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DHC Technologies, Today and Tomorrow

This report was elaborated in the framework of the Ecoheat4cities project supported by the Intelligent Energy Europe Programme.

Supported by INTELLIGENT ENERGY EUROPE

Project Summary

Supported by the Intelligent Energy Europe Programme (IEE), the Ecoheat4cities project promotes awareness and knowledge-based acceptance of District Heating and Cooling (DHC) systems through the establishment of a voluntary green heating and cooling label. The label will provide useful information on key energy related parameters of DHC systems to interested stakeholders throughout Europe and participating countries, including local policy makers, other DHC companies, citizens and related industries.

The three labeling criteria: **Renewability, Resource efficiency (Primary Energy Factor) and CO2 efficiency/emissions** reflect the aims of the EU 2020-targets and will thus enable stakeholders from all over Europe to see and show how District Heating and District Cooling can contribute to reaching the EU's energy targets and assess DHC as a competitive and viable option in Europe's heating and cooling market.

Project outcomes include:

- a label design tool, labeling governance and guidelines, including all details concerning the calculation methods as well as related technical and scientific background research on DH performance and best available and not available technologies;
- a tool enabling cities and municipal planners to compare different heating and cooling options;
- a guide for city planners and DHC companies to better understand the labeling process, also offering insight into how the label can provide added value and a green image.

The Ecoheat4cities label provides a way to measure sustainability and performance of DHC systems based on available and verified, local knowledge and resources.

If your organization would like to know more about the Ecoheat4cities green label, governance structure of the labeling scheme, or participate in any of its activities, please contact Euroheat & Power or its national partners. DHC companies and cities are actively invited to provide additional guidance and feedback about the on-going work by contacting us.

All information is available on the Ecoheat4cities website at www.ecoheat4cities.eu

Project Partners

Preface

This report is part of the Ecoheat4cities project, Assessment of the improvement potential of DHC based on an analysis of best available technology (BAT) and best not available technology (BNAT).

The assessment consists of two parts:
Part I. Technology catalogue and Part II. System catalogue.

The technology catalogue is divided into 4 sections (Section 2-5 of this report) that each describes important issues of the district heating system: ‘Buildings and heat consumption’, ‘Building substations and installations’, ‘Distribution pipes and pumps’ & ‘Fuels and production’. In each field of technology, the products and solutions are divided into ‘best available’ and ‘best not yet available technology’.

Based on the technology catalogue, benchmark of performance levels are considered for two types of district heating systems for year 2020:

- New small districts 2020
- Large existing network 2020

The benchmarks of performance levels are calculated based on simple models of different networks and production facilities and are included in the system catalogue (section 6-9 of this report). The system catalogue is divided into the sections: ‘System approach’, ‘Model of distribution network’, ‘Model of production facilities’ and ‘Calculation of labelling criteria for DH Systems’.

The input to this report is based on references available until June 2011 including research, European legislation and policies. However, the report is using the draft report of the guideline for certification of district heating systems of 26 April 2012 developed in WP 3, for the calculation of labelling criteria.

The reports will provide input into WP 4 (Guidance to companies) and WP 5 (Guidance to cities).

The following entities have been contributing to the report:

- Danish Technological Institut (preparation and finalisation)

- Ecoheat4cities Steering committee (review)

21 May 2012, Danish Technological Institute

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0 EXECUTIVE SUMMARY

The objective of this report is to give an overview of district heating technology in order to set benchmarks of performance level of district heating systems on short and long term; where are we going to be tomorrow? The technology presented is state-of the art (and beyond) of district heating systems. For a more general view of district heating systems performance in EU is referred to the base line study which is also part of WP 2. The benchmark of performance levels are based on the 3 criteria: primary energy factor, CO_2-emission and renewability and is to be used as input for the work packages 3, 4 and 5 of the Ecoheat4cities project. The report is divided into two parts: Part I: Technology Catalogue and Part II: System Catalogue.

Part I: Technology Catalogue: Firstly, the different technologies that forms a district heating system is divided into 4: 'Buildings and heat consumption', 'Building substations and installations', 'Distribution pipes and pumps' & 'Fuels and production'; And evaluated in terms of defining best available technology (BAT) and best not yet available technology (BNAT).

In case of buildings, 'nearly zero energy buildings' will be implemented in national legislation as part of EPBD in 2020. Implementation is a national issue. Based on different inputs the net heat demand for space heating and domestic hot water for these buildings is estimated to about 40 kWh/m^2 per year (2020), whereas the buildings of today are constructed for a heat demand of about 75 kWh/m^2 per year or higher (2010). Differences in climate and national performance standards exist. The heat demand is very important in terms of defining efficient and feasible district heating systems. In this regard there is a lower limit of area heat consumption that has been suggested to be about 10 kWh/ m^2 per year per area of land. Again national differences exist.

From a district heating system approach the distribution network heat losses are reduced the lower the supply temperature is. Furthermore low supply temperatures also open up for supplying district heating based on low exergy sources like industrial surplus heat, solar heat and deep geothermal heat without any temperature boost. In general hydronic systems are used for space heating in district heating connected residential buildings. In new buildings these systems can be designed for very low flow temperatures – e.g. floor heating systems are typical designed with a flow temperature of 35°C or even lower. However, the domestic hot water at the tapping point typically require a temperature of 40-45°C and due to the risk of Legionella typically a temperature 55-60°C is required in central domestic water heaters and domestic hot water circulation pipes (some differences in legislation exist in EU). Different district heating temperature approaches was found and categorised. Among these Low Temperature Systems (LTS) with supply/return temperatures of 80/40°C, Very Low Temperature Systems (VLTS) with supply/return temperatures of 60/30°C and Ultra Low Temperature systems with supply/return temperatures of 45/30°C. The latter supplies district heating with a temperature of 45°C to the houses to serve the space heating demand whereas the domestic hot water is prepared with a heat pump.

Besides the temperature levels, also the pipe design and materials are important for the distribution losses; Insulation thickness, pipe placement and heat conductivity. Modern insulation made of cyclo pentane foam results in a heat conductivity as low as ~23 mW/(m·K) which is considered best available technology. At experimental level the heat conductivity is today very close to 20 mW/(m·K) with foams. Taking into account the properties of aero gels its not unrealistic that heat conductivities of 17 mW/(m·K) can be reached in 2020 and beyond. So this value will be considered as best not yet available technology.

On the production side also a large number of different technologies and fuels are presented. Many technologies will co-exist and the development will primarily be further improvement of existing technology to reach very high electric efficiency (50-60%). However, fuel cells is considered best not yet available technology in case of small natural gas fired generator sets and Carbon Capture and Storage (CSS) might be a solution in combination with larger power plants for coal, but also for other fossil fuels. Further, biomass and thermal solar is considered as well as heat pumps and deep geothermal heat.

Part II: System Catalogue. Based on the technologies presented in the Technology Catalogue, benchmark of performance levels are considered for two types of district heating systems for year 2020:

- New small districts 2020
- Large existing network 2020

Simple models of distribution networks and production facilities are used to calculate performance levels of different systems.

In case of new small districts, the heat demand of 'nearly zero energy buildings' is used with different size of plot ratio to define a network layout. Different options of pipe technology and design temperatures are investigated to find heat loss from the defined district and network layout. On top of that, the performance levels of different fuels and production technologies are calculated. The reference is a gas engine CHP plant that is believed to be used in Europe for new districts also in 2020. This technology will have net electric efficiency in the range of 45% and is combined with a backup/peak load boiler. Other technologies calculated are combinations with thermal solar panels, biomass boiler, biogas engine CHP plant with gasifier and natural gas-fired SOFC fuel cells.

For the larger existing network, an area with 6000 customers with an average district heating consumption of 150 MWh is anticipated. The distribution network heat losses are set to 10%. It is assumed that energy savings in buildings will lead to reduction of the district heating consumption at the end user of 10% in 2020 to 135 MWh. This will result in extra capacity of the district heating system that can be used for expansion. In this case study, the simple approach is taken that the extra capacity released is used to expand into new developing areas very close to the existing network e.g. at left industrial sites, the water front and the like. Expanding into new existing areas instead has not been considered because of very limited impact it on the benchmark of performance levels. The building of 'nearly zero energy buildings" in new districts will result in connection of about 30% more building area. This hypothetical existing network is supplied from a pulverized coal CHP plant with advanced design data (supercritical) and extraction turbine. The plant is considered put into operation in 2005 and has a net electric efficiency in condensing mode of 44% (best available technology). Because of the age of the plant (15 years in 2020 with expected lifetime of additional 25 years) it might be reasonable to make improvements of the plant in 2020. In addition light fuel oil peak load/backup boilers are supplying heat to the network at an efficiency of 95%. With this network and production facilities as reference, different options for fuels and production facilities are investigated e.g. Fuel exchange of the peak load/backup boilers from fossil-oil to bio-oil, fuel exchange of the CHP plant of 50% coal with biomass pellets, application of Carbon Cature and Storage technology (CCS) and finally application of an even more efficient pulverized coal CHP plant.

In addition, a few parameters were changed in order to investigate sensitivity. If more ambitious energy savings are considered, for instance 30%, the reduced district heating consumption will results in about 4% higher network relative heat losses. Also the influence of a higher network heat loss of 30% was looked at.

The draft report of the guideline for certification of district heating systems of 26 April 2012 developed in WP 3 is used for the calculation of performance based on the 3 criteria: primary energy factor, CO_2-emission and renewability. Labelling approach is on EU-level (Tier 1) with the related 7 ranking-classes proposed. The label design will consist of a flower with 7 petals, where class 1/7 petals are given for the best performing systems. Accordingly, a system in class 3 will be labelled with 5 petals and so on.

Primary energy factor: In case of small new districts, all the proposed cases (case 1-8) will get class 1/7 petals. For the large existing network with pulverized coal CHP plant with advanced design data the benchmark will be class 2/6 petals. However, with choice of the best future technology class 1/7 petals are within reach. Also the application of biomass only will result in class 1/7 petals whereas CSS-technology will actually reduce the performance level due to lost electricity production (class 3/7 petals).

CO_2-emission: For the small districts with natural gas engines CHP, class 2/6 petals are obtainable and in combination with solar thermal panels class 1/7 petals can be reached. Not surprisingly, this is also the case for biomass boilers and biogas gas engine CHP. The SOFC Fuel Cell is having electric efficiency higher than used in the reference allocation method, resulting in negative CO_2-emission. However, as the fuel cells are best not yet available technology, the reference values is expected adjusted to also cope with these appliances when relevant. The large existing network with pulverized coal CHP plant will get class 2/6 petals even if 50% fossil fuel is replaced with biomass. As seen for the primary energy factor, applying future best available technology of coal fired CHP plant, class 1/7 petals can be reached. CSS technology can also help reaching class 1/7 petals.

Renewability: Biomass boilers will reach top ranking, class 1/7 petals. However, also using 10% bio-oil in peak load/backup boilers or 10% of thermal solar heat will result in reasonable ranking: class 5/3 petals. By supplying eat from 50%/50% coal biomass mix CHP, class 2/6 petals are reached**.**

These results will be used as input for other parts of the Ecoheat4cities-project.

1 INTRODUCTION

1.1 Background

District heating is a system of different technologies that are producing, distributing and delivering heat and domestic hot water to the end user. The technologies include, as sketched on figure 1:

- Buildings and their heat and domestic hot water consumption
- Building substations and heating installations
- Distribution pipes and pumps
- Production plants and fuels

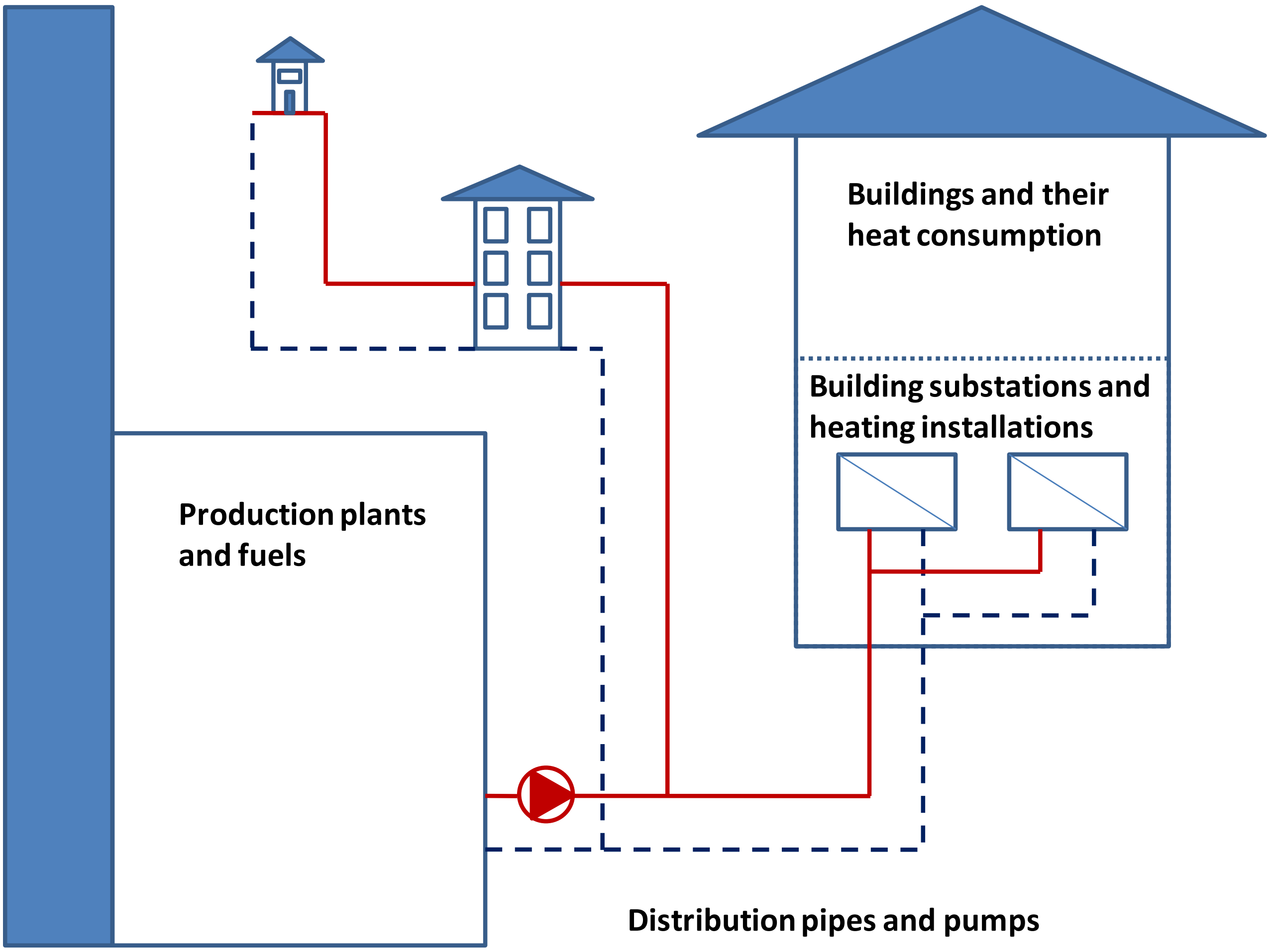


Figure 1 Sketch of the technologies involved in a district heating system

In each of these technologies research and development is taking place in order to improve energy efficient use of primary energy, increased use of renewables and reduction of CO_2-emissions of district heating systems.

The technology catalogue gives a brief overview of technologies already on the market as well as technologies that are still at an experimental level and thus, has not yet been introduced to the market. Another catalogue, the system catalogue, gives some examples of systems using the technologies of the technology catalogue.

1.2 BAT and BNAT

The terms 'BAT' and 'BNAT' based on the definitions used in the Ecodesign MEEup Methodology report [1] will be used to categories the technologies:

BAT (**B**est **A**vailable **T**echnology): Best performing products and technology available on the market

BNAT (**B**est **N**ot yet **A**vailable **T**echnology): Experimental options that is not yet available on the market [1]

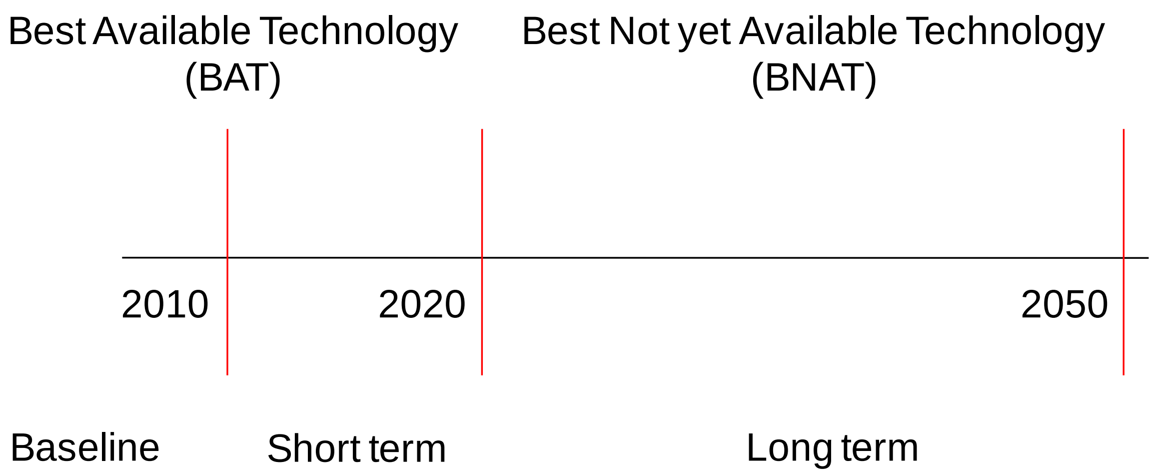
Further the technology in this catalogue is linked to some time periods on short and long term:

BAT: Available on the market in 2010 (and until 2020)

BNAT: Available on the market in 2020 and beyond

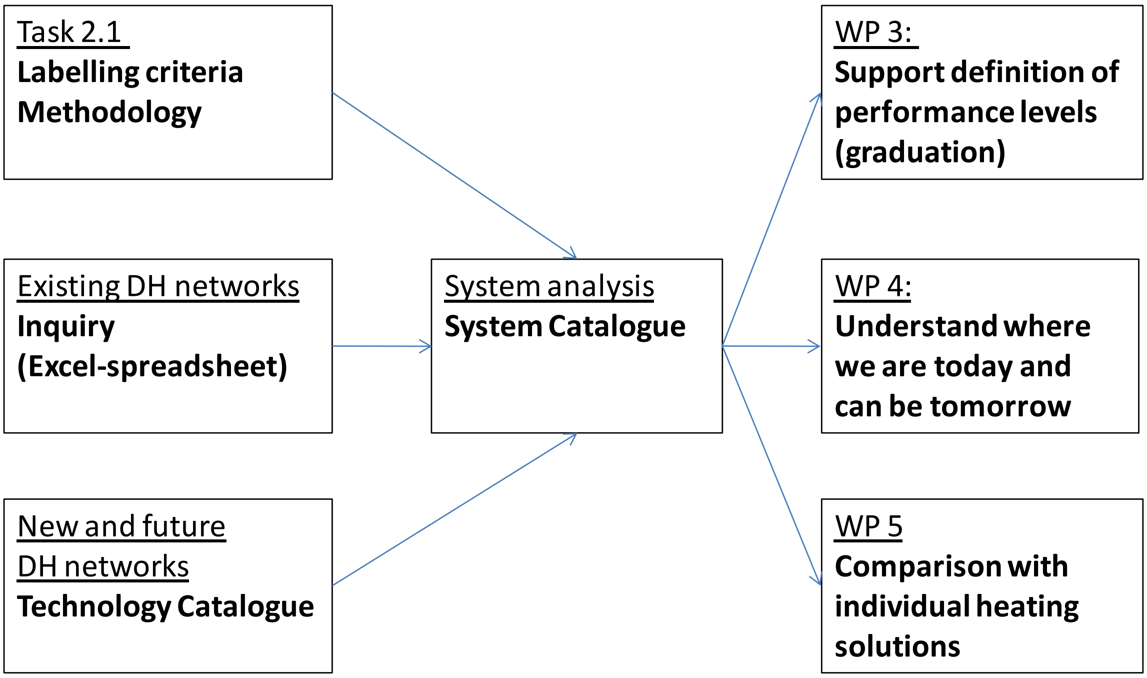
The time line is of the technologies is seen on figure.

The focus is on technology - no cost considerations will be included in this catalogue (saved for WP4 and WP5)



1.3 Objective

The objective of this report is to give an overview of district heating technology and to give input to benchmarks of performance level of district heating systems to be used in the work packages 3, 4 and 5 as sketched in the figure:



The output is a Technology Catalogue (Part I of this report) and a System Catalogue (Part II) of this report.

1.4 Description of work

The technology catalogue is divided into 4 sections that describes important issues of district heating that all together forms the district heating system: 'Buildings and heat consumption', 'Building substations and installations', 'Distribution pipes and pumps' & 'Fuels and production'.

In each section an introduction and description of the technologies are given. The technologies are divided into 'base case', 'best available' and 'best not yet available technology'. The characteristics are summarised in some general tables to be used in the system catalogue.

The system catalogue is based on simple model calculations of district heating systems. The catalogue is divided into 4 sections: 'System approach', 'Model of distribution network', 'Model of production facilities' & 'Calculation of labelling criteria for DH Systems'.

The report is using the draft report of the guideline for certification of district heating systems of 26 April 2012 developed in WP 3, for the calculation of labelling criteria.

Part I: Technology Catalogue

2 BUILDING DESIGN AND HEAT CONSUMPTION

2.1 Introduction

District heating system design starts at the buildings as heat consumption has considerable influence on the system design. Therefore this section addresses the technology development of buildings on short and long term.

EU has with the Energy Performance of Buildings Directive (EPBD) [2] focus on reducing the primary energy consumption of buildings both in new built and existing buildings. All over Europe the national building codes are tightened aiming at implementing requirements for ‘nearly zero-energy buildings’ for all new built buildings by end of 2020. Also intermediate targets must be set by 2015.

It is obvious, that ‘nearly zero-energy buildings’ would have very low net energy consumption for heating. For district heating companies, this means that the heat sold per building will be reduced considerable in the future. As the heat sold shall cover a large amount of fixed costs like distribution network, administration and maintenance, it is important to know the limits of feasibility. Though, in this section only the technological aspects are addressed.

Net energy consumption for heating is typically expressed as heat consumption per area of heated building (specific heat consumption). Another dimension is how dense buildings are built in a certain urban district to be supplied with district heating. To describe that, the plot ratio is used which expresses how much heated building area there is per area of land. The plot ratio is low in park areas with detached houses and high in inner cities.

Both plot ratio and specific heat consumption has a large impact on the relative heat losses from district heating distribution networks. High specific heat consumption and high plot ratio will result in relatively low distributions losses, whereas low specific consumption and low plot ration gives high relative losses. This is schematically shown in figure 2:

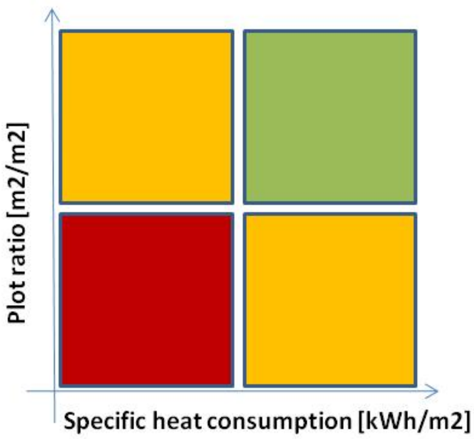


Figure 2 Plot ration versus specific heat demand

Plot ratio and specific heat consumption are often multiplied resulting in the area heat consumption. In relation to district heating systems also the line heat consumption is used, which describes the heat consumption connected to the network per length of pipes.

The line heat density varies considerable from country to country as seen from table 1. Some of this variation is of course due to climate and different specific heat demand of the existing building stock, but also the plot ratio has significant influence. In Denmark the line heat consumption is just about 1 MWh/m due to the fact that also minor cities and more than 700.000 single family houses are connected to district heating systems. In other countries like e.g. France mostly larger buildings within the cities are served, which results in much higher line heat consumption.

	GJ/m	MWh/m
Bulgaria	53	14,7
Hungary	41	11,4
France	38	10,6
Russia	37	10,3
Czech/Poland	31	8,6
Romania	28	7,8
Germany	24	6,7
Switzerland	21	5,8
Slovenia	20	5,6
Austria/Sweden	18	5,0
Norway	17	4,7
Finland	13	3,6
Italy	11	3,1
The Netherlands	8	2,2
Denmark	5,5	1,5

Table 1 Line heat density - data from 1993 [4]

The following terms and the plot ratio will be adopted to divide urban areas into categories [3]:

Inner city areas:	$0.5 \le e$
Outer city areas:	$0.3 \le e < 0.5$
Park areas:	$0 \le e < 0.3$

2.2 Technology description

From a district heating perspective, the building technology itself required to obtain very low heat demand is less interesting. The interesting part is the resulting heat consumption and design load for space heating and domestic hot water. Therefore, this section will primarily deal with these issues.

2.2.1 Base case technology

In regards of buildings, base case technology is in principle all existing buildings. Among these is a large variety in heat consumption because of building design as well as user behaviour.

Figure 3 shows district heating consumption (kWh/m^2) of approx 30.000 detached and semi-detached single family houses in Denmark in relation to building year [9]. The district heating consumption covers both space heating and domestic hot water and the mean heat consumption is in the interval 75-150 kWh/m^2. For information, the Danish average climate has about 2900 degree days. It is seen that the district heating consumption has decreased with year of construction – especially since the late 1970's where strict requirements for insulation were introduced in the Danish building code. Another interesting aspect is the large deviation of the heat consumption that, however, decreases with the building year. Similar data can be shown for multi-storey residential buildings, but with even lower heat consumption. The share of the district heating consumption covering net domestic hot water is typically about 10-20 kWh/m^2 (without distribution losses).

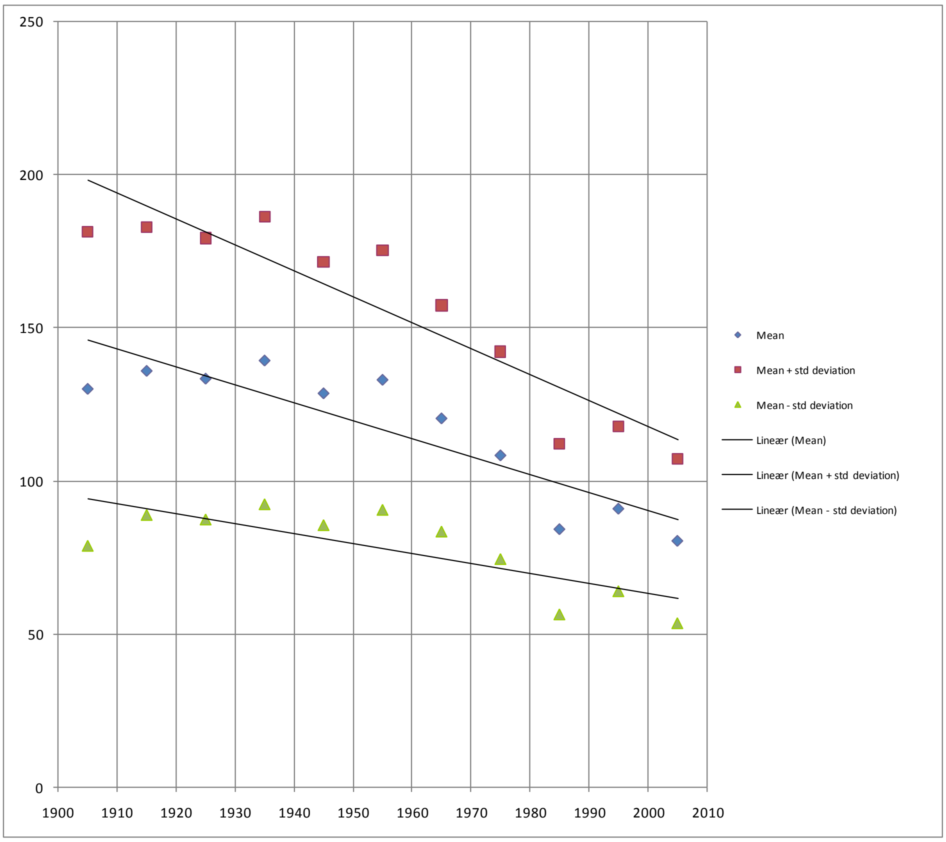


Figure 3 Average district heating consumption (kWh/m2) of approx 30.000 single family houses in relation to year of construction

In countries with other traditions of building design and climates the heat consumption can be much higher. In a rehabilitation project in Kaliningrad, the heat consumption used for design was 250 kWh/m^2 for space heating and 100 kWh/m^2 for domestic hot water [10].

2.2.2 Best available technology – BAT

The minimum energy performance requirements of national building codes are an indicator of what is achievable with best available building technology. These minimum requirements do typically include the heat demand for space heating, domestic hot water and the electricity consumption of technical installations but also conversion of energy and distribution losses. The methodology, national climate and the level of ambition vary from country to country, which make it difficult to compare the requirements directly. Primary energy consumption of electricity is typically accounted for with a factor of 2.5-2.7. Primary energy factor of other sources may vary as well. Especially for district heating some variation is seen. In Germany the primary energy factor of district heating is calculated due to performance of the actual district heating system, in other countries a fixed national value is set.

A survey from 2009 [11] gives an overview of the energy performance requirements of standard buildings in Denmark, France, Germany, Netherlands and UK, gross heat consumption according to EPBD outline [2], see table.

Building type	**Denmark**	**France**	**Germany**	**Netherlands**	**UK**
	kWh/m2	kWh/m2	kWh/m2	kWh/m2	kWh/m2
Single family houses of different types	90	90-180	80-150	100-130	85-95
Block of flats	75	80-150	n/a	95-100	n/a
Non-residential buildings - excluding hospitals	80-150	75-180	80-150	120-315	170-270

Due to the variation from country to country some clarification of the figures was investigated. Based on input from the project participants values of hot water demand of dwellings used in calculations was found to vary between 13 kWh/m^2 up to about 40 kWh/m^2 and heat demand for space heating to be in the range 40-125 kWh/m^2 for new buildings.

District heating for single family houses

Single family houses are sometimes considered not feasible to supply with district heating, but in North European countries more than 1 million such houses are supplied. An IEA-DHC study [5] says that areas with line heat consumption of 0.3 MWh/m or with area heat consumption 10 kWh/m^2 can be economically served by district heating. In Denmark these figures might be even lower. The table below shows some key figures of a number of different districts with low heat density:

Number of houses	Type	Average house load	Line heat consumption	Area heat consumption	Plot ratio	Year	Country	Reference
-	-	MWh	MWh/m	kWh/m^2	m^2/m^2	-	-	-
103	Detached	15	0,5	-	-	1995-2004	Sweden	[5]
44	Link-attached	16,8	0,8	25	-	1970's	Sweden	[5]
63/20	Detached/not connected	13	0,5	8	-	1960's	Sweden	[5]
28/3	Detached/Row houses	-	1,4	-	-	2004-2007	Finland	[5]
16	Detached	20,2	0,6	-	-	1960's	Denmark	[5]
41	Row house apartments	5,8	0,3	14	0,25	2009	Denmark	[7]
92	Detached	6,75	0,2	6	0,12	(2007)	Denmark	[6],[7]

The connected average heat consumption is in the interval 5.8 to 20.2 MWh and the line heat consumption is varying from 0.2 to 1.4 MWh/m.

2.2.3 Best not yet available technology – BNAT

Different national standards for low energy buildings exist in Europe and such houses are built today. An example of that is the German Passivhaus [12] that requires a net heat demand of just 15 kWh/m^2 for space heating. However, the market share is little and different demonstration projects have shown that there are still some challenges that need to be addressed before they can become standard constructions. Therefore, in this relation they are considered as best not yet available technology.

The EU aim is that low energy buildings shall be 'Nearly zero-energy buildings' in 2020.

The UK definition of zero carbon buildings [13] and the Danish definition of 'Nearly zero-energy buildings' [14] will have approximately 15 kWh/m^2 for space heating and 15 kWh/m^2 hot water consumption, in total a net demand of 30 kWh/ m^2. In the Netherlands the 'Nearly zero-energy buildings' are not expected to have a total net space heating and hot water demand below 40 kWh/m^2 ,and other countries are expected to have even higher figures. Based on that, it is decided to use a total heat demand 40 kWh/m^2.

In addition also other general aspects will have influence on district heating system design and consumption. No detailed analyses have been made, but some megatrends of buildings and their environment are listed below:

1) more building space per capita
2) more compact building design in cities (higher plot ratio)
3) higher room temperatures (higher level of comfort)
4) higher outdoor temperatures (due to global warming)

2.3 Characteristics

2.3.1 Input to system catalogue

Based on the technology description of section 2.2, area heat consumption for 4 plot ratios and 4 specific heat consumptions are defined in the table below:

			2020 - BNAT	2010 - BAT	Existing, low	Existing, high
			Specific heat consumption [kWh/m2]			
			40	75	150	300
			Area heat consumption [kWh/m2]			
Plot ratio [m2/m2]	Inner city	1	**40**	**75**	**150**	**300**
	Inner city	0,6	**24**	**45**	**90**	**180**
	Outer city	0,4	**16**	**30**	**60**	**120**
	Park area	0,15	**6**	**11,25**	**22,5**	**45**

It is seen from the table, that with a specific heat consumption of BNAT-level, areas with plot ratio of 0.4 will have an area heat consumption of 16 kWh/m^2 which is still above the feasibility criteria from the IEA-DHC study [5] that suggests 10 kWh/m^2 area heat demand as lower limit.

2.4 References

[1] Ecodesign MEEup Methodology report
[2] Energy Performance of Buildings Directive – recast 2010 (EPBD)
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[9] Paulsen, O. et Al.: Anvendelse af varmeenergimåleren med fjernaflæsning til diagnose og fejlretning af varmeanlæg, med særlig henblik på energiøkonomi og afkølingsforhold. Rapport Københavns Energi 2009
[10] Danish Energy Authority, Gusev District Heating Rehabilitation Study 2002-2004, 2005
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[12] Passivhaus Institut, www.passivhaus.de
[13] Note from Antonio Rullan, BRE
[14] Draft Building Code of Denmark dealing with 'Nearly-zero-energy buildings,Høringsudkast til BR 2020, 2010
[15] Personal communication with Willem van der Spool, TU Delft

3 BUILDING SUBSTATION AND INSTALLATIONS

3.1 Introduction

From a district heating system approach the network heat losses are reduced the lower the supply temperature is. Furthermore low flow temperatures also open up for supplying district heating based on low exergy sources like industrial surplus heat, solar heat and deep geothermal heat without any temperature boost.

The temperatures in the district heating network are dependent on, what flow temperature is to be delivered at the building substation in order to fulfil the space heat and domestic hot water demand at the building - the latter at a hygienic satisfactory level.

In general hydronic systems are used for space heating in district heating connected residential buildings. In new buildings these systems can be designed for very low flow temperatures – e.g. floor heating systems are typical designed with a flow temperature of 35°C or even lower.

However, the domestic hot water at the tapping point typically require a temperature of 40-45°C and due to the risk of legionella typically a temperature 55-60°C is required in central domestic water heaters and domestic hot water circulation pipes (some differences in legislation exist in EU).

Taking that into account, the Euroheat&Power guideline [1] on substations describes some target design conditions of space heating systems as given in the table below and specifies a minimum supply temperature of 65°C to take into account the legionella issues.

Table 5 Target design temperature

	Max. district heating supply temperature, HT/LT system	Max. district heating return temp.	Max. radiator and ventilation system supply temp.	Max. radiator and ventilation system return temp.	Max. floor heating system temp.
Heating systems	100/80°C	43°C	70°C	40°C	28 - 35°C
Ventilation systems	100/80°C	33°C	60°C*	30°C	
All systems	Max. pressure drop in district heating side		Max. pressure drop in radiator and ventilation side		
	25 kPa		20 kPa		

In the Euroheat&Power guideline on substations also two types of district heating systems are defined: High temperature systems (HTS) and Low-temperature systems (LTS)

Table 1

District heating system	Operating data	Design data
High-temperature system (HTS system)	100°C; 1,6 MPa differential pressure 0,8 – 0,10 Mpa	110°C; 1,6 MPa
Low-temperature system (LTS system)	Max 85°C; 0,6 MPa differential pressure 0,35 – 0,3 MPa	90°C; 0,6 MPa

These recommendations and definitons are to be used for new building substations and reflects general best practice in Europe in new networks. Though, in some countries the design temperatures could be even lower.

The next section will describe the substation and installation technology and the corresponding operating temperatures of the network.

3.2 Technology description

3.2.1 Base case technology

A large variety of district heating distribution systems exist today with very different operational temperatures. Some got hot water as medium, others pressurised hot water or steam. In some cases substations are distributing both district heating and district domestic hot water. As a result many different types of substations and installations exist. These will not be described in detail here as focus is on best available and best not yet available technology.

3.2.2 Best available technology – BAT

Based on the Euroheat&Power guideline on substations, the overall average operating temperatures of high temperature (HTS) and low temperature systems (LTS) are set to:

HTS (Supply/return temperature): 100/50°C

LTS (Supply/return temperature): 80/40°C

In new districts the operating temperatures might be even lower with thorough design of the whole system. Based on that a very low temperature system (VLTS) is defined:

VLTS (Supply/return temperature): 60/30°C

In figure 4 a system for multi-storey residential buildings with substations placed in each flat is sketched (solar heating system is not important in this regard) [2]. The substations have instantaneous water heaters with effective plate heat exchangers, which make it possible to produce domestic hot water with a temperature just about 3 °C below supply temperature on the primary side. With a limited volume of domestic water on the secondary side, that is replaces by each tapping, the solution provides a satisfactory hygienic level [3].

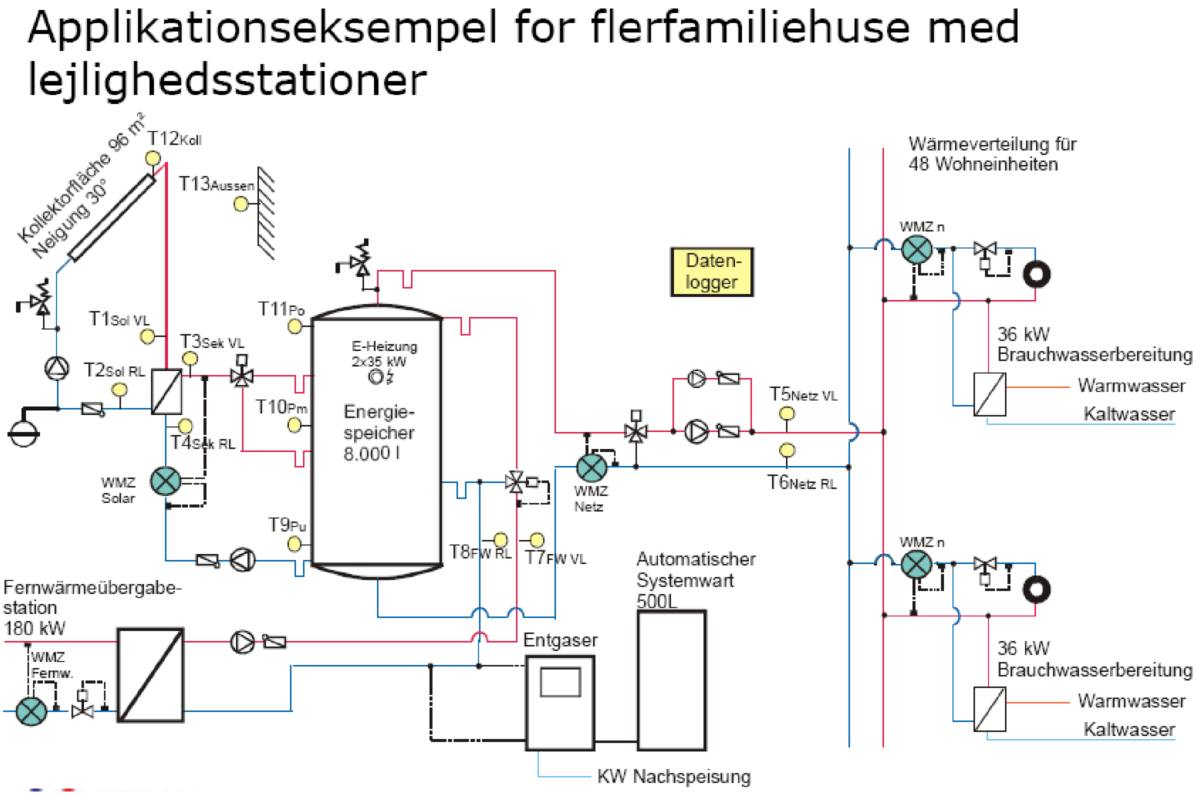

Figure 4 Sketch of district heating building installation. Small substations are placed in each flat. The solar system is not essential for description of the idea of flat substations and will be left out in most cases.

3.2.3 Best not yet available technology - BNAT

Further developments of the VLTS are expected within the next few years. For instance demonstration of systems with supply temperature of only 50-55°C in single family houses is ongoing [4].

On experimental and conceptual level even lower temperatures are considered and might be solutions on longer terms. These solutions are typically combining district heating with other heating technologies. Supply temperatures of 40-45 °C are proposed – the heat supply can be taking from the return pipe in some situations.

Based on that, an ultra low temperature system (ULTS) is defined:

ULTS (Supply/return temperature): 45/30°C

Such low temperatures will typically require floor heating systems. In figure 5 a system that uses heat from the return temperature is sketched [5]. The design is conceptual and presented as an alternative solution to electrical heat pumps for a low energy multi-storey residential building.

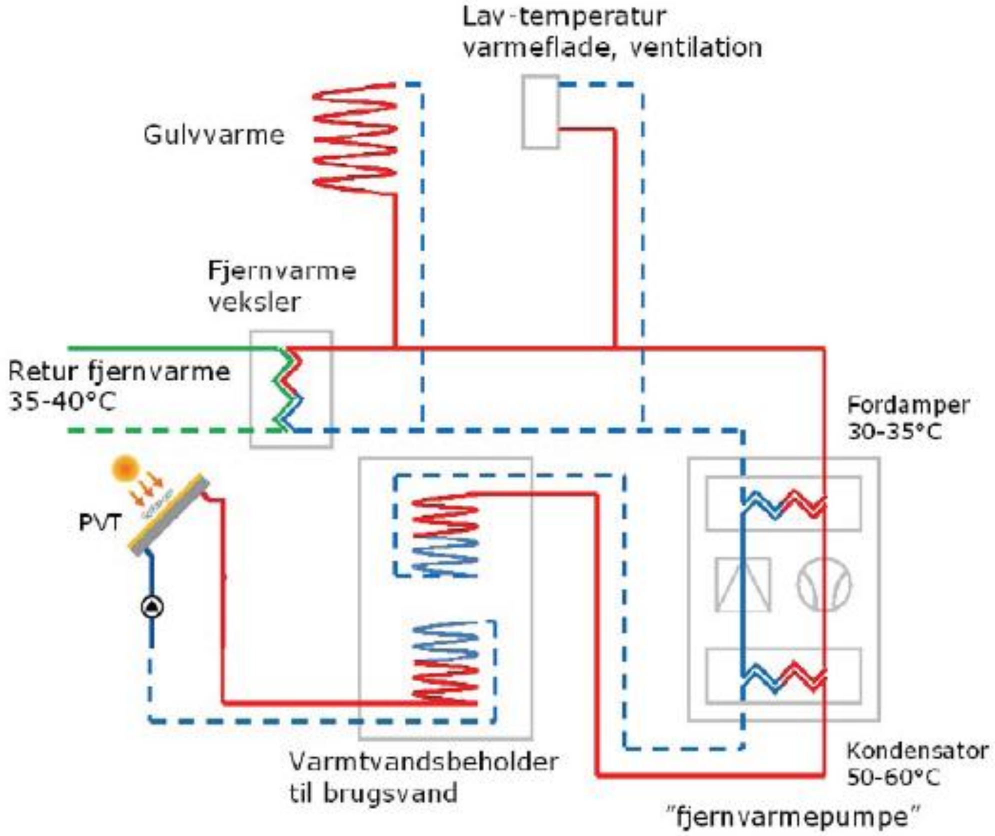

Figure 5 Conceptual layout of building installation supplied with district heating from the return pipe. Space heating is supplied with floor heating and a combined heat pump and solar system is delivering domestic hot water

A solution for single family houses is sketched in the figure below [6]. In this case supply temperature of 45 °C is supplied during summer only. An electric heating element is making sure the domestic hot water can be delivered above 55°C. During winter the flow temperature is 60°C or equal to the VLTS system.

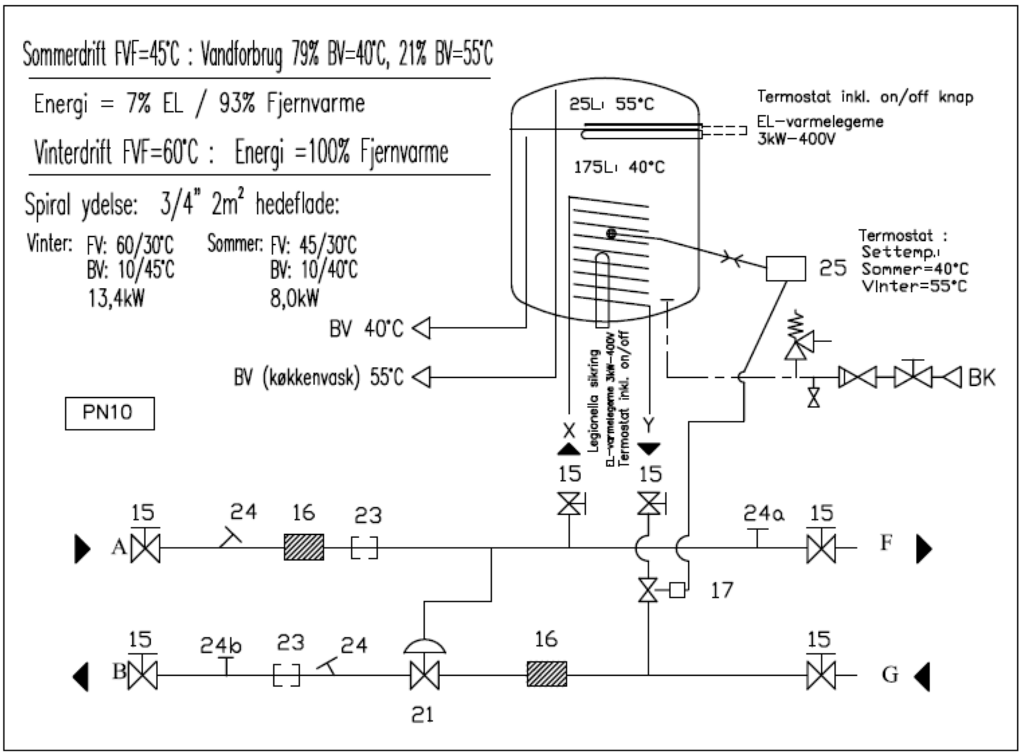

Figure 6 Example of district heating substation for single family house. VLTS during winter and ULTS system during summer.

In the Netherlands an ULTS system is planned in Waalsprong a suburb to Nijmigen [7]. The distribution system, called a hybrid heating network, supplies district heating with a temperature of 45°C to the houses to serve the heating demand whereas the domestic hot water is prepared with a heat pump.

In the Netherlands also some examples of distribution networks with 11-15°C supply temperature exists e.g. the Hague Duindorp and the Hague Spoorwijk systems [8]. These serve as heat (and cooling) source for individual heat pumps. However, in this technology catalogue, they will not be considered as district heating systems.

3.3 Characteristics

3.3.1 Input to system catalogue

Based on the technology description of section 3.2, the following temperature regimes and installation requirements are defined:

DH system		Heating system	
T_{flow} [°C]	T_{return} [°C]	Design temperature [°C]	Type
100	50	90/70	Radiator
80	40	70/40	Radiator
60	30	55/30	Radiator
45	30	35/30	Floor heating

3.4 References

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[5] Kold fjernvarme, Metro Therm, note 2009
[6] Design contest material Bolig+, Aalborg 2010
[7] Presentation, Sustainable heat supply for Waalsprong, January 2011.
[8] Personal communication, Laure Itard, OTB TU Delft

4 DISTRIBUTION PIPES AND PUMPS

4.1 Introduction

To distribute the produced heating energy a network of flow and return pipes between the plant(s) and the consumers (substations) is required. Depending on the size, dimension, power distribution, temperature and pressure of this network the pipes are usually based on three types of pipelines: Transmission pipes, distribution pipes and connection pipes.
Transmission pipes between the plant(s) and heat- and pressure exchangers on large networks, distribution pipes between heat- and pressure exchangers and close to the consumers, and connection pipes between the distribution pipes and the consumers.
Transmission pipes are mostly used in connection to relative large systems and can be placed over or under the ground. Distribution pipes and connection pipes are usually directly dug in the ground or placed in concrete channels. The pipes can be insulated by a variety of materials like polyurethane foam, mineral wool or cellular concrete in channels. The flow and return pipes can be two separate pipes as a pair of pipes or a combined pipe called twin pipes containing both flow and return in the same casing.

The heat loss from distribution networks strongly depends on the insulation of the pipes. Some networks losses more than twice the energy compared to energy efficient networks.
The heat loss can be reduced by replacing old pipes with poor insulation into new pipes with high efficient insulation. The heat loss from dug pipes depends less of the depth in the ground, but the deeper the more constant ground temperature over the year. A pair of pipes (flow and return) does have some influence on the heat loss on each other in the ground, and will be less than the heat loss from only one single pipe. In twin pipes the flow and return makes some interaction on each other, so the flow pipe transfers some of its energy to the return.

The pumps distribute the water by a combination of flow and pressure. In a basic network a number of pumps controlled by the production and the demand produce a satisfying combination of flow and pressure to deliver the amount of required heat energy transmission.

4.2 Technology description

4.2.1 Best available technology – BAT

In order to reduce the heat loss, save energy, money and reduce the CO_2 emissions it's essential to use pipes with an insulation layer made of as low heat conductivity material as possible. Caused by the fact that the insulation layer is a mechanical separation between the service pipe and the casing, the strength of the insulation is important to transfer the forces due to the temperature variations in the service pipe to the surroundings of the casing.
Since the heat conductivity in some way is related to the density of the insulation material, this material on one hand needs to be non-solid and on the other hand requires a low density. These two requirements are met in the insulation made of polyurethane foam. The polyurethane foam has a cellular structure with a density of ~60 kg/m^3 depending on the production method. Years ago the foam was made with Freon as the insulating gas, but today a gas like CO_2 or even better C_5H_{10} (cyclo pentane) is used. Over the years the cell gasses in

the foam will exchange with the atmosphere resulting in higher heat conductivity. This can be prevented by placing a thin metallic diffusion barrier between the insulation and the casing. Modern insulation made of cyclo pentane foam results in a heat conductivity as low as ~23 mW/(m·K).

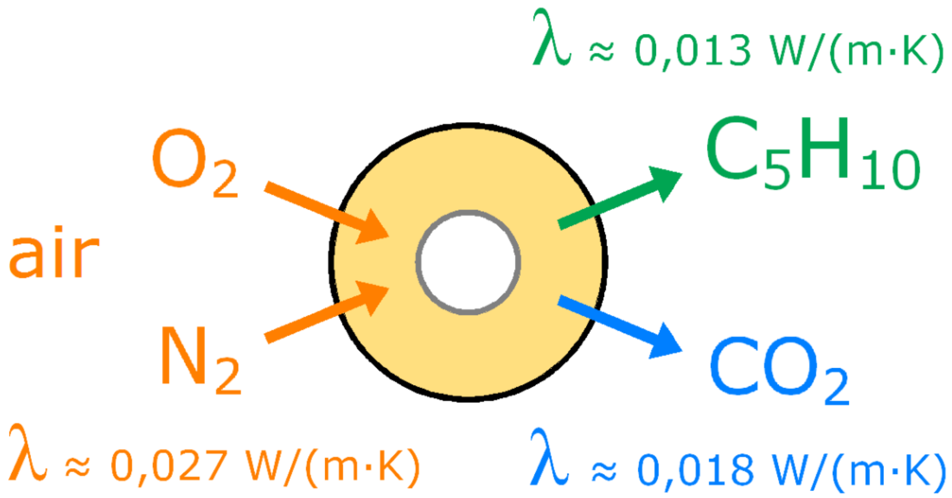
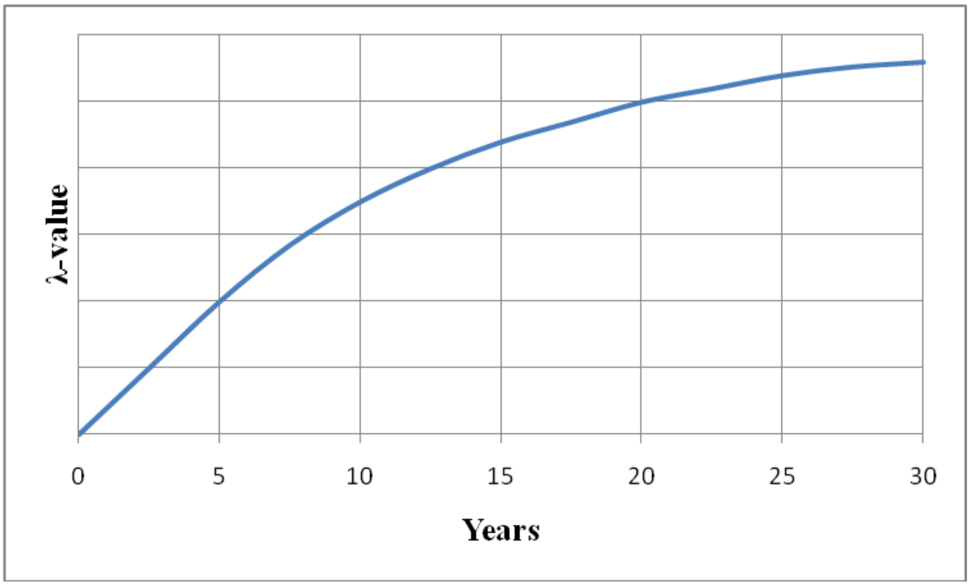


Figure 7 Exchange of cell gasses with the atmosphere, heat conductivity refers to the gas properties

The development of the heat conductivity of the foam as a function of years is sketched in the figure below:



The increase in heat conductivity is usually in the range of 3-5 mW/(m·K) almost independent of the start value (the heat conductivity for a new produced pipe)

New Ecodesign requirements on electric motors have been put into force 16 June 2011 requiring IE2-standard for all motors in the power range 0.75 to 375 kW. This also includes motors used on pumps in the district heating distribution networks. IE2-standard corresponds to efficiencies of about 94% in the upper range: 200 kW and above. Already by 1 January 2015, these requirements will be tightened for the range 7.5-375 kW, so all electric motors need to be IE3-standard or be IE2-standard with variable speed drive (VSD). Changing from IE2 to IE3 will improve pump efficiency by about 1 percent-point, where introduction of variable speed drives will typical result in much larger savings in variable flow systems, despite internal losses of 3-5% in the VSD.

4.2.2 Best not yet available technology - BNAT

To decrease the heat conductivity and the heat loss from district heating pipes new materials and methods are required. Due to the requirements of the mechanical strength of the foam as described above it's hard to decrease the heat conductivity only based on a decreased density. New cell gasses with an even lower heat conductivity compared to e.g. cyclo pentane could be one step to reduce the heat loss. Another way could be a combination of polyurethane foam, aero gel and vacuum - vacuum is used today for very large steel transmission pipes. Under vacuum aero gel can get a heat conductivity as low as ~4 mW/(m·K). The challenge would then be to keep the vacuum to the aero gel and not to the foam because of the volatile gas. At experimental level the heat conductivity is today very close to 20 mW/(m·K) with foams. Taking into account the properties of aero gels its not unrealistic that heat conductivities of 17 mW/(m·K) can be reached in 2020 and beyond. So this value will be considered as BNAT.

A great goal in the way of getting better insulation with low heat conductivity combined with a satisfactory mechanical strength would be to develop such a material. By reducing the heat loss from district heating pipe networks the total efficiency of this widespread way to distribute heating energy in a modern civilization would be increased in order to reduce the emissions and in advance to reduce the flow temperature according to the fact that the total heat loss is related to the temperature difference between the flow and the surroundings.

Even more efficient pumps are foreseen within the next years. IEC 60034-2-1 proposes a super premium pump called IE4, that are even more effective, but this technology has not been developed yet.

4.3 Characteristics

Some characteristics related to the type of pipes (pair of pipes or twin pipes) and insulation material and thickness (In standards the insulation thickness is divided into 3 classes: series 1, 2, 3) can be observed from calculations of the heat loss. It is obvious that an increased insulation layer results in a decreased heat loss. Calculations furthermore show a very small difference between soil coverage of 0,5 m or 1,0 m. As expected the heat loss from concrete channels is much higher than from pre insulated pipes.

4.3.1 Input to system catalogue

The system catalogue contains a complete table of heat loss from different insulation series calculated for each nominal dimension of pre insulated pipes with service pipe of steel and PEX. As described above the difference between soil coverage of 0,5 or 1 m is negligible as seen in the following table of selected pipe dimensions with heat loss calculated by manufacturer calculator (steel conti pipes, λ_{ground} = 1,6 W/(m·K), T_{ground} = 8 °C, T_{flow} = 80 °C and T_{return} = 40 °C):

[W/m]	Soil coverage					
Series	1		2		3	
Soil coverage [m]	0,5	1,0	0,5	1,0	0,5	1,0
Pair of DN 50	19	19	17	17	15	14
Pair of DN 100	25	25	21	21	18	18
Pair of DN 200	38	37	32	31	26	26

The soil coverage is therefore set to 0.75 m for all further calculations.

The manufacturer calculator works with pre set heat conductivity values for the selected pipe dimensions and series and can't be changed to make a comparative calculation. The multi pole calculation method for twin pipes based on the formulas derived by Petter Wallentén, Lund Institute of Technology, makes it possible in e.g. Excel to change the heat conductivity values to make comparative calculations, and the method is verified in the next table for selected pipe dimensions and series (soil coverage = 0,75 m, λ_{ground} = 1,6 W/(m·K), $\lambda_{insulation}$ = 0,023 W/(m·K), T_{ground} = 8 °C, T_{flow} = 80 °C and T_{return} = 40 °C):

[W/m]	Manufacturer calculator	Multi pole	Manufacturer calculator	Multi pole
Series	1		2	
Twin pipe DN 20	8	9	7	8
Twin pipe DN 40	12	13	10	10
Twin pipe DN 80	16	17	13	13

Compared to the general uncertainty related to calculating heat loss from dug pipes where e.g. determination of the heat conductivity of the ground plays a role, it is concluded to use the multi pole method for twin pipes since it is suitable for use in a spreadsheet and the heat conductivity values for the insulation can be changed instead of using the manufacturer calculator where the values are fixed.

4.3.2 Calculated heat loss

The heat loss from different pipe dimensions at different temperatures in flow and return is given in the next table. The pipe dimensions are DN 20 – DN 150 and the temperature sets are with reference to 3.4.1:

- **H**igh **T**emperature **S**ystem, 100/50 °C
- **L**ow **T**emperature **S**ystem, 80/40 °C
- **V**ery **L**ow **T**emperature **S**ystem, 60/30 °C
- **U**ltra **L**ow **T**emperature **S**ystem, 45/30 °C

Pair of pipes, heat loss, $\lambda_{insulation}$=23 mW/(m·K), λ_{ground}=1,6 W/(m·K), series 2 [kWh/m/yr]	DH temperatures [°C]							
	HTS		LTS		VLTS		ULTS	
	100/50 °C		80/40 °C		60/30 °C		45/30 °C	
	Pair of pipes	Twin pipes	Pair of pipes	Twin pipes	Pair of pipes	Twin pipes	Pair of pipes	Twin pipes
DN 20	117	86	91	67	64	47	51	38
DN 25	138	91	107	70	76	50	61	40
DN 32	150	99	116	77	83	55	66	44
DN 40	169	116	131	90	93	64	74	51
DN 50	188	112	146	87	104	62	83	49
DN 65	211	133	164	103	117	73	93	58
DN 80	224	146	174	113	124	80	99	64
DN 100	233	143	181	111	129	79	103	63
DN 125	264	134	205	104	146	74	116	59
DN 150	304	160	236	124	168	88	134	70

A comparison of different pipe dimensions at the same temperature set but with different insulation heat conductivity is given in the next table:

Twin pipe heat loss, 80/40 °C, series 2, λ_{ground}=1,6 W/(m·K) [kWh/m/yr]	EN 253:2003	EN 253:2009	BAT	BNAT
	Heat conductivity [mW/(m·K)]			
	33	**29**	**23**	**17**
DN 20	94	83	67	50
DN 25	99	88	70	53
DN 32	108	96	77	58
DN 40	126	112	90	68
DN 50	122	108	87	65
DN 65	144	128	103	77
DN 80	157	140	113	85
DN 100	156	138	111	84
DN 125	146	129	104	78
DN 150	173	154	124	93

It can be noticed that the heat loss from a DN 20 pipe with an insulation heat conductivity of 33 mW/(m·K) (94 kWh/m/yr) is almost the same as from a DN 150 with an insulation heat conductivity of 17 mW/(m·K) (93 kWh/m/yr).

The gain of using higher series of insulation is shown in the next table comparing twin pipes of series 1 and 2:

Twin pipe heat loss, $\lambda_{insulation}$=23 mW/(m·K), λ_{ground}=1,6 W/(m·K), T_f=80 °C, T_r=40 °C [kWh/m/yr]	Insulation series according to EN 253:2009	
	1	2
DN 20	76	66
DN 25	83	70
DN 32	91	77
DN 40	111	89
DN 50	106	87
DN 65	128	102
DN 80	148	112
DN 100	147	110
DN 125	133	103
DN 150	165	122

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5 FUELS AND PRODUCTION

5.1 Introduction

The fuels are defined as the energy input to produce heat and electricity. Fuels can be liquids, solids or gases. Except for nuclear technology the fuels are converted into energy production by burning the fuels. Fuel cells are using an electro-chemical conversion, whereas geo thermal and solar heat sources can be used directly (without conversion) or in combination with a heat pump using electricity/fuel.

In many cases the same technology is used to convert the fuels to heat and electricity for more fuels. However, in the following section the technology will be ordered in relation to the fuels which are the most common used.

5.2 Technology description

Reference for this description is mainly the document *Technology Data for Energy Plants* that has been published by the Danish Energy Agency, 2010 [1]. Other references has been consulted as well [2], [3], [4].

5.2.1 Best available technology – BAT

According to the environmental pollution like emissions of soot, NO_X and CO_2 the best available technology is fuels with as low emission as possible combined with the best production method of heat and power to get the highest efficiency of the total production unit.

<u>Coal</u>

Best practice technology for new coal-fired large CHP plants is pulverised fuel combustion and supercritical (advanced) steam data: above 240-260 bars and 560-570 °C. The term 'ultra-supercritical' has been used for plants with steam temperatures of approximately 580 °C and above. The supercritical power plants operate with steam extraction and with high electricity efficiency (in condensing mode 43-45%) and with high total efficiency in backpressure mode (90%). The process is primarily based on coal, but will be applicable to other fuels such as wood pellets and natural gas. The units are typical of a size of 400-1000 MW electric.

In case of refurbishment of older coal fired power plants more options exist. Repowering of steam turbines can be done by adding a gas turbine where the heat in high temperature flue gas is used for pre-heating feed-water in the steam cycle or is led directly into the steam plant boiler as pre-heated air. The net electricity efficiency improvements are of the size 2-2.5%.

Another option is that existing coal power plants are rebuilt for biomass combustion (if suited for). The easiest and cheapest solution is to convert some (or all) of the coal to a fuel with similar characteristics, such as wood pellets. In such cases it is possible to maintain steam data, efficiencies and other characteristics. The units that can be rebuilt are typically of the size 200-400 MW electric.

Natural gas, light fuel oil and other liquid/gaseous fuels

Gas turbines can be used either as single turbines or in combined cycle with a steam turbine. In the combined cycle, heat from flue gas of the gas turbine is used to supply heat for a steam cycle. The combined cycle can be operated as CHP plant and the steam cycle part can be designed with steam extraction or as pure backpressure. The net electricity efficiency of the best available combined cycle plant is up to 60% and total efficiency in back pressure mode is 82-89%. Combined cycles with steam extraction are typical of the size 100-400 MW electric. Pure backpressure combined cycle have typically electric capacity of 10-100 MW.

Single turbines running as CHP plants got net electric efficiencies of 35-44% and total efficiency of 80-85% for turbines with electric capacity of 40-125 MW. Smaller single gas turbines are on the market, but electric efficiency drops as capacity goes down. In the lower capacity range gas engines with electric capacity of 1-10 MW can be used with net electric efficiency of 40-45% and total efficiency of 88-96%.

Best available heat only boilers in the range 0.5-10 MW have efficiencies of 97-105%, the high efficiency with flue gas condensation. With full flue gas condensation natural gas fired boilers have a theoretical obtainable efficiency of 111%, whereas light gas-oil fired boilers will be able to obtain efficiency of 108% (in theory).

All the above mentioned technologies can also be used together with biogas, landfill gas, and bio syngas (from thermal gasification). In the latter case with reduced net electricity efficiency as a result.

Biomass

District heating boilers can be fired by e.g. wood-chips from forestry and/or from wood industry. If the moisture content of the fuel is above 30-35 %, flue gas condensation should be employed. In well-designed district heating systems with return temperature below 40 °C efficiencies above 110 % is seen. The boilers can burn wood-chips with up to 45-63% moisture content, depending on technology. Typical heat output is of the size 1-50 MW.

Biomass CHP plants can use e.g. residues from wood industries, wood chips (collected in forests), peat, straw and energy crops. Both straw and wood residues may also be delivered as pellets. If wood pellets are used, the advanced steam cycle that is also used for coal, may be applied. Different furnace technology exists for medium sized CHP plants. With straw as fuel, the best available technology, the net electricity efficiency is about 29% and the total efficiency is between 93% and 102% depending on if flue gas condensation is applied. CHP plants using wood chips can reach even higher net electric efficiency of about typically 33-34%.

Municipality Solid Waste

Municipality Solid Waste can be incinerated in heat only boilers or CHP plants. Heat only boilers are typically designed for thermal input of 15 to 50 MW and can achieve total efficiencies of 96%. The CHP-plants are typically designed for 100-120 MW with total efficiencies of 99% and net electricity efficiencies of 22-26%.

Electricity
Electric boilers are typically of the size of 1-25 MW and got total efficiencies of close to 100% (99%). If heat pumps are used instead, referring to [1], the following types and heat sources results in efficiencies of 170% to 360% for sizes of 1-15 MW:

- Large heat pumps for district heating systems, heat source ambient temperature
- Large heat pumps for district heating systems, heat source 35°C
- Large absorption heat pumps – flue gas condensation (steam driven)
- Large absorption heat pumps – geothermal (steam driven)

Other renewable sources
Among other renewable sources are large scale solar thermal plants (+ 1000 m2 solar collectors) and deep geothermal heat.

A large scale system, with solar panels and a short-term heat store of 0.1 - 0.3 m^3 per m^2 solar collectors, covers 10 – 25% of the annual district heating demand. The capacity is about 0.5 MWh per m^2 per year.

Deep Geothermal heat is extracted from drilled wells. The water temperature increases with about 3°C per 100 meter depth. The temperatures extracted are typically 30-70°C. For district heating use a heat pump might be used to increase supply temperature to the district heating network. The typical capacity per well is about 10-15 MW

If heat source temperature is above 50°C an Organic Rankine Cycle (ORC) machine might be used to extract electricity. However, at these temperatures electricity efficiency will be rather low, efficiencies below 10% has been reported.

5.2.2 Best not yet available technology – BNAT

In the following some BNAT are described. Other kinds of BNAT are increased efficiency measures of existing methods, plants and technologies.

Coal

In case of pulverized coal combustion, research on materials (nickel-based alloys) is going on allowing for steam temperature up to 700 °C and pressure of 350 bar. Such best not yet available technology will makes it possible to reach electricity efficiencies of 55%.

Another technology, the integrated coal gasification combined-cycle (IGCC), has also been subject for intense research and plants are expected to achieve electric efficiencies above 50% in demonstration projects before year 2020.

In addition intensive research on carbon capture & storage technology (CCS) takes place. CSS involves three main issues: the capture, the transportation and the storage. More CO2 capture systems are already available on a smaller scale using different principles of capture. However, no large scale demonstration is conducted yet. The CO_2 capture efficiency is estimated to 85% and the decrease in electric efficiency to 8-10%-points.

Natural gas, light fuel oil and other liquid/gaseous fuels

For combined cycle plants it is expected that the net electricity efficiency will go beyond 60%. Also improvement of single turbines and gas engines are expected. However, no revolutions are foreseen within this technology. Natural gas fired combined cycle plants will also be able to use CSS.

Different principles of fuel cells exist, but main research focus has in recent years been on the Solid Oxide Fuel Cell (SOFC) and the Proton Exchange Membrane (PEM). SOFC is a high-temperature fuel cell (600-1000°C) and the exhaust gas can be used to drive gas or steam turbines in combined cycle mode. Electricity efficiency of a single cycle SOFC-plant in the range 1-200 kW can be approximately 60%, when fuelled with natural gas at atmospheric pressure. The systems may achieve overall efficiencies up to 88 % or beyond, if low temperature heat can be utilized. Some vendors expect electrical efficiencies of 70-75 % when combining with gas turbines. SOFC will be available in the MW-size and are therefore expected to get some relevance for the district heating market. PEM fuel cell is the fuel cell technology, which is most developed so far, and it is currently available on the market up to 250 kW. On the application side PEM fuel cells has primarily been demonstrated for micro and mini CHP units (up to 15 kW electric) with electric efficiencies in the range 35-40%.

Virtual power plants (VPP) are foreseen to be developed as part of introducing electric smart grid in Europe. VPP is typically defined as aggregation of distributed electricity production like miniCHP or microCHP (up to about 15 kW), but should also be seen as aggregation of larger plants connected to district heating network.

Biomass
Improvement of efficiency to about 40% electric efficiency.

Municipality Solid Waste
Improvement of efficiencies to about 30% electric efficiency.

Electricity
Improvement of efficiencies of heat pumps to about 180-380% for the technologies mentioned in section 5.2.1.

5.3 Characteristics

5.3.1 Input to system catalogue

Based on the previous sections the technologies and fuels can be summarized in the following table:

		Coal	Wood Pellets	Wood chips	Straw	Natural gas	LPG	Biogas	Landfill gas	Hydrogen	Municipal solid waste	Light oil	Methanol	Electricity
1.	Advanced Pulverized Fuel Power Plant	X	X			X								
2.	Gas Turbine Single Cycle, Large					X	X	X				X		
3.	Gas Turbine Single Cycle, Medium					X	X	X				X		
4.	Gas Turbine Single Cycle, small					X	X	X				X		
5.	Gas Turbine Combined Cycle, Steam extraction					X	X	X				X		
6.	Gas Turbine Combined Cycle, Back Pressure					X	X	X				X		
7.	Gas Engines					X	X	X	X					
8.	Waste-to-Energy CHP Plant										X			
9.	Medium-scale Biomass Power Plant, wood chips			X										
10.	Medium-scale Biomass Power Plant, straw				X									
11.	Gas engine, gasifiers, biomass			X	X									
12.	Solid Oxide Fuel Cells					X							X	
13.	Heat Pump electric, Large, ambient air													X
14.	Heat Pump electric, Large, heat source 35°C													X
15.	Heat Pump absorption, Large, flue gas condensation													X
16.	Heat Pump absorption, Large, geothermal													X
17.	Electric immersion boilers													
18.	Waste-to-Energy District Heating Plant										X			
19.	District Heating Boiler, Wood-chips Fired			X										
20.	District Heating Boiler, Gas Fired					X						X		
21.	Geothermal district heating													
22.	Solar district heating													

Capacity and efficiency are summarized in the table below, electric efficiencies are given in condensing mode:

		Electric Capacity	Heat Capacity	Total net efficiency [%]			Net electric efficiency [%]			Auxilary electricity
		MW	MW	2010	2020	2050	2010	2020	2050	
1.	Advanced Pulverized Fuel Power Plant	400-1000		-		-	43-45	46-51	52-55	Approx. 4 %
2.	Gas Turbine Single Cycle, Large	40-125		80-85	-	-	35-44	42-50	-	
3.	Gas Turbine Single Cycle, Medium	5-40		80-85	-	-	36-40	36-42	-	
4.	Gas Turbine Single Cycle, small	0,1-5		80-85	-	-	28-35	-	-	
5.	Gas Turbine Combined Cycle, Steam extraction	100-400		-	-	-	55-58	59-64	-	
6.	Gas Turbine Combined Cycle, Back Pressure	10-100		82-89	91	-	41-55	48-56	-	
7.	Gas Engines	1-10		88-96	88-96		40-45	43-48	-	
8.	Waste-to-Energy CHP Plant	20		99	97		22-26	30	-	Approx. 4%
9.	Medium-scale Biomass Power Plant, wood chips	10-100					33-34	40	-	
10.	Medium-scale Biomass Power Plant, straw	10-100		93-102			29			
11.	Gas engine, gasifiers, biomass	1-20		103	105		35-40	37-45		
12.	Solid Oxide Fuel Cells	1		90			44-47	55-65		
13.	Heat Pump electric, Large, ambient air		1-10	280	290	320				
14.	Heat Pump electric, Large, heat source 35°C		1-10	360	370	380				
15.	Heat Pump absorption, Large, flue gas condensation		2-15	170	175	185				
16.	Heat Pump absorption, Large, geothermal		5-10	170	175	180				
17.	Electric immersion boilers		1-25	99	99	99				
18.	Waste-to-Energy District Heating Plant		50	96	98				-	Approx. 4%
19.	District Heating Boiler, Wood-chips Fired		1-50	108	108					
20.	District Heating Boiler, Gas Fired		0.5-10	97-105	97-105					
21.	Geothermal district heating		15							Approx. 5-10%
22.	Solar district heating		-							

In case of CHP-plants with steam extraction, the total efficiency can be about 90% in full back-pressure mode, but will decrease with increased electricity production

5.4 References

[1] Technology Data for Energy Plants, Danish Energy Agency, 2010

[2] Establishing harmonised efficiency reference values for separate production of electricity and heat in application of Directive 2004/8/EC of the European Parliament and of the Council, 2006

[3] IEA Energy Technology Essentials, January 2007, Biomass for Power Generation and CHP

[4] Data sheets e.g. Bergen B35:40VAG, Siemens SGT5-8000H, Alstom Advanced Supercritical boilers.

Part II: System Catalogue

6 SYSTEM APPROACH

6.1 Introduction

For the calculation of different district heating system some simple considerations are made:

- Land is divided into small districts each of a size of 30.000 m^2
- For each of these small districts heat demand and distribution network are laid out
- More of these small districts can be combined to form a larger district for which a production facility can be designed (schematically shown in figure 8) or the larger districts can be connected to an existing district heating network (see figure 9)
- Different options for heat demand, distribution network, production facilities and fuels are chosen from the technology catalogue

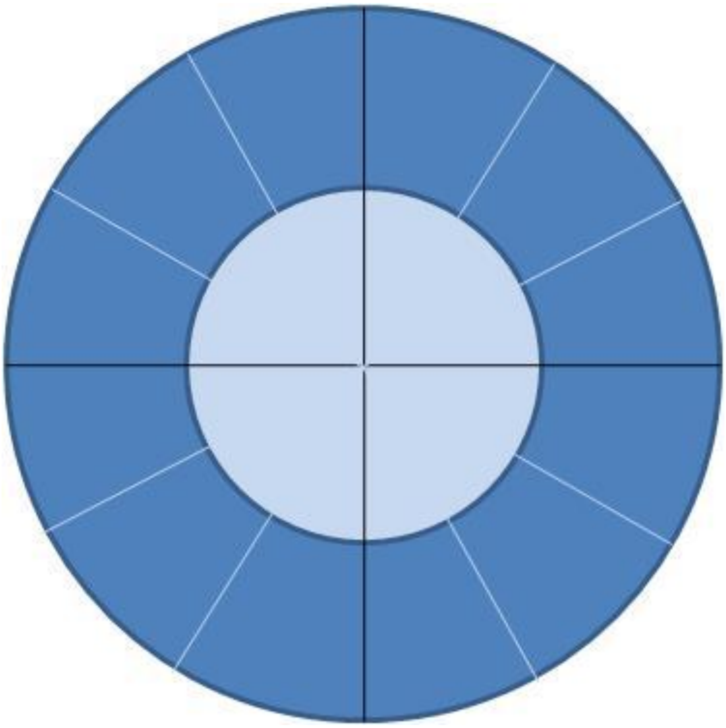


Figure 8 Sketch of system approach for new system consisting of small districts

Based on these models for distribution network, production facilities will be set up and calculations of labelling criteria of different systems will be carried out.

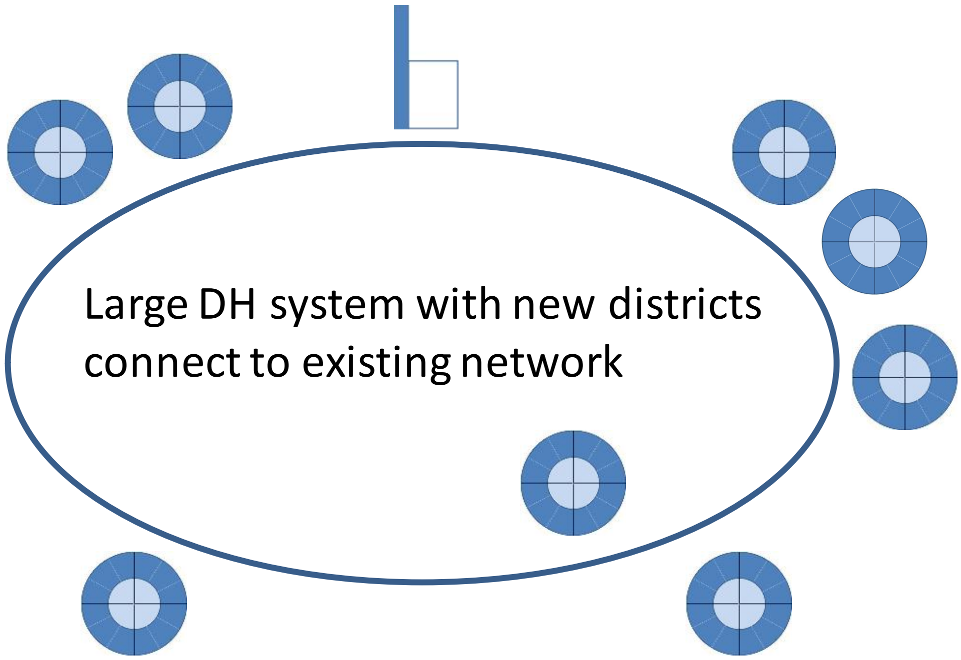


Figure 9 Sketch of system approach for existing system with new districts

7 MODEL OF DISTRIBUTION NETWORK

7.1 Introduction

The model of the distribution network is based on different assumptions to meet average areas of a city. The first assumption is the plot ratio, e.g. the total building area divided with the ground area. The plot ratio for single family houses in park areas is ~0.15 (150 m² building on a 1000 m² ground or 100 m² building on a 667 m² ground and so on). For city areas the plot ratio increases, and in this model plot ratios of 0.4 and 1.0 are chosen to show a relative low and high city plot ratio.

The model is based on the figure 10 showing 12 equal buildings like cubic tower blocks with four flats on each floor. The total ground area for the 12 buildings is 30.000 m² (2500 m² ground area per building) giving a building area of 1000 m² with a plot ratio of 0.4 and a building area of 2500 m² with a plot ratio of 1.0.

Divided into floors and apartments the plot ratio of 0.4 gives 4 floors of 4 apartments of 62.5 m² each (0.4·2500/(4·4)) and the plot ratio of 1.0 gives 10 floors of 4 apartments of 62,5 m² each (1.0·2500/(10·4)).

The schematic layout of the distribution network is shown in figure 10 as well. The network is laid out as a traditional comb with one main line divided into six sub lines each supplying two blocks of flats.

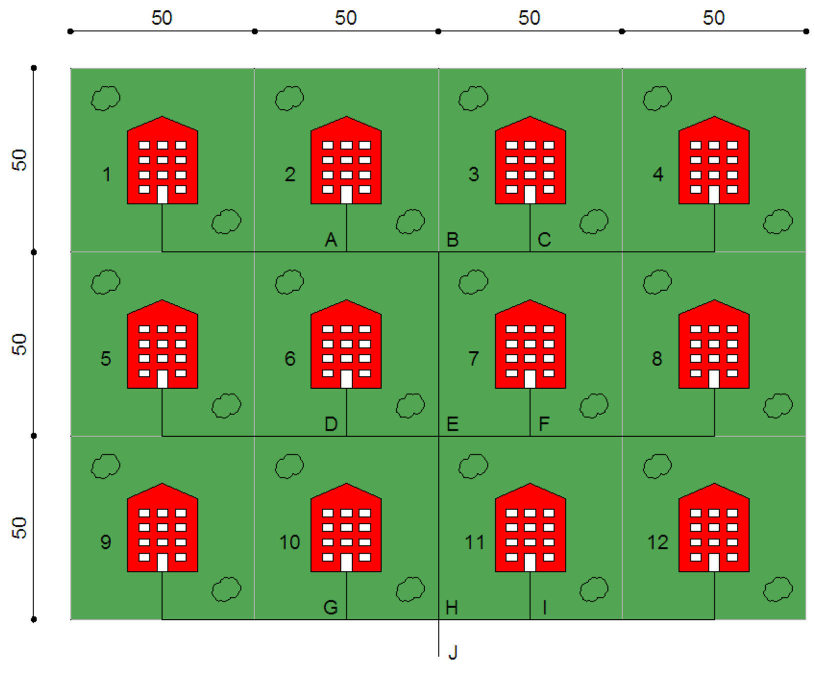


Figure 10 Sketch of network of small district

The nodes for the calculations in chapter 5 is shown in the figure above giving the lines as follows: 1-A, 2-A, A-B, 4-C, 3-C, C-B, B-E, 5-D, 6-D, D-E, 8-F, 7-F, F-E, 9-G, 10-G, G-H, 12-I, 11-I, I-H, H-J.

7.2 New small districts 2020

For the new districts it is decided to only consider ‘nearly zero energy buildings’ that will be standard buildings in 2020. These buildings are expected to have a yearly district heating consumption of 40 kWh/m^2 as described in the technology catalogue.

The network design is calculated based on input from the technology catalogue and a number of general assumptions:

Soil coverage heat conductivity = 1.6 W/(m·K)
Soil coverage = 0.75 m
Hot tap water design capacity = 33 kW
Design full load hours = 1800 hr/yr

Furthermore three different design options are considered:

- **Traditional:** Operating temperatures, pressure loss gradient and pipes as built today. Medium plot ratio (0.4).
- **BAT (2010):** Very low operating temperatures, high pressure loss gradient (>> 200 Pa/m) and best available pipes. Medium plot ratio (0.4).
- **BNAT (2020):** Very low operating temperatures, high pressure loss gradient and best not yet available pipes. High plot ratio (1.0) corresponding to the megatrend of more compact buildings. This design option will also be compared with a medium plot ratio (0.4)

The design options are summarised in the table below:

	Traditional	2010 (BAT)	2020 (BNAT)
Plot ratio [-]	0.4	0.4	1.0
Area heat consumption [kWh/m^2]	16	16	40
Pipe type [-]	Single	Twin	Twin
Insulation series [-]	1	2	2
T_f/T_r [°C]	80/40	60/30	60/30
Avg. pressure loss [Pa/m]	100	500	500
Insulation heat conductivity [W/(m·K)]	0.029	0.023	0.017

From these assumptions and options the distribution network is laid out by iterative calculating the pipe dimensions from the normal hydraulic formulas as:

- the friction factor formula (Colebrooks formula)
- the continuity formula
- the Reynolds number formula
- the pressure loss formula

The simultaneity for the heating and the hot tap water is calculated as [3]:

Heating: $c = 0{,}62 + \frac{0{,}38}{n}$

Hot tap water: $c = \frac{51 - n}{50 \cdot \sqrt{n}}$, $n \leq 51$

where *n* is the number of connected consumers.

After the pipe dimension is calculated the nearest trade pipe dimension is chosen. However, for the option 2020 (BNAT), it was chosen to keep the same piping as for the option 2010 (BAT). The total length of the different pipe dimensions are given in the table below:

	Pipe length [m]		
DN	Traditional	2010 (BAT)	2020 (BNAT)
25	0	740	740
32	790	50	50
40	50	50	50
Sum	840	840	840

Because of the low heat demand and even more the simultaneity for the hot tap water, the pipe dimensions are relative small. For the 2010 (BAT) and 2020 (BNAT) options the average pressure loss is set higher than for the traditional option decreasing the pipe dimensions in general and thereby reducing the heat loss.

Below a comprehensive table of the different distribution network options related to the figure 10 are given. The network efficiency is a function of the annual network energy loss (Q_{loss}) and the annual delivered energy (Q_{del}) calculated as:

$$\eta = 1 - \frac{Q_{loss}}{Q_{loss} + Q_{del}}$$

	Case 1	Case 2	Case 3
Number of consumers connected [-]	192	192	480
Avg. pressure loss [Pa/m]	105	606	360*
Total connected power [kW]	105	104	259
Delivered energy [MWh]	480	480	1200
Network power loss [kW]	16	5	4
Network energy loss [MWh]	138	43	32**
Efficiency [-]	0.78	0.92	0.97***

*Due to 40 apartments per building in case 3, compared to 16 apartments per building in case 2, the simultaneity factors in case 3 are getting very low. This results in lower avg.

pressure loss in case 3 compared to case 2 even though the network layouts are identical.
** The lower network energy loss in case 3 compared to case 2 is due to lower insulation heat conductivity.
*** If a plot ratio of 0.4 is used for case 3 (2020 – BNAT), the network efficiency will be about 0.94 {480/(480+32)}

Considering a new developing area in a city, where 120,000 m^2 of apartments are to be build, the 'Traditional' and the 'BAT' design option will result in 120 buildings of 1,000 m^2 each on 300,000 m^2 of land (10 small districts). The 'BNAT' design option will result in 48 buildings of 2,500 m^2 each on 120,000 m^2 of land. The table below shows the heat loss in actual figures as well as the heat delivered to the network.

Design option, new districts	-	Traditional	BAT	BNAT
Average specific district heating consumption	kWh/m2	40	40	40
Average building area	m2	1000	1000	2500
Average district heating consumption per building	MWh	40	40	100
Number of buildings	-	120	120	48
Number of small districts	-	10	10	4
Total building area	m2	120000	120000	120000
Total consumption	MWh	4800	4800	4800
Network losses*	MWh	1354	417	148
Network losses	%	22	8	3
Heat delivered an net	MWh	6154	5217	4948
Total network efficiency	%	78	92	97

* In this simple model it is assumed that the small districts are placed close together and that production facilities are placed at a central spot in the area (see also figure 8). Based on that, connection to the small districts will be short and the additional distribution losses low. In this comparison they are neglected. In real life systems there will be large variation in design and length of network that of course must be taking into account.

The figures of the above table will be used for further calculations in section 9.

7.3 Existing large network 2020

A large existing network is considered supplying 6000 buildings with an average annual district heating consumption of 150 MWh each in 2010. The network heat losses are 10%. Towards 2020, energy savings in the building stock of 10% is assumed resulting in district heating consumption of 135 MWh per building in 2020. The reduced district heating consumption will results in about 1% higher network heat losses relatively seen, but also make room for more capacity to supply additional buildings, as 90 GWh are saved. If more ambitious energy savings are considered, for instance 30%, the reduced district heating consumption will results in about 4% higher network relative heat losses. The main data are shown in the table below:

Year	**-**	**2010**	**2020**	**2020**
Average specific district heating consumption	kWh/m2	150	135	105
Average building area	m2	1000	1000	1000

Average district heating consumption per building	MWh	150	135	105
Number of buildings	-	6000	6000	6000
Total building area	m2	6000000	6000000	6000000
Total consumption	GWh	900	810	630
Network heat losses	GWh	100	100	100
Network heat losses	%	10,0	11,0	13,7
Heat delivered an net	GWh	1000	910	730

The new capacity of the network is used to supply a rather large number of new districts in the city, that are all built as 'nearly zero energy buildings' from 2020 and beyond. The districts are all being situated close to the existing network e.g. at left industrial sites, the water front and the like. With the very low district heating consumption of 'nearly zero energy buildings' there is capacity for a lot of square meters. The table below shows that the expansion depends very much on what design option is chosen (network + plot ratio). If the traditional network layout is chosen the expansion can be about 29%, if the BNAT approach is chosen the expansion can be about 36%. All this with the same amount of energy delivered to the network in 2020 as in 2010 (when considering 10% savings in the existing building stock)

Design option, new districts	**-**	**Traditional**	**BNAT**
Average specific district heating consumption	kWh/m2	40	40
Average building area	m2	1000	2500
Average district heating consumption per building	MWh	40	100
Number of new buildings	-	1752	876
Total building area	m2	1752000	2190000
Total consumption	GWh	70	88
Network losses	GWh	20	3
Network losses	%	22	3
Heat delivered an net	GWh	90	90

The table below shows the district heating consumption and network efficiency for 3 different cases:

- Existing network as in 2010
- Existing network + 10% energy savings in buildings + new districts with traditional design (2020)
- Existing network + 10% energy savings in buildings + new districts with BNAT design (2020)

Year	**-**	**2010**	**2020**	**2020**
Design option, new districts	**-**	**-**	**Traditional**	**BNAT**
Total district heating consumption	GWh	900	880	898
Total heat delivered an net	GWh	1000	1000	1000
Total network efficiency	%	90,0	88,0	89,7

It is seen that the relative high heat losses for the traditional design option in new districts (22%) will only have impact of 2 percentage-points on the total network efficiency of the city. On the other hand, thorough network design and high plot ratio may actually result in the preservation of the total network efficiency or even a reduction.

MODEL OF PRODUCTION FACILITIES

7.4 Introduction

This section shows the production facilities and fuels to be used for the calculation of the labelling criteria in section 9, where 18 different combinations (cases) of production facilities and networks are presented. The background data of production facilities can be found in the technology catalogue [2].

7.5 New small districts 2020

For the new small districts in 2020 the basic production facility is a natural gas engine CHP plant and a peakload/backup natural gas fired boiler. The CHP plant has a net electric efficiency of 45% and an overall efficiency of 95%. For the condensing boiler a total average efficiency of 100% is assumed.

These production facilities are used for the calculation of case 1, 2, 3 and 4. Though, in case 4 in combination with solar panels, that contributes to 10% of the annual heat production. Solar panels have production of about 0.5 MWh/year/m^2.

In case 1, 2 and 3, the three different network design options are used: 'Traditional', 'BAT' and 'BNAT' whereas the production facilities are kept constant.

For the next cases (5-8) only the network design option 'BNAT' is used. In case 5 a production facility with only a biomass boiler is used. The efficiency of that is set to 110%. The biomass boiler combined with solar panels contributing with 10% of the annual production is used in case 6.

Case 7 is a natural gas fired SOFC fuel cell with net electric efficiency of 60% combined with a peakload/backup natural gas fired boiler similar to that of case 1-3. The overall efficiency of the SOFC fuel cell is set to 90%.

Case 8 is a biomass gasifier combined with producer gas engine CHP plant. Due to added electricity consumption of the gasifier among other things, the net electricity efficiency is set to 35%. Because of flue gas condensation of the combination the overall efficiency is set to 105%.

In both case 7 and 8, the same peak load/backup boiler as of the previous cases is used.

7.6 Large existing network 2020

The large existing network is supplied with district heating from a pulverized coal CHP plant with advanced design data (supercritical) and extraction turbine. The plant is considered put into operation in 2005 and has a net electric efficiency in condensing mode of 44%. Because of the age of the plant (15 years in 2020 with expected lifetime of additional 25 years) it might be reasonable to make improvements of the plant in 2020. The overall efficiency is 90% and electricity to heat ratio is 0.66 in backpressure mode. The CHP plant is operating at 80% of full backpressure mode and a fixed rate of power loss per heat unit of heat generated of 0.15 is assumed. Based on this the efficiencies of the plant are calculated [4]. The CHP plant is contributing with 90% of the district heating. In addition light fuel oil peak load/backup boilers with efficiencies of 95% in average delivers the remaining 10% of the district heating.

In case 9, 10 and 11 these production facilities and fuels are used to calculate the labelling criteria for the existing network (2010) and for the existing network with energy savings and new developed areas with 'nearly zero energy building' (2020).

Case 12 is identical to case 11 except for the fuel of the peak load/backup boilers. In case 12 the light fuel oils is exchanged with a light bio fuel oil in order to reduce CO_2-emissions.

In pulverized coal CHP-plants it is in many cases possible to mix hard coal with wood pellets. In case 13, a 50%/50% mix (by energy) is fired into the plant.

CO_2 Carbon Capture and Storage (CCS) facilities are foreseen to play an important role in order to reduce CO_2-emissions beyond 2020. In case 14 the CHP plant is equipped with CCS. Due to the electricity consumption in the CCS process, the net electric efficiency is reduced with 8 percentage-points to 36% in condensing mode. The CCS is expected to be able to reduce the CO_2-emission by 85%.

The final case (15) is a pulverized coal CHP plant with even more advanced design data (supercritical) and extraction turbine. Net electric efficiency in condensing mode is 48%, the overall efficiency is 90% and electricity to heat ratio is 0.84 in backpressure mode.

In addition to these cases which are mainly focussed on fuels and production technologies, a small sensitivity study is made in order to see the influence of higher energy savings in buildings in 2020 compared to 2010 (30% instead of 10%) and of higher network losses (30% instead of 10%).

In case 16, 17 and 18, the same production facilities and fuels as in case 9 are used. It is assumed that these are scalable (which is of course not realistic in real life without changes of the facilities). However, for the purpose of the sensitivity study it is an acceptable assumption. Further, the released capacity of the system due to energy savings in buildings is not used for expansion.

In case 16, the energy savings in buildings is set to 30%, which results in a heat demand of 105 kWh/m^2 in 2020 compared to 150 kWh/m^2 in 2010. The network heat loss in actual figures is kept constant (100 GWh per year).

Case 17 is identical to case 9 except for the network heat losses which are set to 30% (386 GWh per year) instead of 10% (100 GWh per year).

Case 18 is combining energy savings in buildings of 30% as in case 16 and the high network losses of case 17.

8 CALCULATION OF LABELLING CRITERIA FOR DIFFERENT DH SYSTEMS

8.1 Introduction

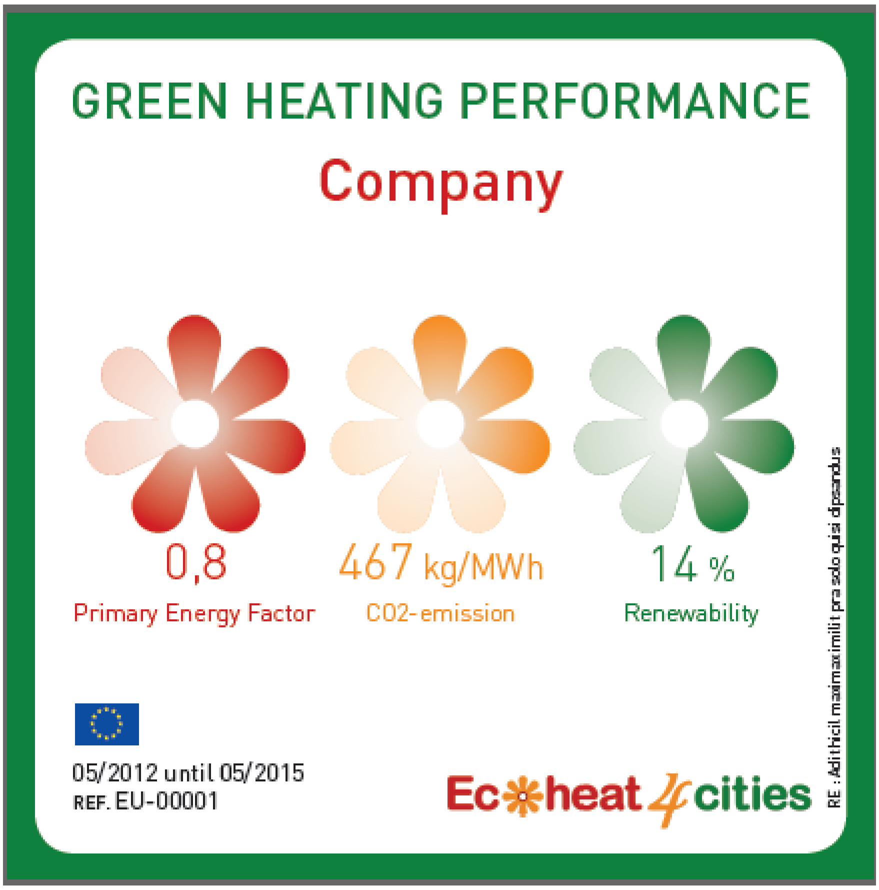
The labelling criteria were defined in the Ecoheat4cities WP 2, Task 2.1 report, April, 2011 [6]. Since the finalization of this report, further discussions have taken place regarding default values of primary energy factors and CO_2-factors. The table below presents the values as of 26 April 2012.

		f_P		K_{CO2} (kg/MWh)	R
		total	nren	nren	
fossil fuels	natural gas	1,1	1,1	230	0
	liquid gas	1,1	1,1	260	0
	light oil	1,1	1,1	290	0
	heavy oil	1,1	1,1	300	0
	coal	1,1	1,1	370	0
renewable	primary bio fuel	1,1	0,1	20	1
	refined primary bio fuel	1,2	0,2	40	1
recycled	secondary bio fuel	0,1	0,1	20	1
	refined secondary bio fuel	0,2	0,2	40	1
	residual fuel from another process	0,2	0,2	40	1
	municipal waste as fuel	0	0	0	1
	industrial waste heat	0	0	0	1
electricity		3	2,6	420	0,2

These values will be used for the calculation of 18 cases of system combinations (cases)

For labelling purpose, the cases will be evaluated according to the 3 criteria and the ranking of the table below. The label design will consist of a flower with 7 petals, where 7 petals is given for the best performing systems. Following the table below, a system in class 1 will be labelled with 7 petals. Accordingly, a system in class 3 will be labelled with 5 petals and so on.

class	$f_{P,dh}$	K_{dh}	R_{dh}
1	$f_{P,dh} < 0{,}40$	$K_{dh} < 111$	$R_{dh} > 60\%$
2	$0{,}40 \leq f_{P,dh} < 0{,}80$	$111 \leq K_{dh} < 222$	$60\% \geq R_{dh} > 20\%$
3	$0{,}80 \leq f_{P,dh} < 1{,}20$	$222 \leq K_{dh} < 333$	$20\% \geq R_{dh} > 16\%$
4	$1{,}20 \leq f_{P,dh} < 1{,}60$	$333 \leq K_{dh} < 444$	$16\% \geq R_{dh} > 12\%$
5	$1{,}60 \leq f_{P,dh} < 2{,}00$	$444 \leq K_{dh} < 555$	$12\% \geq R_{dh} > 8\%$
6	$2{,}00 \leq f_{P,dh} < 2{,}40$	$555 \leq K_{dh} < 666$	$8\% \geq R_{dh} > 4\%$
7	$f_{P,dh} \geq 2{,}40$	$K_{dh} \geq 666$	$R_{dh} \leq 4\%$



8.2 Introduction

The table below shows the calculation of the 3 criteria of case 1-8 with main results in the last 3 lines.

Production facilities and fuels	-	**1. N-gas engine CHP + N-gas boilers**	**2. N-gas engine CHP + N-gas boilers**	**3. N-gas engine CHP + N-gas boilers**	**4. N-gas engine CHP + N-gas boilers + solar panels**	**5. Biomass boiler**	**6. Biomass boiler + solar panels**	**7. N-gas SOFC Fuel Cell + N-Gas boilers**	**8. Bio-gas engine CHP + gasifier + biomass boiler**
Year	-	**2020**	**2020**	**2020**	**2020**	**2020**	**2020**	**2020**	**2020**
Design option, new districts	-	**Traditional**	**BAT**	**BNAT**	**BNAT**	**BNAT**	**BNAT**	**BNAT**	**BNAT**
Total district heating consumption	MWh	4800	4800	4800	4800	4800	4800	4800	4800
Total heat delivered an net	MWh	6154	5217	4948	4948	4948	4948	4948	4948
Total network efficiency	%	78	92	97	97	97	97	97	97
Aux network electricity consumption	%	1	1	1	1	1	1	1	1
Gas engine									
Share of heat delivered an net	%	75	75	75	70	0	0	75	75
Cb	-	0,9	0,9	0,9	0,9	0,9	0,9	2	0,5
Cv	-	0	0	0	0	0	0	0	0
eta, electric	%	45	45	45	45	45	45	60	35
Qmc/Qb	-	1	1	1	1	1	1	1	1
Heat delivered an net	MWh	4615	3913	3711	3464	0	0	3711	3711
eta, heat, mc	%	50	50	50	50	50	50	30	70
Fuel concumption, CHP	MWh	9231	7826	7423	6928	0	0	12371	5302
eta, electricity, mc	%	45	45	45	45	45	45	60	35
Electricity delivered an net	MWh	4154	3522	3340	3118	0	0	7423	1856
eta, total, mc	%	95,0	95,0	95,0	95,0	95,0	95,0	90,0	105,0
Fuel concumption, heat	MWh	4615	3913	3711	3464	0	0	3711	3711
Boiler									
Share of heat delivered an net	%	25	25	25	20	100	90	25	25
Cb	-	0	0	0	0	0	0	0	0
Cv	-	1	1	1	1	1	1	1	1
eta, cond	%	100	100	100	100	110	110	100	100
Qmc/Qb	-	1	1	1	1	1	1	1	1
Heat delivered an net	MWh	1538	1304	1237	990	4948	4454	1237	1237
Electricity delivered an net	MWh	0	0	0	0	0	0	0	0
eta, total	%	100,0	100,0	100,0	100,0	110,0	110,0	100,0	100,0
Fuel consumption, heat	MWh	1538	1304	1237	990	4499	4049	1237	1237
Other									
Share of heat delivered an net	%	0	0	0	10	0	10	0	0
Cb	-	0	0	0	0	0	0	0	0
Cv	-	1	1	1	1	1	1	1	1
eta, cond	%	100	100	100	100	100	100	100	100
Qmc/Qb	-	1	1	1	1	1	1	1	1
Heat delivered an net	MWh	0	0	0	495	0	495	0	0
Electricity delivered an net	MWh	0	0	0	0	0	0	0	0
eta, total	%	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
Fuel consumption, heat	MWh	0	0	0	495	0	495	0	0
Labelling criteria									
f,P,F,nren, total	-	**0,25**	**0,21**	**0,20**	**0,15**	**0,12**	**0,11**	**-0,88**	**-0,71**
K,F,tot, total	kg/MWh	**142**	**121**	**114**	**99**	**23**	**21**	**-21**	**15**
R,F,total	%	**0,0**	**0,0**	**0,0**	**10,0**	**100,0**	**100,0**	**0,0**	**100,0**

The reduction of the district heating primary energy factor and the CO_2-emission from case 1 to 3 is due to the improved network efficiency in case 3. Introduction of 10% solar panels share in case 4 reduces these indicators even further even though, CHP-share is reduced by 5 %-points. However, 100% biomass boiler-share as in case 5 or a biomass boiler combined with solar panels as in case 6 result in even better figures. In case 7 a SOFC fuel cell is delivering the heat and electricity, the latter with 60% net electricity efficiency. Both the district heating primary energy factor and the CO_2-emission factor are negative (reference electricity efficiency is 52.5% for natural gas) and must be set to zero. Case 8 is also showing fine figures.

8.3 Large existing system 2020

The table below shows the results case 9-15 for the large existing system in 2020 with main results in the last 3 lines.

Production facilities and fuels	-	**9. Coal CHP + light fuel oil peak/ backup boilers**	**10. Coal CHP + light fuel oil peak/ backup boilers**	**11. Coal CHP + light fuel oil peak/ backup boilers**	**12. Coal CHP + light bio fuel oil peak/ backup boilers**	**13. Coal bio mix CHP + light fuel oil peak/ backup boilers**	**14. Coal CHP with CCS + light fuel oil peak/ backup boilers**	**15. Coal CHP + light fuel oil peak/ backup boilers**
Year	-	2010	2020	2020	2020	2020	2020	2020
Design option, new districts	-	-	Traditional	BNAT	BNAT	BNAT	BNAT	BNAT
Total district heating consumption	GWh	900	880	898	898	898	898	898
Total heat delivered an net	GWh	1000	1000	1000	1000	1000	1000	1000
Total network efficiency	%	90,0	88,0	89,7	89,7	89,7	89,7	89,7
Auxilary network electricity consumption	%	1,0	1,0	1,0	1,0	1,0	1,0	1,0
Advanced pulverized coal CHP								
Share of heat delivered an net	%	90	90	90	90	90	90	90
Cb	-	0,66	0,66	0,66	0,66	0,66	0,42	0,84
Cv	-	0,15	0,15	0,15	0,15	0,15	0,15	0,15
eta, electric, condense	%	44	44	44	44	44	36	48
Qmc/Qb	-	0,8	0,8	0,8	0,8	0,8	0,8	0,8
Heat delivered an net	GWh	900	900	900	900	900	900	900
eta, heat, mc	%	43	43	43	43	43	51	39
Fuel concumption, CHP	GWh	2071	2071	2072	2072	2072	1782	2321
eta, electricity, mc	%	37	37	37	37	37	28	42
Electricity delivered an net	GWh	776	776	777	777	777	506	979
eta, total, mc	%	80,9	80,9	80,9	80,9	80,9	78,9	81,0
Backup/peak load boiler								
Share of heat delivered an net	%	10	10	10	10	10	10	10
Cb	-	0	0	0	0	0	0	0
Cv	-	1	1	1	1	1	1	1
eta, cond	%	95	95	95	95	95	95	95
Qmc/Qb	-	0	0	0	0	0	0	0
Heat delivered an net	GWh	100	100	100	100	100	100	100
Electricity delivered an net	GWh	0	0	0	0	0	0	0
eta, total	%	95,0	95,0	95,0	95,0	95,0	95,0	95,0
Fuel consumption, heat	GWh	105	105	105	105	105	105	105
Labelling criteria								
f,P,F,nren, total	-	**0,45**	**0,46**	**0,45**	**0,34**	**-0,59**	**0,87**	**0,17**
K,F,tot, total	kg/MWh	**168**	**172**	**169**	**136**	**111**	**78**	**82**
R,F,total	%	**0,0**	**0,0**	**0,0**	**10,0**	**45,0**	**0,0**	**0,0**

Very little differences are seen for case 9-11 as network efficiencies are almost the same. Replacing the fossil fuel oil to bio-fuel oil for the back-up boiler (case 12) or mixing coal with wood pellets (case 13) are quite effective measures. The latter resulting in negative primary energy factor, that will be adjusted to zero. The CCS-technology as used in case 14 will reduce the CO_2-emission radically, but due to loss in electric efficiency the non-renewable primary energy consumption will actually increase. In case 15 best available coal-fired CHP technology is used which also due to the improved electricity efficiency, result in very low figures.

The calculation of the small sensitivity study, case 16-18, is seen in the table below with main results in the last 3 lines.

Production facilities and fuels	-	9. Coal CHP + light fuel oil peak/ backup boilers	16. Coal CHP + light fuel oil peak/ backup boilers + 30% savings in buildings	17. Coal CHP + light fuel oil peak/ backup boilers + 30% network losses	18. Coal CHP + light fuel oil peak/ backup boilers + 30% network losses + 30% savings in buildings
Year	-	2010	2020	2010	2020
Design option, new districts	-	-	-	-	-
Total district heating consumption	GWh	900	630	900	630
Total heat delivered an net	GWh	1000	730	1286	1016
Total network efficiency	%	90,0	86,3	70,0	62,0
Auxilary network electricity consumption	%	1,0	1,0	1,0	1,0
Advanced pulverized coal CHP					
Share of heat delivered an net	%	90	90	90	90
Cb	-	0,66	0,66	0,66	0,66
Cv	-	0,15	0,15	0,15	0,15
eta, electric, condense	%	44	44	44	44
Qmc/Qb	-	0,8	0,8	0,8	0,8
Heat delivered an net	GWh	900	657	1157	915
eta, heat, mc	%	43	43	43	43
Fuel concumption, CHP	GWh	2071	1512	2663	2104
eta, electricity, mc	%	37	37	37	37
Electricity delivered an net	GWh	776	567	998	789
eta, total, mc	%	80,9	80,9	80,9	80,9
Backup/peak load boiler					
Share of heat delivered an net	%	10	10	10	10
Cb	-	0	0	0	0
Cv	-	1	1	1	1
eta, cond	%	95	95	95	95
Qmc/Qb	-	0	0	0	0
Heat delivered an net	GWh	100	73	129	102
Electricity delivered an net	GWh	0	0	0	0
eta, total	%	95,0	95,0	95,0	95,0
Fuel consumption, heat	GWh	105	77	135	107
Labelling criteria					
f,P,F,nren, total	-	**0,45**	**0,47**	**0,57**	**0,65**
K,F,tot, total	kg/MWh	**168**	**175**	**216**	**244**
R,F,total	%	**0,0**	**0,0**	**0,0**	**0,0**

Comparison of case 17 with case 9 shows that some improvement of primary energy factor and CO_2-emission is obtained by more efficient networks or improving existing network. However, improvement of network heat losses from 386 GWh per year (case 17) to 100 GWh per year (case 9) is a radical improvement that must be taking place over a longer time horizon.

From case 9 and 16 it is seen, that saving energy in buildings (30%), will only have limited impact on the criteria, about 4%, as long as the distribution losses are low (10%). If the distribution losses are high (30%) as in case 17 and 18, the impact on the criteria is about 13-14%.

In comparison, fuel exchange, as seen in case 12, has a much larger impact on criteria.

8.4 Label classes

This section shows tables of the different cases considered, with their performance levels and ranking and divided into the 3 different criteria.

8.4.1 Label – Primary Energy Factor

In case of small new districts, all the proposed cases (case 1-8) will get class 1/7 petals. For the large existing network with pulverized coal CHP plant with advanced design data the benchmark will be class 2/6 petals (case 9-11 + 16-18). However, choice of the best future technology class 1/7 petals is within reach. Also the application of biomass will result in class 1/7 petals whereas CSS-technology will actually reduce the performance level due to lost electricity production (class 3/7 petals).

	Primary Energy Factor		
	Value [-]	Class	Petals
1. N-gas engine CHP + N-gas boilers	0,25	1	7
2. N-gas engine CHP + N-gas boilers	0,21	1	7
3. N-gas engine CHP + N-gas boilers	0,20	1	7
4. N-gas engine CHP + N-gas boilers + solar panels	0,15	1	7
5. Biomass boiler	0,12	1	7
6. Biomass boiler + solar panels	0,11	1	7
7. N-gas SOFC Fuel Cell + N-Gas boilers	0,00 (-0,88)	1	7
8. Bio-gas engine CHP + gasifier + biomass boiler	0,00 (-0,71)	1	7
9. Coal CHP + light fuel oil peak/ backup boilers	0,45	2	6
10. Coal CHP + light fuel oil peak/ backup boilers	0,46	2	6
11. Coal CHP + light fuel oil peak/ backup boilers	0,45	2	6
12. Coal CHP + light bio fuel oil peak/ backup boilers	0,34	1	7
13. Coal bio mix CHP + light fuel oil peak/ backup boilers	0,00 (-0,59)	1	7
14. Coal CHP with CCS + light fuel oil peak/ backup boilers	0,87	3	5
15. Coal CHP + light fuel oil peak/ backup boilers	0,17	1	7
16. Coal CHP + light fuel oil peak/ backup boilers + 30% savings in buildings	0,47	2	6
17. Coal CHP + light fuel oil peak/ backup boilers + 30% network losses	0,57	2	6
18. Coal CHP + light fuel oil peak/ backup boilers + 30% network losses + 30% savings in buildings	0,65	2	6

8.4.2 Label – CO_2-emission

For the small districts with natural gas engines CHP, class 2/6 petals are obtainable and with combination with solar thermal panels class 1/7 petals can be reached. Not surprisingly, this is also the case for biomass boilers and biogas gas engine CHP. The SOFC Fuel Cell is having electric efficiency higher than used in the reference allocation method, resulting in negative CO_2-emission. However, as the fuel cells are best not yet available technology, the methodology is expected developed to also cope with these appliances when relevant. The large existing network with pulverized coal CHP plant will get class 2/6 petals (case 9-13) even if some fossil fuel is replaced with biomass (case 12-13). As for primary energy factor, applying future best available technology of coal fired CHP plant (case 15) class 1/7 petals can be reached. CSS technology (case 14) can also help reaching class 1/7 petals, but at the same level as for the very efficient CHP plant of case 15.

	CO2-emission		
	[kg/MWh]	Class	Petals
1. N-gas engine CHP + N-gas boilers	142	2	6
2. N-gas engine CHP + N-gas boilers	121	2	6
3. N-gas engine CHP + N-gas boilers	114	2	6
4. N-gas engine CHP + N-gas boilers + solar panels	99	1	7
5. Biomass boiler	23	1	7
6. Biomass boiler + solar panels	21	1	7
7. N-gas SOFC Fuel Cell + N-Gas boilers	0 (-21)	1	7
8. Bio-gas engine CHP + gasifier + biomass boiler	15	1	7
9. Coal CHP + light fuel oil peak/ backup boilers	168	2	6
10. Coal CHP + light fuel oil peak/ backup boilers	172	2	6
11. Coal CHP + light fuel oil peak/ backup boilers	169	2	6
12. Coal CHP + light bio fuel oil peak/ backup boilers	136	2	6
13. Coal bio mix CHP + light fuel oil peak/ backup boilers	111	2	6
14. Coal CHP with CCS + light fuel oil peak/ backup boilers	78	1	7
15. Coal CHP + light fuel oil peak/ backup boilers	82	1	7
16. Coal CHP + light fuel oil peak/ backup boilers + 30% savings in buildings	175	2	6
17. Coal CHP + light fuel oil peak/ backup boilers + 30% network losses	216	2	6
18. Coal CHP + light fuel oil peak/ backup boilers + 30% network losses + 30% savings in buildings	244	3	5

In case 18 is seen, that class 3/5 petals can be the result when building heat consumption is low and the distribution network losses are high even for a fairly efficient coal CHP-plant.

8.4.3 Label – Renewability

Biomass boilers as in case 5 will reach top ranking class 1/7 petals. However, also using 10% bio-oil in peak load/backup boilers (case 12) or 10% of thermal solar heat (case 4) will result in reasonable ranking: class 5/3 petals. By supplying 45% of the heat from coal biomass mix CHP as in case 13, class 2/6 petals are reached.

	Renewability		
	[%]	Class	Petals
1. N-gas engine CHP + N-gas boilers	0	7	1
2. N-gas engine CHP + N-gas boilers	0	7	1
3. N-gas engine CHP + N-gas boilers	0	7	1
4. N-gas engine CHP + N-gas boilers + solar panels	10	5	3
5. Biomass boiler	100	1	7
6. Biomass boiler + solar panels	100	1	7
7. N-gas SOFC Fuel Cell + N-Gas boilers	0	7	1
8. Bio-gas engine CHP + gasifier + biomass boiler	100	1	7
9. Coal CHP + light fuel oil peak/ backup boilers	0	7	1
10. Coal CHP + light fuel oil peak/ backup boilers	0	7	1
11. Coal CHP + light fuel oil peak/ backup boilers	0	7	1
12. Coal CHP + light bio fuel oil peak/ backup boilers	10	5	3
13. Coal bio mix CHP + light fuel oil peak/ backup boilers	45	2	6
14. Coal CHP with CCS + light fuel oil peak/ backup boilers	0	7	1
15. Coal CHP + light fuel oil peak/ backup boilers	0	7	1
16. Coal CHP + light fuel oil peak/ backup boilers + 30% savings in buildings	0	7	1
17. Coal CHP + light fuel oil peak/ backup boilers + 30% network losses	0	7	1
18. Coal CHP + light fuel oil peak/ backup boilers + 30% network losses + 30% savings in buildings	0	7	1