form and content of heat planning in Denmark and marked the beginning of a new era in public heat planning, which still exists today.

High energy efficiency is one of the results of long-term planning
Today, 63% of all Danish residential homes are connected to district heating for space heating and domestic hot water. When producing heat and power using CHP, the overall energy efficiency is significantly higher than when producing heat and power separately. A CHP plant may have a total efficiency (combined heat and power) of 85-90% resulting in an overall fuel saving of approximately 30%, compared to separate production of heat and electricity. District heating and CHP have been – and continue to be – a key ingredient to Denmark's green transition.

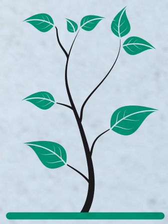
Flexibility to develop and continuously support different policy goals
District heating ensures that Denmark has a sound and reliable heating supply. It also greatly supports Denmark in maintaining a sustainable energy sector and fulfilling its long-term energy policy targets. Looking ahead, district energy will remain a key element of the energy system in Denmark. By 2020, about half of the Danish electricity consumption will be supplied from wind power. This has created heightened focus on flexible district energy systems that will support the integration of wind power into the energy system. Therefore, district energy not only contributes to achieving Denmark's climate goals but also plays a major role in balancing the future energy system.

FOCUS ON CLIMATE, RENEWABLE ENERGY AND ENERGY EFFICIENCY



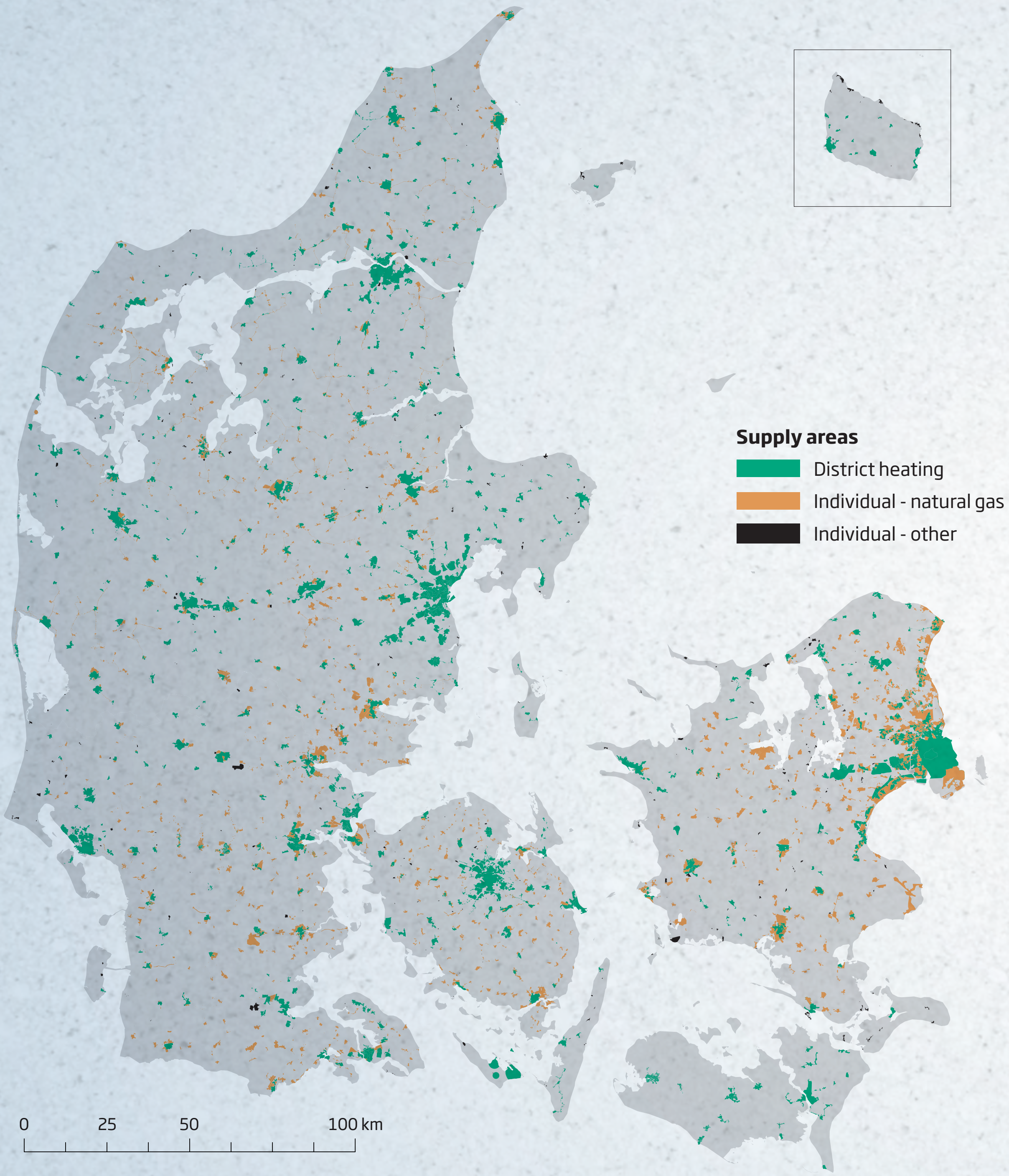
2008. Political agreement improving the conditions for wind energy and other renewable energy sources.

2012. Major political agreement about Danish energy policy for the period 2012-2020, containing a wide range of ambitious initiatives and investments within energy efficiency, renewable energy and the energy system.

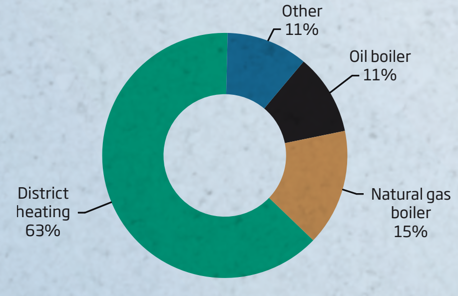


2020. Results from the implementation of the agreement will in 2020 be app. 50% of electricity consumption supplied by wind power, more than 35% of final energy consumption supplied from renewable energy sources and a 12% reduction in energy consumption compared to 2006.

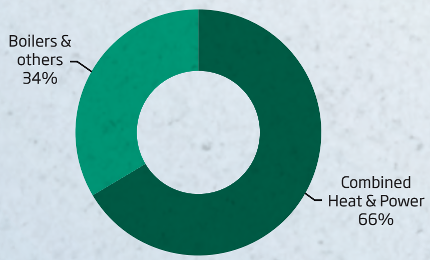
MAP OF DENMARK'S HEAT SUPPLY



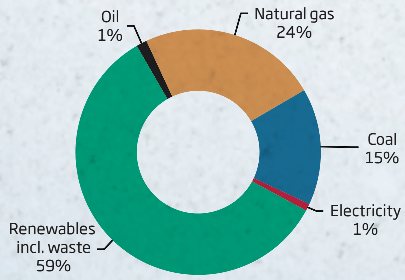
Heating installations in homes



District heating production



Energy sources for district heating



Sources: Annual Energy Statistics 2015 - Danish Energy Agency, PlansystemDK as of 01.08.2017 - Danish Business Authority. Ramboll/TSR

PLANNING AND REGULATION – A PREREQUISITE

The regulatory process, responsibilities and requirements when approving district heating projects in Denmark

The first Heat Supply Act from 1979 defines the division of authorities and responsibilities. It is the main law regulating heat planning and implementation of heat projects.

Morten Bæk, Director General, Danish Energy Agency

Clear roles and responsibilities
The Danish district heating legislation is set out in the Heat Supply Act from 1979 that regulates the heating sector. It provides local authorities (i.e. municipalities) with the power to engage in local heat planning, decision-making on energy infrastructure and resource prioritisation. Local decision-makers have full authority over local heating system designs, but they do so by relying on a centralised policy and a technical framework provided at the national level. This ensures that district heating projects are in line with the overall national ambitions concerning the development of the heating sector. The Danish Energy Agency (DEA) developed the legislation and accompanying guidelines, but simultaneously, the evaluation and decision on the individual heating project are conducted by a local authority with detailed knowledge of local urban development, heat demand and any other relevant local considerations.

Main principles of the initial Danish Heat Supply Act from 1979:

- Local authorities are responsible for the approval of new heating supply projects.
- Local authorities have to make sure that the heating project with the highest socio-economic benefits is chosen.
- Where possible, heat must be produced as combined heat and power.
- The collective heat supply price must offer consumer prices based on "necessary costs", meaning that the heat price cannot be higher or lower than the actual heat production costs.

The Danish Heat Supply Act has also established specific zones of heat networks throughout the country. Within each zone a specific type of heat supply is promoted through the Danish heat legislation.
The zones are as follows:

- Individual heat supply
- Natural gas
- Decentralised district heating
- Centralised district heating

Choice of heat supply based on socio-economic cost benefit analysis
The choice of heat supply must be based on socio-economic cost-benefit analyses. To help local authorities complete relevant economic analyses, the DEA provides guidelines and methodologies with a number of socio-economic assumptions. These assumptions include, among others, fuel prices, electricity prices, externality costs of emissions and interest rates. The DEA also provides technology data, which can be used as a reference. This forms a uniform basis for assessing the heat supply possibilities for local authorities nationwide.

Regulation of consumers' heat price
The price of heat is not the same in all Danish district heating areas, but the principles of determining the heat price are the same.
The method for setting the heat price is set by law. The legislation states that the heat price paid by the consumer should cover all necessary costs related to supply heat. However, heat supply companies must remain not-for-profit, under Danish law.
The heat plants cannot charge more for the heat than the actual costs of producing and transporting heat to consumers. It is, however, important to emphasise that these costs also include depreciation of assets and financing costs, so that the heating companies can be financially sustainable both in the short and long term. Cost of heat to the consumer is therefore affected by the following parameters:

- Production facility investment
- District heating network investment
- Production facility operation and maintenance
- District heating network operation and maintenance
- Fuel prices
- Efficiency of the production facility
- Heat loss in the district heating network
- Taxes and VAT
- Financial support/grants
- Electricity price (relevant for district heating production facilities that either use or produce electricity)

Investment costs versus operating costs
Establishment of district heating systems requires large investments in infrastructure compared to individual heat supply options. However, the operational costs and the environmental impacts will in many cases be significantly lower. This is particularly true if the heat is produced by an energy-efficient CHP unit or if heat is produced by utilizing excess heat from an industrial plant, for example a steel or cement plant.

Levelised costs of energy
Danish experiences show that when evaluating the feasibility of district heating, it is important to consider the costs over the full lifetime of a heat supply system (typically referred to as "levelised costs of energy" or LCoE). In many cases, district heating is the most feasible solution over a full lifecycle analysis. Large infrastructure investments will be recovered after some years by lower annual costs. Of course, viability depends on a number of factors including heat demand and the heat density in the specific area.
The use of high-quality components, although initially increasing the capital cost, usually results in lower annual costs and therefore, in many cases, a lower lifetime cost due to lower maintenance costs and longer life time. This also means lower annual heating costs for heat consumers. It is important to consider that the technical lifetime of a high quality district heating network is typically 40-50 years.

Natural monopoly
The costs of a district heating system highly depend on economies of scale both for heat production plants and network costs. It would not be cost effective to have a parallel grid to supply heat to individual consumers. Therefore, it requires thorough and detailed planning to ensure consumer protection as well as benefits for society while creating reliable investment conditions for a technology that plays a major role in the green transition.

THE INTEGRATED DISTRICT HEATING SYSTEM IN GREATER COPENHAGEN

Cost-effective low carbon heat supply to 1 million residents in 22 municipalities

Municipal and consumer owned district heating companies have established an integrated district heating system. The heat is produced efficiently by waste incinerators (25%) and power plants (70%). Only 5% is from boiler plants. The system is in transition towards 4th generation district heating.

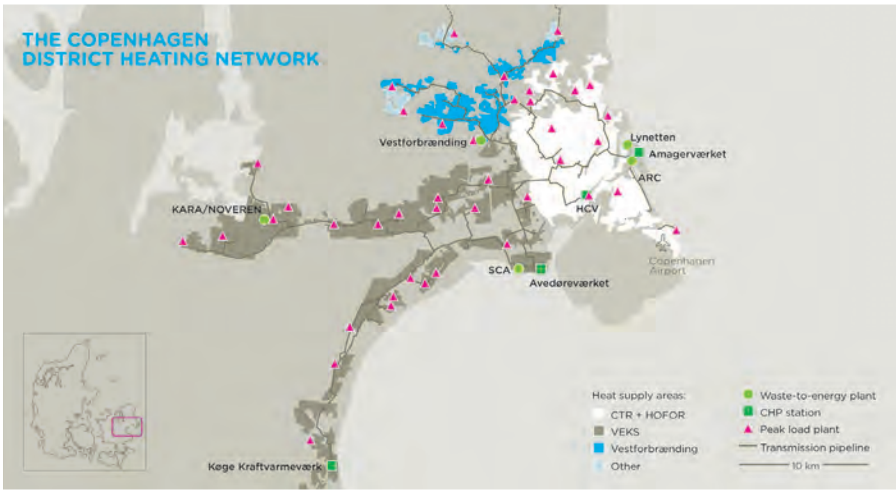
Anders Dyrelund, Senior Market Manager, Ramboll

The History
From 1903 to 1979, district heating developed steadily based on surplus heat from power plants and waste incinerators, as well as heavy oil boilers, providing a good alternative to individual boilers. Since 1979 the system has increased significantly, regulated by the Heat Supply Act and in symbiosis with the power and waste sectors. Recently, many natural gas districts have changed to district heating and the heat transmission has been extended in order to meet the objectives of cost-effective heat supply taking into account the cost of CO_2 emissions.

The ownership
The heat transmission and waste management companies are owned by the municipalities they serve, and the 20 heat distribution companies are owned either by municipalities or consumers. Thus, all companies have a strong interest in working together to find the most cost-effective solutions for the consumers in Greater Copenhagen.

The district heating system
The transmission system, the heat storage tanks and the heat load dispatch unit are vital for the optimal use of the resources and competitive heat prices. The system supplies 75 million m^2 of heated net floor area. The annual heat sale is 8,500 GWh and the production is 10,000 GWh. The back-bone of the system is a 160 km long 25 bar transmission system (max 110 °C) and 3 x 24,000 m^3 heat storage tanks. This system is connected to distribution systems via heat exchangers. A heat market unit organised by the transmission companies is responsible for optimising the heat production (hour to hour and day to day) from CHP plants, waste incinerators, more than 50 peak boiler plants and other smaller heat producers.

Future development
The system is in transition towards 4th generation district heating:
- The CHP plants will shift from coal and gas to mainly straw and wood.
- The heat storage capacity will be increased significantly with large tanks and storage pits.
- The number of district cooling systems will be increased from 5 systems to more than 20 systems, mainly with chilled water storages, co-generation of heat and cold and seasonal storages (ATES) in symbiosis with district heating.
- Consumers representing more than 1,000 GWh are expected to shift from individual gas boilers to the district heating system.
- The heat transmission will be extended further to near-by distribution companies in two more municipalities.
- More large heat pumps and electric boilers will be installed in order to integrate the fluctuating wind energy.
- The remaining parts of an original steam system will be fully replaced with hot water shortly after 2020.
- The only super-heated network (165 °C) will partly shift to low temperature network, as super-heated water from the CHP plant will only be supplied as process energy to industries.
- Consumers will renovate their heating systems to lower the return temperature and the need for supply temperature.
- Accordingly, temperatures and heat losses in the grid will be reduced.



The heat transmission system owned by CTR and VEKS interconnects the two CHP plants and the 3 largest waste incinerators with 20 distribution companies to ensure optimal production and operation. HOFOR, the largest distribution company, also operates a steam system, which is being replaced with hot water. Vestforbrænding distributes heat to own consumers and transmits surplus heat in the summer to Hillerød, which is 20 km away in northern Zealand.

SYMBIOSIS BETWEEN WORLD'S LARGEST SOLAR HEATING AND CHP PLANT

Solar heating and CHP share a large heat storage and heat pump

In symbiosis with the new solar thermal heating plant, the CHP plant becomes more efficient as a back-up for fluctuating wind energy, thanks to investments in expanding the heat storage and a heat pump.

Manager Jens Jørgensen, Silkeborg District Heating Company

First stage, efficient CHP
Silkeborg District Heating Company is a municipal owned utility. District heating supplies 21,000 buildings and meets approximately 95% of Silkeborg's 45,000 citizens heating needs. Two decades ago, the utility invested in Denmark's largest decentralized gas-fuelled CHP plant (108 MW electric and 85 MW heat) in order to meet national energy policy objectives. Thanks to co-generation, fuel consumption for heating was reduced compared to indvidual gas boilers.

Second stage, solar and back-up for wind energy
Due to low electricity prices, the CHP plant has been less competitive and production has declined. Moreover, the government and the city council have decided to reduce the consumption of fossil fuels even further. Instead of closing down the plant, it will function as a back up to secure the power supply in periods with no wind and, consequently, higher electricity prices.

The first step taken was to install an electric boiler (30 MW) in 2015. The boiler uses the excess wind power and helps balance supply and demand on the electricity market.

Symbiosis between solar and CHP
The second steps taken were to upgrade the CHP plant and add a large-scale solar heating plant, a larger storage capacity, and a large heat pump. In this symbiosis, the solar heating and the CHP both benefit from the larger storage and the heat pump. The heat pump (absorption) provides a boost to the heat production from the CHP plant (+30 MW heat) by lowering the temperature from the exhaust (from 65 °C to 23 °C) and increases solar production due to low operating temperatures. The solar plant was the world's largest when it became operational in 2017.

Doubling the heat storage tank capacity from 2 x 16,000 m^3 to 4 x 16,000 m^3 ensures production fluctuations from the solar heating are accommodated. The storage also makes it possible to increase the utilization of the CHP plant.

The 25 MW cooling capacity of the absorption heat pump increases production from the solar heating by 15% and increases the total efficiency of the CHP plant via flue gas condensation, from 87% to 102% (based on the lower calorific value).

Heat production solar	70 GWh
Heat pump from solar	10 GWh
Heat production CHP	280 GWh
Heat pump condensation	40 GWh
Heat production boilers	3,5 GWh
Heat production electric boilers	2,5 GWh
Waste heat (from server cooling, supermarket etc.)	9 GWh

The world's largest solar heating plant on the outskirts of Silkeborg optimises the whole DH system. The green area between the two sections has been left untouched in order to make room for the future construction of a highway.

DISTRICT HEATING IN HAFENCITY HAMBURG

Sustainable and profitable district heating in exciting new city development

HafenCity is a whole new city quarter being built in the heart of Hamburg, Germany. It is currently Europe's largest inner-city development project, setting new standards for city development.

Jonna Senger, Communication Advisor, Danfoss Heating Segment

Superlative city development
In Germany, approximately 14% of all households are connected to district heating systems. The city of Hamburg stands out as a front runner in district heating. The city has a vast district heating network supplying 19% of all households. Politicians in charge have declared that the district heating infrastructure will continue to be expanded. Their goal is to connect 50,000 additional households to the district heating network by year 2020.

With HafenCity, a whole new city quarter has been created in the heart of Hamburg. It covers 155 hectares of harbour area with a mix of apartments, offices, recreational facilities, retail trade and culture. City planners have chosen the most sustainable and economically advantageous long-term solution for heat supply: All buildings are supplied with district heating.

The aim has been to develop an energy supply concept that fulfils the strictest economic and environmental requirements. In essence, the concept is based on the combination of the existing, well-proven Hamburg district heating system with decentralised, local heating distribution units. The fuel used is mainly coal, along with household and industrial waste, natural gas, and very small quantities of light fuel oil.

To further reduce carbon dioxide emissions, the existing HafenCity heating plan is equipped as a pilot plant with a steam turbine and a fuel cell. In addition, two new combined heat and power plants are planned in the Überseequartier and at the cruise ship terminal. Buildings, which are mainly for residential use, will be equipped with thermal solar panels for the central domestic hot water supply.

HafenCity setting new standards for sustainable city development
The combination of heat and power ensures that surplus heat from the power plant is used to heat buildings in the HafenCity area instead of being wasted. This way, 90% of the primary energy can be utilised – a concept which could easily be expanded to other residential areas and cities. Compared to a conventional fossil heat supply, approximately EUR 3.7 million in fuel costs and 14,000 tons of CO_2 are saved every year.

The district heating is distributed to the buildings in HafenCity via Danfoss sub-stations and domestic hot water systems, ensuring that every single kilowatt of energy is used as efficiently as possible to the benefit of house owners, tenants and the energy supplier. The buildings are also equipped with additional Danfoss technologies that control the energy consumption of the heating and cooling systems in order to deliver a comfortable indoor climate.

BUNHILL HEAT AND POWER

Utilising Innovation to Deliver Public Benefits

Islington Council is delivering a world-leading urban heat network to provide communities with low-cost, low-carbon, sustainable heat.

Stephen Mirkovic, Energy Projects & Programmes Officer, Islington Council

Islington Council has created a publicly owned heat network which has been developed in two phases. The first phase was opened in 2012. It has 1.4 km of pipework and serves 820 dwellings, two leisure centres and four office blocks. It is powered by a 1.95 MWe CHP engine and has a 115 m^3 thermal store. Phase 1 has produced a saving of 2,000 tonnes CO_2/year.

For the second phase, a major 1km expansion is underway which will connect 450 existing social housing units, 150 new-build homes and a primary school.

The extension includes a 50 m^3 thermal store and features an energy centre built around a 1 MW heat pump, which extracts waste heat from the London Underground. The heat pump's two-stage high temperature system works in tandem with a bi-directional fan that can both draw warm air from the London Underground tunnels, or provide air that has had heat extracted into them.

Co-located with the heat pump are two low NOx 237 kWe CHP gas engines that supply electricity to the heat pump (effectively a 'gas fired' heat pump) and export electricity to the grid.

A new smart control system will control both energy centres, allowing the network to provide demand response to the national grid by;

- Consuming electricity directly (heat pump only operation)
- Operating with no electrical load on the national grid (heat pump and CHPs both operating)
- Exporting electricity to the national grid (CHP only operation).

The extension of the district heat network piping is the largest series three insulated pipe installation project in the UK. Phase 2 will produce a carbon saving of 500 tonnes CO_2/year.

The network provides a customer-focused approach to energy. This includes unrestricted contact hours and a four-hour response time for vulnerable customers.

The fixed heating bills are set at least 33% lower than the government threshold for fuel poverty. Bunhill Heat and Power's performance has exceeded all expectations over the past year, saving the housing department £87,000. This saving is passed on to tenants by reducing the impact of increases in wholesale gas prices, and reducing the service charges of leaseholders connected to the network. There has been an 18% reduction in charging costs to tenants in 2016/17 compared to the previous year, and it has been frozen for 2017/18.

The energy centre of Bunhill 1 which contains a 115 m^3 thermal store and a 1.95 MW CHP Engine.

A rendered image of the Bunhill 2 Energy Centre when it is completed.

Shangri-La used to be covered in a thick blanket of air pollution due to its many coal fired stoves. Today, the citizens can once again enjoy this heavenly view from the rooftop of the world due to the introduction of energy efficient district heating.

BOOSTING ENERGY EFFICIENCY IN SHANGRI-LA

New standard for energy-efficient heat distribution in China

Shifting from inefficient individual stoves to one coherent district heating system protects the environment, spurs economic development and improves the quality of life.

Martin B. Petersen, Regional Marketing & Sales Manager, ABB Northern Europe

District heating reduces air pollution and improves the local environment
Shangri-La is plagued by air pollution from individual stoves using fossil fuels and wood as the primary heat source among its 50,000 residents. Now air pollution is substantially reduced and protection of the local ecological environment is promoted by introducing district heating. Shangri-La is located 3,300 meters above sea level in the northwest of Yunnan Province in China. There is a substantial need for heating in Shangri-La. Daily temperatures are low and can vary quite dramatically in winter, from as low as -27 °C to 1 °C.

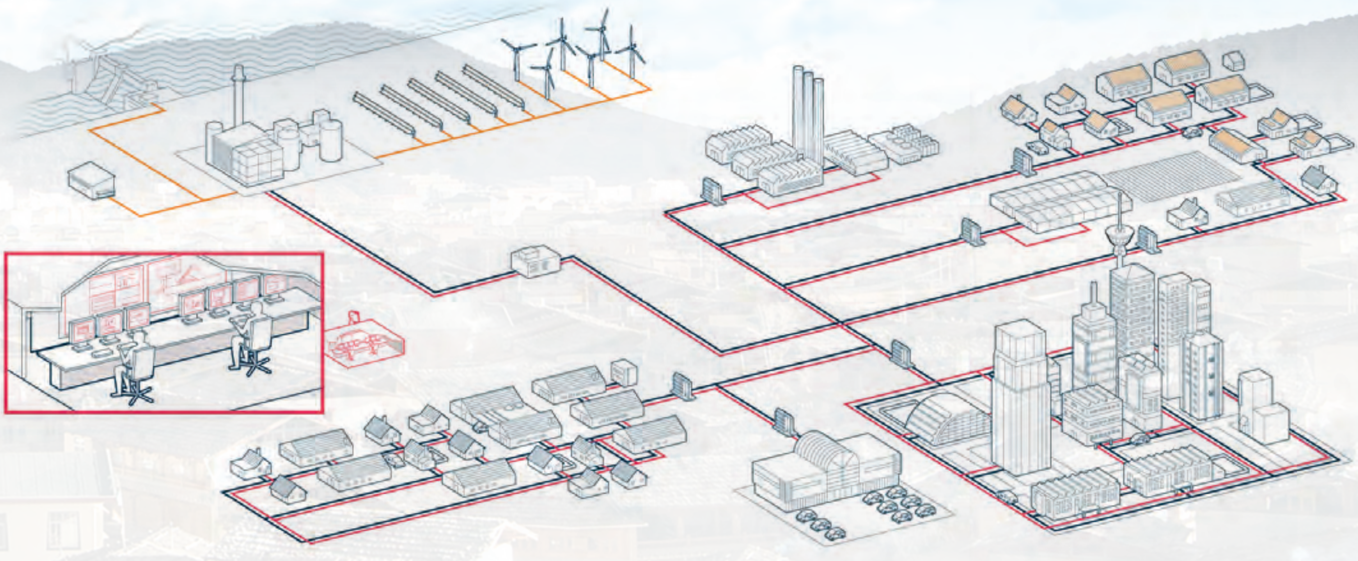
Implementation of the entire district heating system
A new and comprehensive district heating system is set up to supply five districts of Shangri-La. ABB supplies the equipment for the system; from the steam to water heat exchanger in the boiler room to the end user installation. This includes electrical and mechanical equipment needed to supply sufficient heat to the citizens. The automation and electrical solution interconnects and monitors the new heating plants for maximum efficiency, which helps providing a safe and reliable source of heat for about 50,000 residents.

In addition, air-source heat pumps are installed, thereby changing from individual heat-only boilers and stoves to boilers based on CO_2 free electricity from hydropower. The pumps boost the system`s energy efficiency and help improve quality of life substantially by reducing coal-fired emissions.

To ensure that the heating needs of the residents are met, five local automation and control systems communicate with a central control and monitoring system in order to deliver enough heat in the most efficient way.

The shift from the use of stoves to the district heating systems will provide substantial environmental benefits by reducing CO_2 emissions by 105,000 tonnes a year and 460 tonnes of dust a year thus, among others, saving 17,000 tonnes of coal each year.

Over decades, energy-efficient and environmental friendly district heating solutions have been developed and implemented by Danish companies including ABB in the Northern part of Europe, resulting in a substantial decrease in CO_2-emssions.



Layout of a district energy system using flexible energy sources to produce centralized heating to a wide city area.

Amager Resource Center, Copenhagen, Denmark – a waste-to-energy (CHP) plant with efficiency above 90%
Illustration: Amager Resource Center

FUEL FLEXIBILITY ALLOWS FOR SUSTAINABILITY IN DISTRICT HEATING

The key to intelligent use of energy

District energy allows for sustainability and flexibility. A vast variety of energy sources can be used, including fluctuating renewable energy and surplus heat.

Morten Jordt Duedahl, Business Development Manager, DBDH

A variety of energy sources

District heating is extremely flexible when it comes to the choice of heat source – it can accommodate all heat sources, even fluctuating ones such as wind, solar and surplus heat from industrial processes. In large district heating systems with several heat sources, district heating makes it possible to switch from one fuel source to another, dependent on local situations, price signals and green ambitions. Therefore, with a district heating system, one does not have to change all the small individual boilers in each house every time new fuel sources become viable and available. This can be done at a central location.

Integration of electrical and thermal energy systems

An increasing share of electricity is produced from fluctuating sources such as solar and wind. Interconnectors and electrical storage can cushion some of the fluctuations in supply, but are not sufficient and often do not represent the most economic and efficient choice. Integration of the electrical and thermal energy systems can be a part of the solution. If introducing electrical boilers and large industrial heat pumps in the production of heat for district heating networks, the networks will act as large energy storages. Surplus renewable electricity can be used in heat production when the electricity price drops due to overcapacity from wind turbines and photovoltaic solar panels.

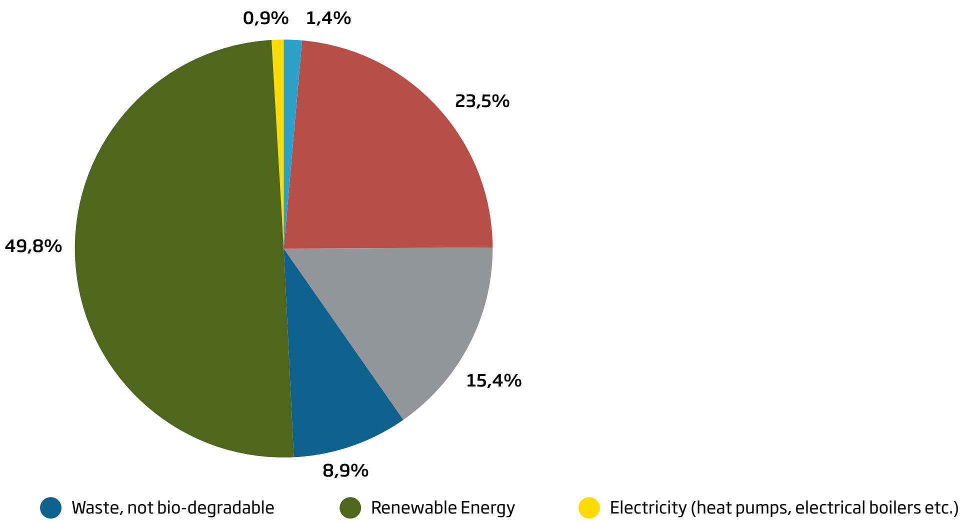
Surplus heat

Surplus heating or cooling from e.g. industry is often wasted, but is a precious resource that can easily be utilised in a district heating or cooling system. Where industrial or commercial buildings are in close proximity to a thermal grid, it can be beneficial to collaborate with the local utility company in utilising the surplus heat. Not only is there a financial benefit, but surplus heat can also replace the use of fossil fuels in heat production.

Energy from waste

Waste is a resource that contains a vast potential. The more value a society can get out of its waste the better. Waste that cannot be reduced, reused or recycled, can be used for energy recovery. Modern waste-to-energy plants handle a waste problem and produce electricity and heat to nearby cities. The best and most modern systems work with an energy efficiency close to 100% through advanced technology. The impact of these plants on the local environment is minimal through advanced use of filters and other technologies to such an extent that they can even be located in the centre of large cities as is seen in Copenhagen, Denmark.

An enormous amount of surplus heat from power production is commonly wasted. This energy resource is increasingly being integrated into district heating systems and used for heating and cooling purposes in buildings.



In Denmark, almost 50% of district heating was produced from renewable sources in 2015. The renewable sources are biomass (wood, waste, straw, bio oil), biogas, solar, geothermal and electricity (heat pumps and electrical boilers).

In Dronninglund, an unused plot of land has been utilised for a solar thermal plant. The solar installation totals 37,537 m² collector area. The underground seasonal storage has a total capacity of 62,000 m³. The installation has an annual output of 18,000 MWh. The solar collectors are installed to follow the lines of the landscape so as not to disturb the environment. Furthermore it makes no noise and releases no odor.

PRIZE WINNING SOLAR DISTRICT HEATING

Solar thermal energy in district heating saves money and benefits the environment

In Dronninglund, Denmark a large-scale solar thermal installation combined with large-scale seasonal thermal energy storage supplies 40% of the annual district heating demand.

Knud Erik Nielsen, Sales Director, Arcon-Sunmark A/S

Solar heating lowers consumers' heating bill

Large-scale solar heating has been installed in numerous district heating power stations since the 1980s. The sun is the cleanest of all energy sources and the most powerful source of sustainable energy, emitting zero CO_2. The cost of the sun is always the same: zero. Even taking the cost of the facilities into account, large-scale solar thermal installations will generate the lowest possible heating costs. Furthermore, it makes no noise, does not release any smell and does not spoil the environment.

With the latest innovative development, allowing also large-scale storage of the solar energy, this technology has been taken to a new level. In Dronninglund, 1,350 district heating customers are happy and proud of their clean, renewable technology because it benefits the environment and has lowered their heating bills by about 20%.

New decisions made a huge impact

It all began when the 40-year-old oil boiler needed replacement. This was a good occasion to rethink the whole setup and decide which installation would serve the district heating plant most effectively in the future. With assistance from advisers, it was concluded that a replacement of a part of the fossil fuels with solar thermal energy would make sense, both in economic and environmental terms.

The installation consists of 2,982 solar collectors equivalent to a 37,573 m^2 solar heating plant. A huge seasonal thermal energy storage has been established. It is a water basin formed by a welded liner with an insulated lid, which is filled with 62,000 m^3 of water. It works like a thermos flask, allowing the energy to be stored from summer to winter. During summer, the plant produces 10 times the demand for heat per day, and the excess heat is stored for later use. That makes it possible to cover 40-50% of the annual heat demand with solar thermal energy, using only solar power from May to October. During winter, the heat supply is supplemented with natural gas and bio oil. The plant has reduced CO_2 emissions by approximately 2 tonnes annually for each household it supplies.

Dronninglund District Heating received EUROSOLAR's European Solar Prize Award 2015. The prize recognises and promotes pioneers and leaders within solar energy, as well as providing fresh impetus to a renewable energy-based and decentralised energy turnaround.

TURNING SURPLUS HEAT INTO WARM HOMES

Optimum co-operation: How to use groundwater as a source for cooling and heat recovery

Partnership between industry and district heating company generates substantial savings for the partners and benefits the environment. Using thermal storage to eliminate energy waste in an existing district heating system brings us closer to zero impact buildings.

Anders Nielsen, Application Manager, Grundfos

In 2013, industrial company Grundfos and Bjerringbro District Heating company inaugurated a joint system to exploit heat extracted from the cooling compressors in the factories for district heating. Operation of compressors requires a lot of energy and is thus expensive. Furthermore, a large amount of surplus heat has to be emitted into the atmosphere by means of cooling towers. Or at least that is how it used to be.

The thermal storage system

The new system is based on three elements: using surplus heat from the cooling machines, indirect storage of heat in an underground aquifer and use of a heat pump to raise the temperature of the stored energy. The surplus heat is used in the local district heating system.

During the summer months, Grundfos doesn't require heat, and therefore all the condenser heat from the cooling compressors are transferred to the storage aquifer, where the heat is put "on stock". In autumn, when the district heating system requires heat, 80-85% of the heat stored during summer is still available.

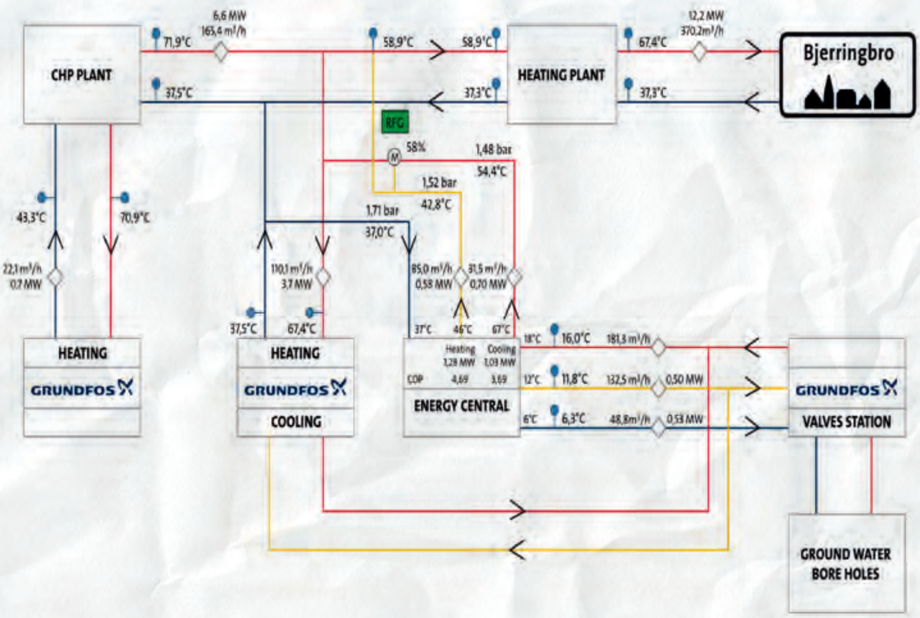
In order to increase the temperature to the level needed in the district heating network, Bjerringbro District Heating increases the temperature by using a heat pump. In winter, the district heating company gets the surplus heat from the storage and directly from the compressors.

Sizeable cost and emission savings

From the start, it was evident that the current system capacity was unable to cover the complete cooling requirement for Grundfos' production. However, after only a few years in operation, it is now clear that the economy in this system is sufficiently attractive to be extended further. This also helps Grundfos achieve its overall goal of reducing carbon emissions by reducing power consumption from conventional chillers.

Grundfos will save up to 90% of the power consumption used up until now in the cooling towers, and the district heating company will be able to cut gas consumption in its combined heat and power plant (CHP). In total, USD 6 million has been invested by the partners, who have split the costs 50/50, and USD 0.5 million will be saved in energy costs annually. The saved costs on water are in addition to this amount.

This corresponds to a payback time of 12-13 years, which is fine for a district heating company, but a little long for an industrial company. However, at the same time, 3,700 tonnes of CO_2 are saved annually, and in light of Grundfos' policies related to energy conservation and sustainability, this result is acceptable for the company.



Groundwater is used for cooling at Grundfos' factory. The water is 6-12 °C when it arrives and 18 °C when returned. The temperature of the water is raised to 46-67 °C with heat pumps and supplied to the district heating network. Coefficient of performance (COP) for heat pumps for heating is 4.60. In summer, when heat demand is low, the surplus heat is stored for later use.

TURNING MOISTURE INTO DISTRICT HEATING

Next generation of waste-to-energy plants increase energy recovery by 20%

In Scandinavia, most waste-to-energy plants are equipped with flue gas condensers. These are often installed in combination with heat pumps that enhance energy recovery even further.

Ole Hedegaard Madsen, Marketing & Technology Director, Babcock & Wilcox Vølund

Does it make sense to burn an apple core?

Due to the technology behind flue gas condensation it is now possible to answer "yes" to the question: Does it make sense to burn an apple core or any organic waste?

It makes sense because heat and electricity can be generated from the energy content of the core, while also recovering the moisture content. In fact, it makes as much sense to process domestic waste as it does to process other types of biomass, for example wood chips. The moisture content is the same, roughly 35%.

In the waste combustion process, the moisture content is evaporated, and a considerable amount of the energy from the fuel is used. Later on, this energy is recovered in the flue gas condensation system of the plant. Water is also recovered from this process.

Flue gas condensation increases energy recovery by 20-25%

The condensation of flue gas in both heat exchangers and absorption heating pumps creates large gains for energy recovery.

The system condenses the flue gas in the washing tower by cooling the gas, extracting the heat, and sending it to the district heating grid. This process consists of two steps. First, the flue gas is led into a heat exchanger, which cools it down to approximately 50 °C. An absorption pump further cools the flue gas to approximately 30 °C. The extra heat extraction provided by the added absorption heating pump results in a 20-25% improvement in energy recovery from the waste. This ensures the investment is quickly paid off. The system can be applied in new as well as existing waste-to-energy plants.

Filbornaverket – thermal efficiency of close to 100%

Prior to 2013, household waste from the citizens of Helsingborg in Sweden was transported to other waste-to-energy plants in Sweden. However, they can now enjoy electricity and heat generated from their own waste.

The main fuel for Filbornaverket is combustible fractions of waste from households, industry and businesses. The plant makes it possible to use the large quantities of combustible waste from the region to produce electricity and district heating for the local grid. Filbornaverket is able to burn approx. 200,000 tonnes of waste per year – with an overall thermal efficiency of close to 100%. This is possible due to the highly advanced flue gas condensation system. Therefore, burning organic waste makes sense, recognizing residual waste as valuable energy source.

A simple way to explain the technology behind flue gas condensation is by looking at what happens with the bathroom mirror after taking a shower. The water drops on the mirror are caused by condensation when the temperature of air containing moisture decreases. Falling air temperatures create condensation because warm air can hold more moisture than cold air. It is the exact same process that takes place in the flue gas condensation system.

Two large day-to-day storage tanks at the Avedøre Plant near Copenhagen. These storage facilities are mainly used to make it possible for the owner of the plant to produce electricity when the prices are right and store the surplus heat for later use when electricity prices are lower. Thereby, the storage system assists in optimising the plant's economy.

THE NECESSITY OF HEAT STORAGE

Saving money and securing supply

A heat storage provides many advantages. It is possible to improve the economy in a district heating system, consumption can be decoupled from production and more sustainable heat sources can be implemented.

Morten Jordt Duedahl, Business Development Manager, DBDH

The value of heat storage

A unique characteristic of district heating is that hot water can be stored – both from day-to-day and from season to season. Heat storage does not differ from the storage of any other product, as it decouples the time of production and the time of consumption. For district heating, this means that you can store heat when it is available from e.g. CHP plants, solar collectors, surplus wind electricity and industrial surplus heat, and use the stored heat when it is needed. In Denmark, both central and decentral district heating combined heat and power (CHP) areas have heat storages.

The day-to-day solutions mainly allow the CHP plants to optimise their cogeneration of electricity and heat according to the demand of electricity, and still be able to supply heat when needed.

With large-scale heat storage, it is possible to utilise much more energy that would otherwise have been wasted. The large scale heat storages allow for storing heat from warmer to cooler seasons. The heat can be collected from many sources, e.g. solar collectors, CHP and industrial processes that do not necessarily have a steady production.

Day-to-day storage

One very important element of all Danish district heating networks is short-term heat storage. The main purpose of the short-term storage is to decouple the power production at CHPs. Thereby, the CHP plants can optimise their cogeneration according to the fluctuating electricity market price without compromising the heating supply. The CHP plant will then only produce electricity (and heat) when the electricity prices are high (normally in the morning and in the afternoon) and simply store the hot district heating water until it is needed during the day. In Denmark, both large and smaller district heating systems utilise short term heat storages. The short-term heat storage introduces flexibility to the energy system, which is crucial for optimising the total system, both economically and environmentally.

Day-to-day storage is also used when external heat production, which cannot be controlled by the district heating company, is introduced into the district heating system. These heat sources can be industrial surplus heat, where production at the plant varies throughout the day or week, e.g. fish industries that only produce when fishing boats unload fish. If there is surplus heat during these periods, it can be stored in smaller day-to-day storages.

Seasonal storage

Today, seasonal storage in Denmark is used mainly for large-scale sun-collectors that produce much more heat during the summer than needed immediately.

Seasonal heat storages are typically a pit, i.e. a very large hole in the ground, with a liner in the bottom, filled with water, and covered by a floating layer of insulation. Other solutions are groundwater storage systems, where surplus heat can be stored at a lower temperature and then utilized later at higher temperatures by using heat pumps. Groundwater systems could well become relevant in cities with no room for large pit storages. For both systems, the heat is stored for weeks or months until the heat demand rises and will be consumed during autumn and winter.

For many Danish district heating systems, seasonal heat storage will become more and more important in the future, as utilising energy that would otherwise have been wasted is an important element in the green transition.

Surplus wind electricity

In Denmark, more than 42% of all electricity comes from wind turbines. Due to the fluctuating production from wind turbines, Denmark often has surplus electricity at very low prices, and there is currently no efficient way of storing electricity directly.

In combination with both short and long term storage, the surplus electricity can be used to make district heating. When prices are right, the district heating companies will use electricity to produce hot water, either directly through a boiler or through heat pumps.

Seasonal storages are very large – the size of several swimming pools. After using months to fill up the storage with water, the next step is to cover the surface with a floating layer of insulation. Subsequent heating of both the water and the walls of the storage also takes months. When it is all warmed up, the storage is ready for use.

DISCOVERING THE OPPORTUNITIES IN LARGE-SCALE STORAGE

Seasonal heat storage - where size matters

The world's largest pit heat storage of 205,000 m³ combined with a 70,000 m² solar heating plant is an efficient and cost-effective way to reduce CO_2 emissions.

Flemming Ulbjerg, Senior consultant, Ramboll Energy

Reducing fossil fuel and consumer prices

The district heating company in Vojens, Denmark, supplies the majority of the town with heat from its new production facilities – the solar panels. Until recently, the main fuel was natural gas. The production was partly combined heat and power and partlyheat only boilers.

Due to lower electricity prices, heat production has become increasingly important for profitability. This change has spurred a search for alternative ways of producing heat. Today, the solar heating plant, including the pit heat storage, delivers 45% of the annual heat demand for the consumers in Vojens.

District heating plants in Denmark are governed by a number of laws and regulations. It is not allowed for plants such as Vojens to switch fuel sources from natural gas, so economic savings from changing to e.g. biomass are not feasible.

However, energy saving measures such as solar heat, heat pumps and surplus heat are allowed. Therefore, after careful consideration, solar heat was chosen as a new heat source to reduce the demand for natural gas. The total investment in solar and heat storage was EUR 16 million. The price for the heat from this facility is 40 €/MWh, which in Denmark is below the average price of heat from a natural gas installation of 60 €/MWh.

Seasonal storage increases flexibility

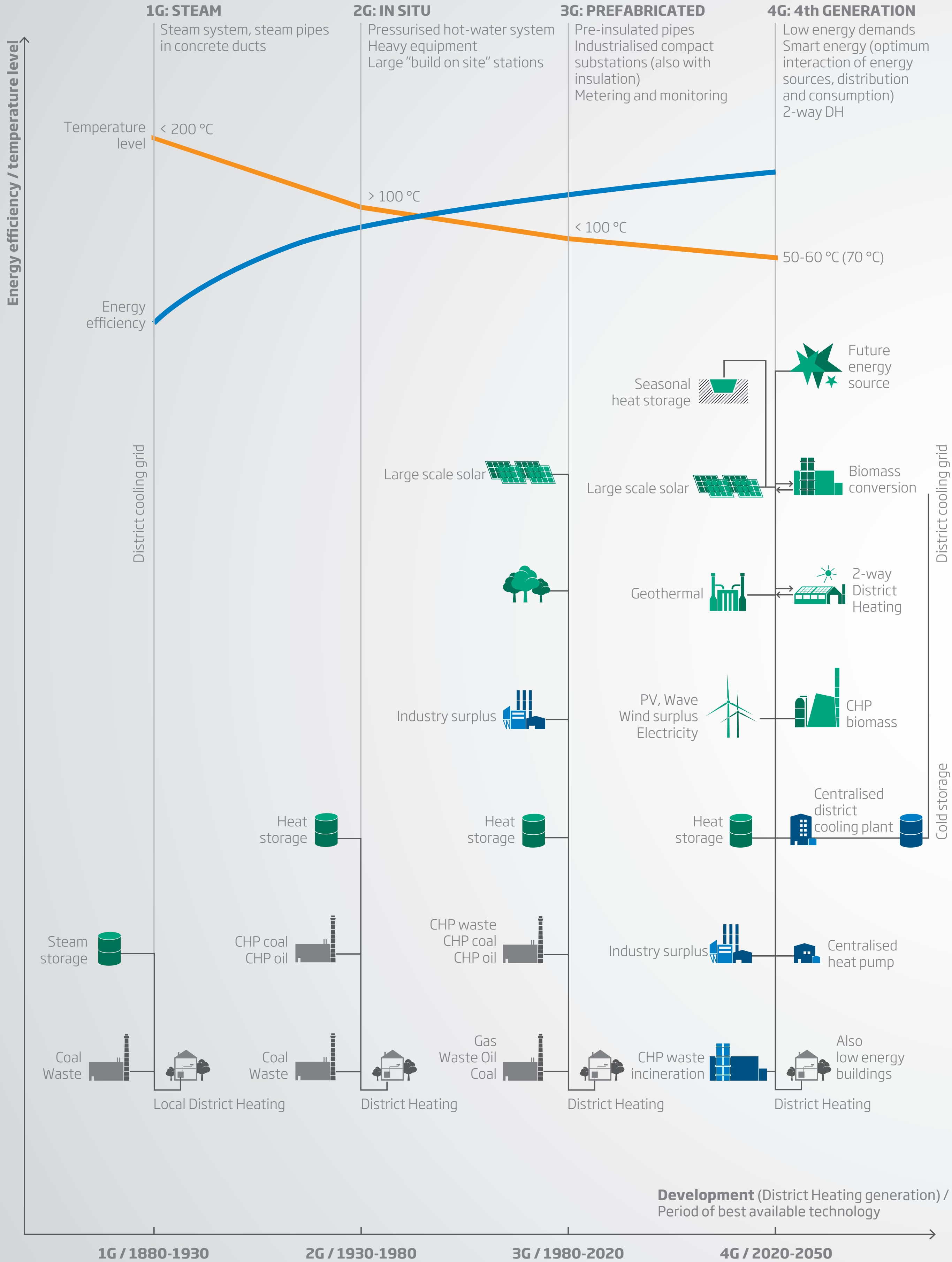
During the summer period (mid-April until end of September), the solar plant supplies 100% of heat demand, mainly for hot domestic water. In addition, during the summer, the solar plant has tremendous excess production capacity and delivers heat to the large pit storage.

From October, the supply comes partly from the solar heating plant and partly from the heat storage. By the end of the year, the storage will normally be completely offloaded. The heat loss from the storage is calculated to only 6 – 8% of the total demand.

The storage makes it possible to store heat from both the CHP unit and the electric boiler, in case it is feasible to operate these units in the summer period. This feature increases the flexibility of the plant and increases income from the sale of electricity.

Due to the high benefit both in terms of flexibility and lower consumer prices, it is expected that many solar and large storage plants, such as in Vojens, will be built in the future – even without subsidies.

The storage in Vojens is heated up by thermal solar energy in summer and provides heat for the town during winter.



Historical development of district heating networks. 4th generation district heating focuses on energy efficiency, flexibility and integration of all available renewable and surplus energy sources. Source: Aalborg University and Danfoss District Energy

THE FUTURE OF DISTRICT ENERGY

Realising a strong global potential

District energy systems are expected to grow in years to come due to increased urbanisation,technological advancements, stronger focus on resource efficiency and consumers' increasing demand for comfort.

Hans Peter Slente, Senior Advisor, Danish Energy Industries Federation

Growing demand ahead

The use of district energy varies widely across countries. This is only in part due to the given circumstances such as the climate, urban density and energy resources available. Differences in regulatory frameworks, building traditions and energy policies also explain the strong variation in the uptake of district heating. In Europe, according to Euroheat & Power, there are approximately 6,000 district heating systems which meet 12% of Europe's heat demand.

The share of district heating in total heat delivery in EU can increase for several reasons. The level of urbanisation in EU is expected to grow to 75% in 2020 and almost 84% in 2050, expanding the market for district heating which operates most efficiently in densely populated areas. Even in Denmark, where currently more than 60% of households get their heat supply through district heating, analyses show that it is economically feasible to increase the market share. The potential lies both in increased urban densification and wider use of district heating in existing supply areas.

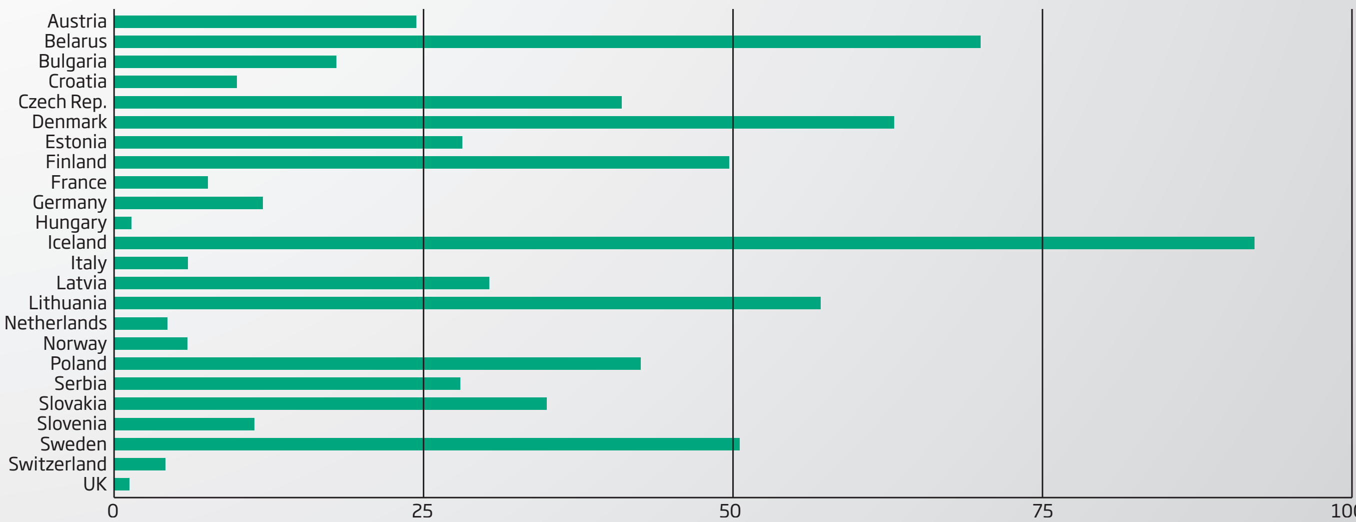
EU's Energy Efficiency Directive obligates Member States to carry out a comprehensive assessment of the potential for the application of high-efficiency cogeneration and efficient district heating and cooling. The European Commission argues that the share of heat produced from high-efficiency combined heat and power (CHP), as well as high-efficiency district heating and cooling, needs to be further promoted by member states. Thus, EU's drive towards decarbonizing the economy is spurring a focus on district heating. Member states are currently drawing up more national heat maps and action plans for district heating.

4th generation district heating

Technological advancements favour the use of district heating. The temperature of the water required in a district heating system is becoming even lower, thereby increasing energy efficiency. This provides economic rationale for more use of surplus heat from industry and for the use of thermal energy storage. Buildings are expected to become still more energy-efficient in the future, thus having a smaller demand for heat per square meter. However, the demand for space and comfort is increasing, which increases the demand for heat. Therefore, efficient low-temperature district heating solutions will play an increasing role in the future. 4th generation district heating builds on the long experience with district heating focusing on integrating all the available energy sources. It integrates still more renewable energy and surplus heat from various sources. Energy storage and dynamic interaction with producers and consumers ensures further flexibility and efficiency in the system. By using water at lower temperatures and still better pipe systems, heat losses are minimised and district heating becomes feasible in still more places. The modern principles of 4th generation district heating are applied today both in new-built district heating systems and when retrofitting and expanding existing ones.

District cooling

The demand for cooling is far higher than for heating on a global scale. Current practices of applying individual cooling solutions to each building, or each room, is expected to be replaced by district cooling solutions. District cooling works according to the same principles as district heating. It provides better energy efficiency, frees up much-needed space in urban areas and provides easier operations of cooling systems for users. The market for district cooling is currently smaller than for district heating and it is mainly used in commercial buildings. It is already growing rapidly and is expected to keep growing in the future – both in temperate countries and even faster in warmer countries where the strongest growth inpopulation, building mass, income levels and thereby cooling demand is expected.



Share of citizens served by district heating in percent

Source: Euroheat & Power "2017 Country by Country"

GLOBAL RENEWABLE ENERGY AND ENERGY SECURITY FOCUS IN THE HEATING SECTOR

Research helps unlock energy savings in buildings and district heating

Climate change, competitiveness, energy security and dependency on imports of, for example, natural gas increase the attention on buildings and heating in Europe and globally.

Dr. Brian Vad Mathiesen, Professor, Aalborg University, Denmark, www.brianvad.eu

The UNFCCC COP21 Paris Agreement, energy security and major health effects arising from the burning of fossil fuels or bioenergy has meant that many countries are turning their focus to district heating and energy efficiency in buildings. Traditionally, renewable energy in the electricity sector or energy efficiency at the building level has attracted most attention. However, heating and cooling in buildings actually account for 40-50% of the final energy consumption in Europe and globally. Thus, cities and countries around the world are now investigating how to improve building standards and utilize district heating to address these challenges. Cities are expected to house two thirds of the global population in 2050, which will increase population density in urban areas. The solutions of tomorrow require joint local and national efforts at policy level.

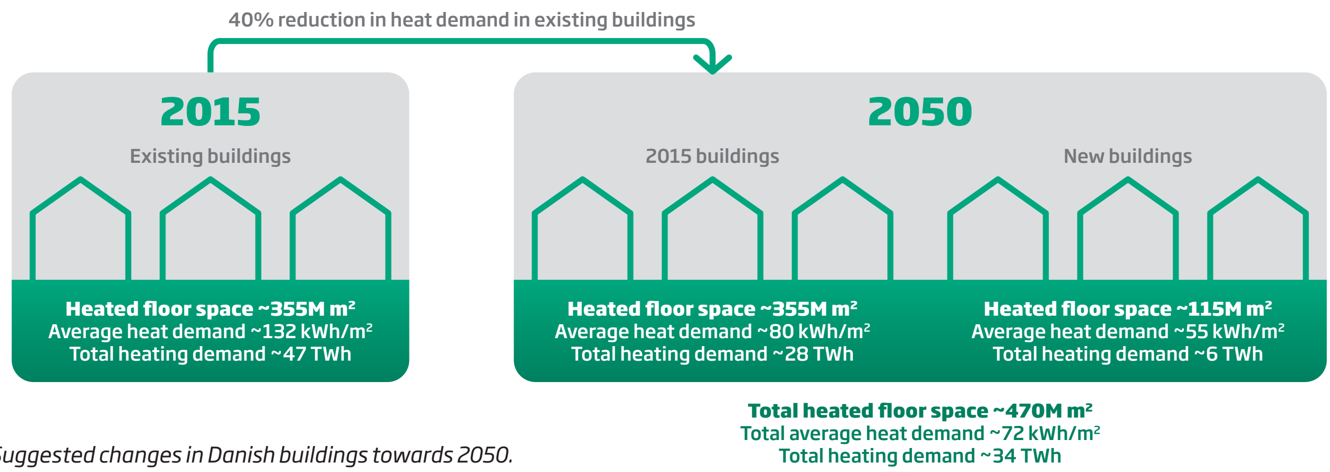
Understanding the roles of the individual technologies is crucial: What is the role of savings, flexible demand or storage at the building level? To what extent do we need on site renewable energy supply? Do we need district heating in the future? What is the role of bioenergy and heat pumps? How can we use low-value heat? What policies and planning methods can facilitate change?

These questions and more are at the heart of research being conducted at the Strategic Research Centre for 4^{th} Generation District Heating Technologies and Systems (4DH). The research has served as inspiration for e.g. European Commission initiatives on heating and cooling as well as globally in the UNEP-led Global District Energy in Cities Initiative (DES Initiative).

The research reveals that savings in buildings and district heating are essential in cost-effective renewable energy systems. A drastic change of direction in the European and global heating sector is needed in the near future if a cost-effective transition is to be achieved. Currently the heat wasted in Europe can supply the heat demand of almost all buildings. Energy sectors need to be integrated (Smart Energy System) to utilize these potentials. Heat Roadmap Europe is a series of studies initiated by 4DH in collaboration with key industrial and university partners. They combine energy system analyses with geographical information systems (GIS). They provide strategies and methods that can be replicated globally together with a pan European Thermal Atlas (Peta4). The studies suggest that 30-50% heat savings and 50% district heating are feasible by 2050 in Europe. In rural areas, high levels of refurbishment are also needed in combination with individual heating technologies such as heat pumps.

References:

- Connolly, David; Mathiesen, Brian Vad; Østergaard, Poul Alberg; Møller, Bernd; Nielsen, Steffen; Lund, Henrik; Persson, Urban; Werner, Sven; Grözinger, Jan; Boermans, Thomas; Bosquet, Michelle; Trier, Daniel (2013). Heat Roadmap Europe 2: Second Pre-Study for the EU27. Department of Development and Planning, Aalborg University.
- Mathiesen, Brian Vad; Drysdale, David William; Lund, Henrik; Paardekooper, Susana; Ridjan, Iva; Connolly, David; Thellufsen, Jakob Zinck; Jensen, Jens Stissing (2016). Future Green Buildings: A Key to Cost-Effective Sustainable Energy Systems. Department of Development and Planning, Aalborg University.
- Publications available at
  www.heatroadmap.eu
  www.4dh.eu
  www.smartenergysystems.eu



Suggested changes in Danish buildings towards 2050.

COPENHAGEN MARKETS

The nordics' largest refrigerator offers reduced district energy bills

Flowers, fruit and vegetables are kept fresh in the Nordic countries' largest and most advanced refrigerator in Høje Taastrup, while simultaneously providing green, inexpensive district heating to its neighbours.

Uffe Schleiss, Technical director, District Heating Høje Taastrup

At the old market square, each business owner had their own cooling systems, with varying levels of efficiency. In the new 67,000 m2 Copenhagen Markets, which opened in Høje Taastrup in April 2016, a 15,000 m2 cooling area has been established, which is supplied by a large, joint district cooling plant. This system is the most comprehensive of its kind in the Nordic countries and has a number of positive impacts on energy consumption, the climate and the working environment.

Although the name of the company providing energy to Copenhagen Markets is Høje Taastrup District Heating, it actually provides district cooling as well. The cooling is delivered from a newly installed electricity and ammonia powered cooling compressor. A heat pump utilises the energy from the cooling process to create green, inexpensive district energy.

It is necessary to deliver water at a temperature of between 2 and 5 °C to the customers at Copenhagen Markets. This requires that the water is chilled to a temperature of minus 8 °C. District Cooling is normally delivered with a flow of 6 °C and a return flow of 16 °C. To meet Copenhagen Markets' requirements, an extra chiller has been installed.

Production of the cooling means that considerable amounts of heat are also generated in the process. An electricity-powered heat pump upgrades the heat and sends water to the nearby district heating system with a temperature of 73 °C, which is a satisfactory flow temperature. The system is a co-production of chill and heat, where the one product cannot be produced without the other.

There is a cooling capacity of 2 MW. Heat corresponding to 2.3 MW is produced at a water temperature at 73 °C. This constitutes approximately 2.5% of the overall heating consumption to Høje Taastrup District Heating's 6,700 customers and is yet another example that systems thinking and utilisation of resources are of the utmost priority.

The cooling system at Copenhagen Markets is designed so that the cooling can be used at different levels according to need. The markets are divided into 80 tenancies under the one roof, whereof 55 use cooling. Each tenant has the option of using cooling and deciding exactly where in their area the cooling should be delivered is needed. Consumption is calculated individually via an innovative meter solution.

The capacity for cooling can be increased as the need develops over time.

Facts about district cooling

- Up to 70% reduction of CO_2 emissions and 40% reduction in total costs when using district cooling compared to local compressor cooling.
- Lower operating costs, lower costs of maintenance combined with lower energy costs and lower cost of capital.
- High reliability of supply.
- District cooling creates a comfortable indoor environment, without noise and vibrations.
- District cooling takes up less space than traditional cooling methods. A cooling system with an estimated usage of 1 MW will free up 115 m^2 on the roof, since all cooling towers are removed. In addition, the basement will only need a heat exchanger which is about 10 m^2 compared to the traditional cooling system taking up 90 m^2 in the basement.

Conventional cooling and air conditioning usually takes up roof and wall space for individual and larger cooling units. At the newly refurbished House of Industry in Copenhagen, green roof terraces now provide recreational roof space for employees instead.

DISTRICT COOLING REDUCES CO_2 EMISSIONS IN CENTRAL COPENHAGEN

A green and cost-efficient alternative to conventional cooling

In the capital of Denmark, district cooling results in up to 70% reduction in CO_2 emissions and up to 40% reduction in total costs compared to conventional cooling.

Henrik Lorentsen Bøgeskov, Head of District Cooling, HOFOR

Increasing demand for cooling
There is an increasing demand for air conditioning and cooling in Copenhagen, as in many other cities around the world. The Copenhagen utility company, HOFOR, has built a district cooling system, which consists of a distribution net and two cooling plants. The district cooling system uses seawater to chill the water supplied to the customers. The system supplies commercial buildings such as banks, department stores and offices as well as cooling for servers and other processes all year round.

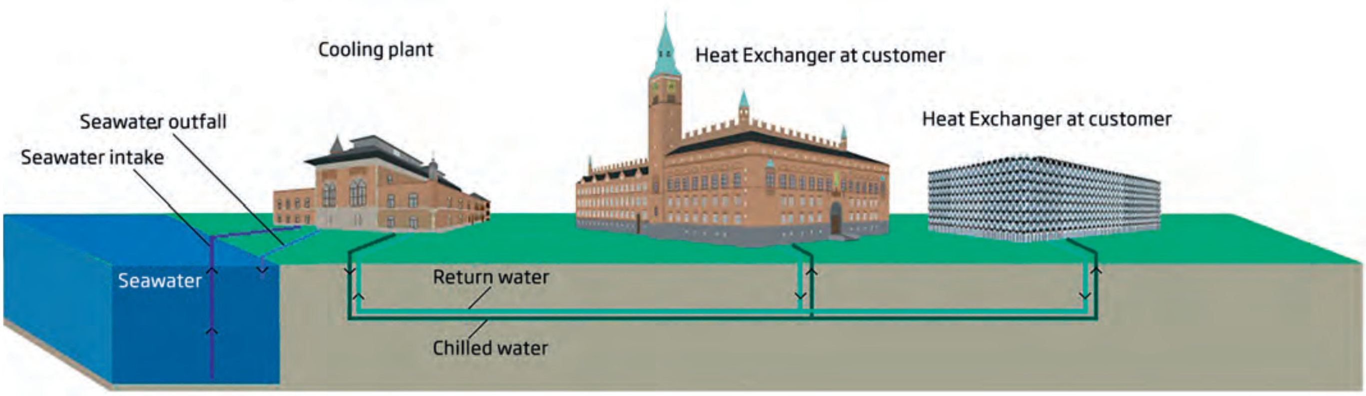
Therefore, HOFOR can supply the increased demand for cooling in Copenhagen and help reduce CO_2 emissions by up to 30,000 tonnes each year. The cooling system now supplies the centre of Copenhagen with cold water, and the pipe system is expanded in order to supply more customers in the future.

HOFOR's district cooling activities are the biggest of their kind in Denmark. The first cooling plant was opened in 2010, the second plant in 2013, and the system is still under expansion. From 2015 until 2020, it is the ambition to expand district cooling further by doubling the amount of customers and thereby contribute further to Copenhagen's target to become CO_2-neutral in 2025.

Cooling is produced centrally in three different ways:
In winter months, the chilled water supplied to customers is produced by using seawater. The seawater is pumped into the cooling plant through a pipe from the harbour. The seawater temperature is a maximum of 6 °C, when it is used directly to cool down the water for the customers. This is known as zero-carbon cooling. However, a small amount of electricity is used when pumping seawater into the cooling plant. In summer months, when the seawater is not sufficiently cold, energy must be used to cool the water. Seawater is used to increase the efficiency of the other installations. Using seawater to remove the heat from the machines reduces electricity consumption by up to 70% compared to a local compressor.

Waste heat from the power plants is also used for cooling during the summer months. This method is known as absorption cooling and is only used when there is waste heat from the power plants available. The absorber minimises the CO_2-emission.

Illustration of district cooling system in the city of Copenhagen



In Albertslund, a 4th generation district heating system provides comfort and clean energy to customers with maximum efficiency and minimum heat loss.

MUNICIPALITY IN TRANSITION TO LOW TEMPERATURE DISTRICT HEATING

From 2nd to 4th generation district heating in an existing supply area

Use of low temperature district heating is realistic and makes it possible to both save energy and reduce dependency on fossil fuels.

Theodor Møller Moos, Chief Project Manager, COWI

Albertslund District Heating Company
Albertslund District Heating Company was established in 1964, and the district heating supply area increased in line with the development of the city. Initially, the district heating network was established for operation with a supply temperature of 110 °C. Over the years, the temperature has been lowered, and today the system operates with a flow temperature of approx. 90 °C.

4th generation
As part of Albertslund municipality's vision for the heat and electricity supply to be CO_2-neutral by 2020, a new low-temperature 4th generation district heating system, where the supply temperature is lowered from 90 to 55 °C, is being established. This allows for more efficient use of the existing heat generation plant and lowers heat losses from pipework, thus helping Albertslund achieve its goal of a CO_2-neutral heat supply.

Based on the success of the first phase, Albertslund have recently taken the bold decision to convert the entire town, approximately 30,000 inhabitants, to low temperature district heating before 2026.

Challenges
While it is relatively easy to supply new apartments with low-temperature district heating, older apartments are generally poorly insulated and require a high flow temperature to give an adequate comfort level. Albertslund Municipality is therefore instituting a renovation program which switches apartments to low-temperature district heating and thereby increases their energy efficiency.

The distribution system
Apartments are connected in phases in line with the renovation plan and the termination of the high temperature distribution system. The low temperature circuit is supplied via the return from the 'old' district heating system, which is mixed to 55 °C through a shunt valve.

The apartment system
New low temperature instantaneous water heaters are installed in the apartments, which supply domestic hot water at 45 °C on the consumer side. Legionella is controlled by design according to the German rule DVGW W55, which requires that only a very small amount of water is held in the heat exchanger and hot water system at any time. After refurbishment, the apartments are supplied with space heating via underfloor heating and radiators. The overall supply temperature from the district heating system is 55 °C and the return temperature from the user will be around 30 °C.

State of Green
Denmark is transitioning to an economy based on green growth and will become entirely independent of fossil fuels by 2050. As the official green brand for Denmark, State of Green gathers all leading players in the fields of energy, environment, urban solutions, water, circular economy and climate adaptation and fosters relations with international stakeholders interested in learning from the Danish experience.

Stateofgreen.com is your online entry point for all relevant information on green solutions in Denmark and around the world. Here you can explore more than 1400 solutions and connect with approximately 600 profiles. Many of the featured profiles welcome visitors and offer investment opportunities.

A cornerstone of the Danish vision is to inspire others and demonstrate how a green society is both possible and profitable - and we invite people to come see for themselves. Places to visit include everything from offshore wind farms and modern energy saving buildings to waste-to-energy plants that provide Denmark with electricity and district heating. Read more about State of Green Tours at www.stateofgreen.com/en/tours

State of Green is a public-private partnership founded by the Danish Government, the Confederation of Danish Industry, the Danish Energy Association, the Danish Agriculture & Food Council and the Danish Wind Industry Association. H.R.H. Crown Prince Frederik of Denmark is patron of State of Green.

The Danish Energy Agency
The Danish Energy Agency is responsible for handling all national and international agreements and tasks linked to the production, supply and consumption of energy in Denmark. The Agency also deals with efforts to reduce emissions of greenhouse gases, and oversees the legal and political frameworks for reliable, affordable and clean supply of energy in Denmark. Furthermore, the Agency has the responsibility to support the economic efficiency of the utilities sector, which, in addition to energy, includes water, waste and telecommunications.

The Danish Energy Agency's Global Cooperation collaborates with partner countries to combine sustainable future energy supplies with economic growth. The initiative is based on four decades of Danish experience with renewable energy and energy efficiency, transforming the energy sectors to deploy increasingly more low-carbon technologies.

The Agency is part of the Danish Ministry of Energy, Utilities and Climate.

Read more about the collaborations here:
www.ens.dk/en/policy/Global-cooperation

DBDH

Danish Energy Industries Federation

The Danish Board of District Heating (DBDH)
DBDH is a member organisation with the mission to promote district energy for a sustainable city transformation. Our purpose is to identify, inform and facilitate partnerships between our members and partners across more than 50 countries.

We invite you to learn from our members by participating in our activities and by inviting us to participate in your events. If you have an interest in learning more about the world's most advanced district heating and cooling system, we also invite you to visit Denmark, where we can help you with a relevant program for your visit.

DBDH represents the leading actors within the Danish district heating sector. This includes:

- Heat and combined heat and power production companies and waste incineration companies
- Heat transmission and distribution companies
- Private consulting companies, R&D institutions and training institutes
- Manufacturing companies of plants, systems, components and products for the sector

DBDH implements conferences, seminars and exhibitions with the purpose of making consolidated experience available worldwide. Furthermore, DBDH develops and maintains cooperative agreements with district heating organisations abroad for the purpose of exchanging information related to all aspects of district heating. You can read more about DBDH at www.dbdh.dk

The Danish Energy Industries Federation (DI Energy)
The Danish Energy Industries Federation (DI Energy) organizes the Danish energy industry across all energy technologies and the whole value chain from exploration and production of energy to development and manufacturing of modern energy technologies and solutions and engineering of whole solutions and systems.

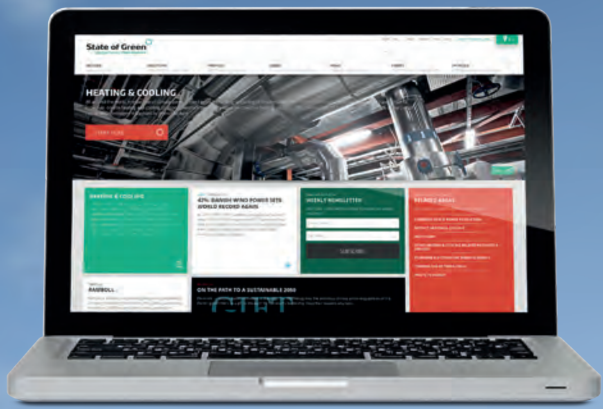
Denmark is home to a strong cluster of innovation, manufacturing and export of sustainable, durable and cost-efficient energy solutions. DI Energy works to further develop Denmark as a base for a strong energy industry with significant international outreach and impact.

DI Energy supports an energy policy at Danish, European and Global level that enables the transition towards higher energy efficiency and the use of more renewable energy.

DI Energy is a strong network for business development with foreign partners and it enables dialogue and promotion opportunities for several sub-sector groupings such as energy efficiency, bioenergy, wind power, district energy, smart grid, oil and gas.

DI Energy engages with international partners to enable exchange of ideas, people, goods, services and investment in the field of energy. Through a strong co-operation with companies and authorities at home and abroad, we contribute to meeting the ever-increasing global demand for energy.

DI Energy is a part of the Confederation of Danish Industry (DI) – the voice of corporate Denmark.



Learn more about Danish solutions
in heating and cooling, find more cases from around
the world and connect with Danish expertise at:

www.stateofgreen.com/heating-and-cooling

State of Green is a non-profit, public-private partnership founded by:

Confederation of Danish Industry

DANISH ENERGY ASSOCIATION

Danish Agriculture & Food Council

DANISH WIND INDUSTRY ASSOCIATION

MINISTRY OF INDUSTRY, BUSINESS AND FINANCIAL AFFAIRS

Danish Ministry of Energy, Utilities and Climate

Ministry of Environment and Food of Denmark

MINISTRY OF FOREIGN AFFAIRS OF DENMARK