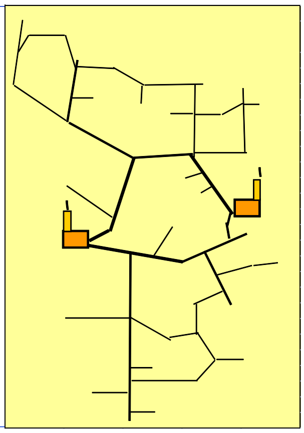
M6

Energy Distribution: District Heating and Cooling - DHC



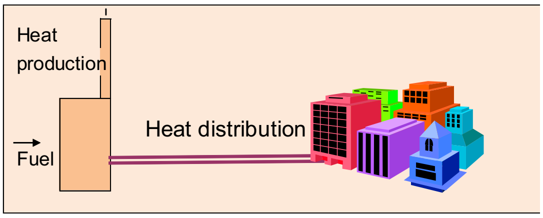
Content

1. Introduction

1.1. District Heating – DH (1)

Definition of district heating (DH):

Interconnection of various heat sources to customers by means of hot water (or steam) networks to serve room space heating (SH) and usually domestic hot water (DHW) as well.



1. Introduction

1.1. District Heating – DH (2)

Benefits provided by DH:

- Economy of scale:
  - By connecting many customers with varying heat demands, central plant runs continuously instead of many individual plants running sporadically
  - Biomass and waste incineration are most feasible at large-scale
- Environment:
  - Centralised plant almost certainly has higher efficiency than many individual plants
  - Enables surplus heat to be recycled instead of thrown away
  - Flexibility enables many low carbon and renewable heat sources to be used...
  - ...including combined heat and power production which is the only way to generate electric power at 90+ % efficiency
  - High quality flue gas cleaning is possible at large plants.
- Safety: No flue gases nor fuel explosion risk at customer premises
- Reliability: Having several heat sources and looped networks interconnected, the reliability is very high
- Maintenance: Centralised plant can be continuously monitored and pro-actively maintained
- Long lifetime: Well maintained DH networks last at least 50 years.

1. Introduction

1.1. District Heating – DH (3)

General Requirements of DH:

- High heat load density: As heat networks are very capital intensive (300-1200€/m), the heated area has to be densely built to minimize the required pipe-length
- Economic viability: As a rule of thumb the heat load density for DH should be higher than 2 MWh per metre of planned network length to be commercially viable
- Location of buildings: the buildings to be connected to the DH networks should be close to the existing network to minimize the connection pipe length. This will reduce both investment and operational costs
- Location of heat sources: modern heat sources have high quality flue gas cleaning systems. Therefore, subject to planning conditions, heat sources can be located near or in the centre of urban areas to minimize network length. The location of the heat sources has to be agreed in advance.

1. Introduction

1.1. District Heating – DH (4)

Land use requirements:

- It is very useful to develop a heat demand map, and a corresponding heat plan for a town or city to identify which areas are most suitable for DH, and which areas are best served by individual building systems
- Heat sources should be close to the customer (economy) but should take into account noise prevention and transportation logistics
- Underground networks require space that is already partly occupied by other infrastructure: eg electricity, telecommunications, sewage, water
- Possible booster pump stations
- Fuel and ash transportation routes should minimize any harm and risk to the population.

Municipal support is needed:

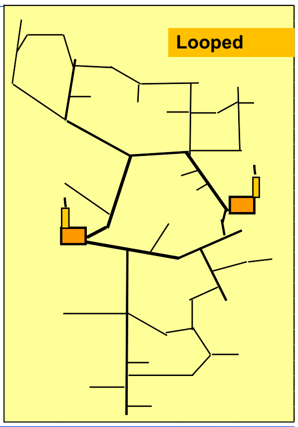
- Enabling access to roads and public land to build networks and heat sources
- Ensuring municipal buildings are connected to the DH system wherever possible.

1. Introduction

1.1. District Heating – DH (5)

Modern DH with looped network:

- Heat can be delivered to most customers from two directions, increasing security of supply
- Several heat sources connected to the same network also increases security
- Different fuel/heat source combinations can be used in parallel to minimize fuel costs
- Fuels are handled centrally, so that fire and explosion risks in buildings are avoided.



1. Introduction

1.1. District Heating – DH (6)

Customers:

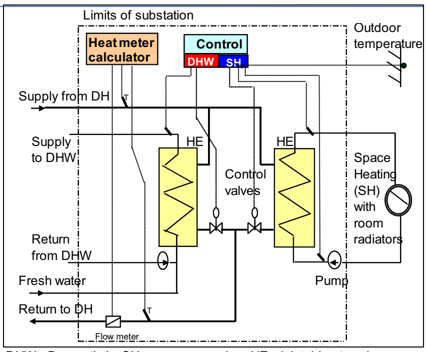
- A contract is needed with the customer that stipulates the rights and responsibilities of both parties: the heat supplier and the heat customer
- The customer representative must have access to the substation room at any time in order to adjust the control system as needed and supervise the overall condition of the substation
- The heat supplier has to have access to the substation room at any time in order to read the heat meter and supervise the overall condition of the substation
- The customer should be responsible for the entire building rather than for individual apartments.

1. Introduction

1.1. District Heating – DH (7)

Consumer substation - main functions:

- Heat exchangers (HE) keep the water circulation in the primary network separate from that in the secondary network
- Space heating (SH) controls regulate the supply temperature (secondary side) according to outdoor temperature;
- Domestic hot water control keeps the DHW water temperature constant at about 55°C
- Heat meter: calculates and stores energy consumption, using information from the flow sensor and temperature sensors.



DHW= Domestic ho SH = room space heat HE= (plate) heat exchanger

1. Introduction

1.1. District Heating – DH (8)

Consumer substation – main components

- The grey boxes at the bottom are the heat exchangers for SH and DHW
- The third box between the heat exchangers is the cylindrical expansion vessel
- The white box above is the temperature controller
- The red unit on the left is the DHW circulation pump
- The blue unit on the left is the mud filter
- The heat meter is missing in the picture but will be delivered by the heat supplier.

1. Introduction

1.1. District Heating – DH (9)

Technical features of DH:

- Water temperatures: DH supply water ranges from 80 to 120°C and the return water from 30 to 70°C depending on the system and weather conditions
- Pressures: the nominal pressure levels are typically 16 bar (1,6 MPa)
- Pipelines: Two main types as follows:
  1. *Modern* pre-insulated pipelines comprise a steel pipe covered by poluyurethane thermal insulation and polyethylene jacket pipe
  2. *Older* pipelines were installed in concrete channels, where the steel pipe is covered by mineral wool.
- Speed of water: the velocity of water circulating in the pipelines is usually below 2 m/s. Therefore, it may take several hours to reach the customer at the far end of the network.
- Heat losses: the heat losses from modern networks usually range from 5 to 10% of the produced heat.

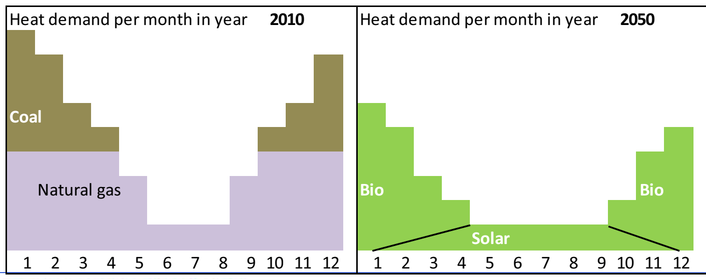
Source: www.energia.fi

1. Introduction

1.1. District Heating – DH (10)

From 2010 to 2050 DH will become carbon neutral according to the strategies of the Nordic Countries and Germany

- Improving energy efficiency reduces the overall heat demand
- Solar heating will be maximized
- The balance will be supplied by renewable (bio) fuel driven CHP and boilers as well as large heat pumps.



1. Introduction

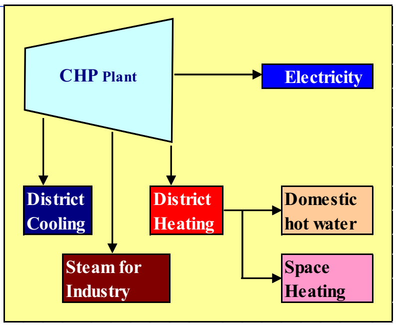
1.2. Combined Heat and Power – CHP (1)

Definition of CHP:

CHP – Combined heat and power when useful heat and electricity are produced from the technical process of the plant

Trigeneration is when both heat and cold as well as electricity are produced from the technical process of the plant.

District cooling with CHP requires an absorption chiller, which uses heat as the driving force to produce cold water.

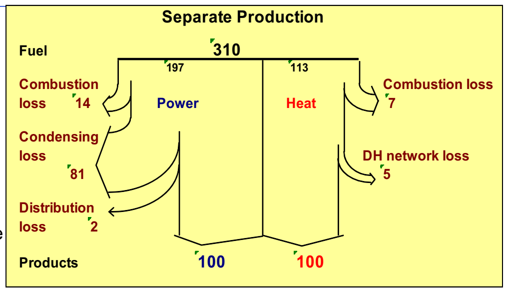


1. Introduction

1.2. Combined Heat and Power – CHP (2)

Separate supply of electricity and district heating:

- The heat losses of power-only generation based on any fuel are substantial, 1-3 times the gained electric power
- The factor depends on the fuel and type of the plant as follows:



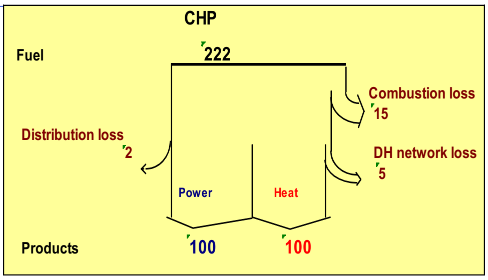
1 = for combined gas and steam fuelled power plants and gas/diesel engines (picture above),
2 = for modern solid fuel power plants,
3 = for nuclear and small power plants.

1. Introduction

1.2. Combined Heat and Power – CHP (3)

Combined heat and power (CHP):

- The same amount of sold energy to customers as in the previous slide (100 and 100)
- Fuel consumption (222) 30% less than without CHP (310)
- The quantitative fuel savings vary but 30% is independent on the type of fuel or the plant



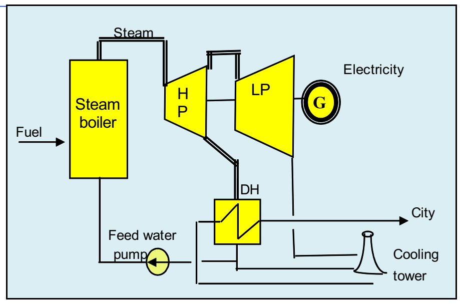
"Fuel" is the largest cost component in energy production based on fossil and renewable fuels. Therefore, the CHP benefits are substantial.

1. Introduction

1.2. Combined Heat and Power – CHP (4)

Typical CHP plant:

- Steam is extracted from the steam turbine (HP) after it has lost most of its energy running the turbine to generate electricity
- Therefore, the extracted steam is more or less waste heat, that would be lost without the existence of the heat load
- The steam flow to LP can be minimized in order to increase DH and improve efficiency
- *At a smaller scale (eg 1MWe) is gas engine CHP, often used in scheme start-up.*

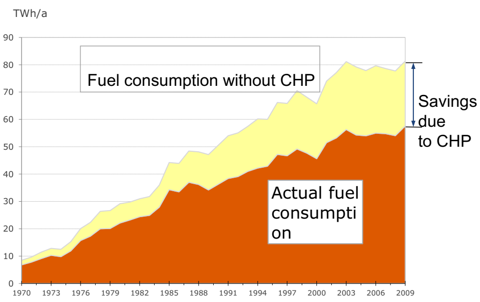


1. Introduction

1.2. Combined Heat and Power – CHP (5)

Example:
CHP benefits in Finland

- In Finland, the annual fuel consumption related to CHP and DH are presented on the right
- With the population of 5,4 million, the fuel savings in 2010 from CHP amounted to 3,7 million tonnes - about 700 kg per inhabitant less than without CHP !



The consecutive CO_2 savings in 2010 equaled to 2 400 kg per inhabitant.

Source: www.energia.fi

1. Introduction

1.3. Large Heat Pumps and District Cooling – DC (1)

Definition of district cooling (DC):
Interconnection of various cooling sources to customers by means of either hot or chilled water or even steam networks to serve room space cooling.

Rationale of DC provides the possibility to:

- Use almost carbon free cooling sources such as **sea, lake and ground water**
- Use the hot water or steam network in summer, when excess heat is available, to cool buildings by means of **absorption chillers**, a sort of fridge in which heat is used instead of electricity
- Use waste heat received from the DC system by means of a **heat pump** to warm up the return water temperature of the DH network
- Thus, the integration of DH, DC and CHP creates ***tri-generation*** in which heating, cooling and electricity are provided at high overall efficiency and with only low flue gas emissions (and low carbon emissions in particular).

1. Introduction

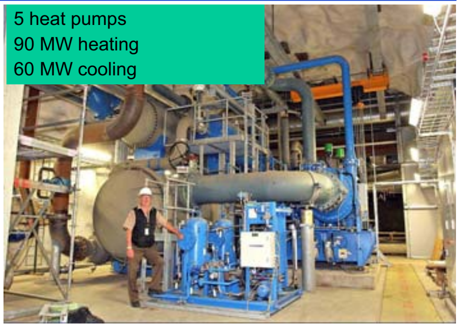
1.3. Large Heat Pumps and District Cooling – DC (2)

- DC combined with DH and CHP requires heat pumps
- Heat pump plant may produce both heating and cooling in the same process
- Utilizes purified sewage water and sea water

1. Introduction

1.3. Large Heat Pumps and District Cooling – DC (3)

Example of heat pump plant in Helsinki

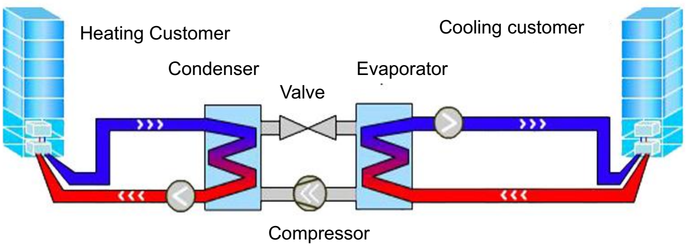


Source: www.helen.fi

1. Introduction

1.3. Large Heat Pumps and District Cooling – DC (4)

Combined production heat pump



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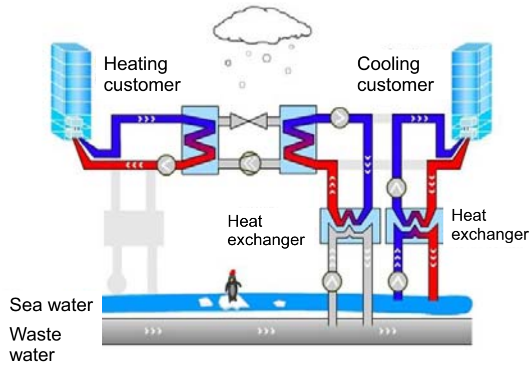
1. Introduction

1.3. Large Heat Pumps and District Cooling – DC (5)

Separate heating cooling production:

Heat only production with the heat pump (left)

Cooling-only production with sea water circulation pump and heat exchanger (right)

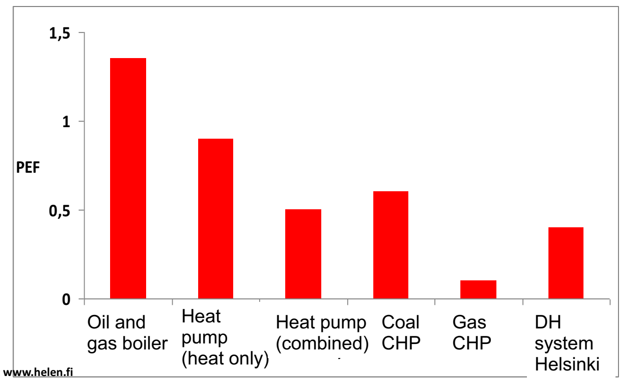


Source: www.helen.fi

1. Introduction

1.3. Large Heat Pumps and District Cooling – DC (6)

Efficiency of heating options (PEF = Primary energy factor)

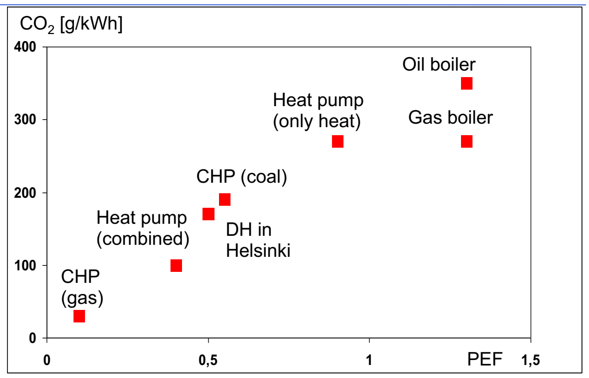


Source: www.helen.fi

1. Introduction

1.3. Large Heat Pumps and District Cooling – DC (7)

CO_2 emissions of heating options

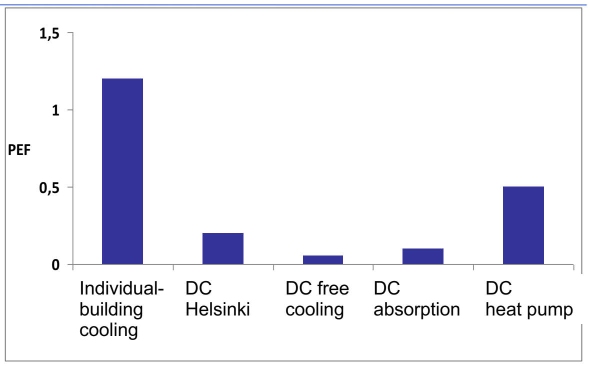


Source: www.helen.fi

1. Introduction

1.3. Large Heat Pumps and District Cooling – DC (8)

Efficiency for cooling solutions

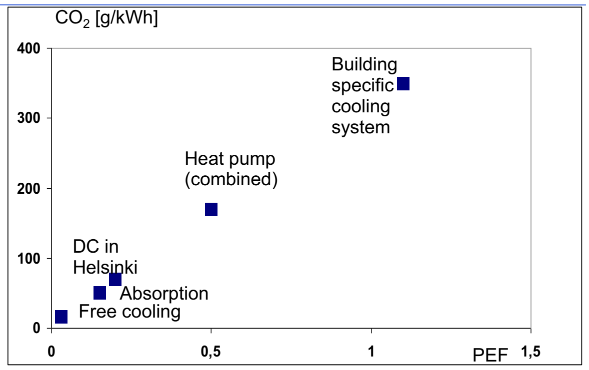


Source: www.helen.fi

1. Introduction

1.3. Large Heat Pumps and District Cooling – DC (9)

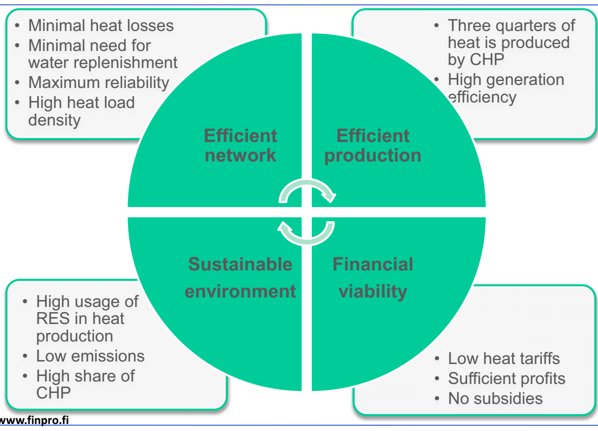
CO_2 emissions from cooling options



Source: www.helen.fi

2. Economy of DH

2.1. General Criteria for DHC Sustainability (1)



Source: www.finpro.fi

2. Economy of DH

2.1. General Criteria of DHC Sustainability (2)

Some other tools to achieve in practise the goals mentioned in previous slides:

- Planned preventive maintenance contributes to longevity of the fixed assets, and reduces the cost of maintenance. The lifetime of the pipelines can be 50 years or more.
- High quality of circulation water is vital to eliminate corrosion and blocking of pipelines and armatures
- Advanced IT systems used in operation, maintenance and financial administration may substantially reduce man-power needs and improve the quality of work.

2. Economy of DH

Example: Construction of DH system
(The numbers can be adapted to the local conditions in the attached spreadheet)

Input parameters

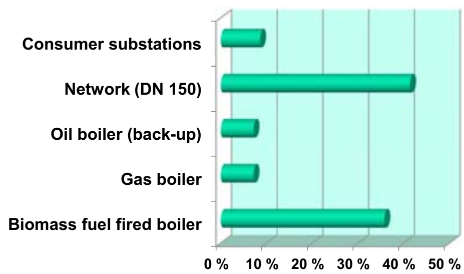
Peak heat load	100	MW
Annual heat energy	250	GWh
Linear heat sales density	2,7	MWh/m per length of network

	Capacity		Unit cost	M€	
Biomass fuel fired boiler	50	MW	400 €/kV	20	36 %
Gas boiler	50	MW	80 €/kV	4	7 %
Oil boiler (back-up)	50	MW	80 €/kV	4	7 %
Network (DN 150)	93	km	250 €/m	23	41 %
Consumer substations	120	MW	40 €/kV	5	9 %
TOTAL investment costs				56	100 %

2. Economy of DH

2.2. Impact of heat sales density on investment costs (2)

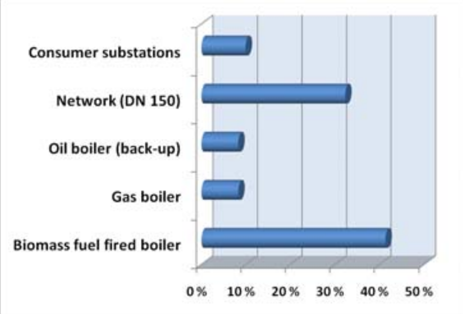
- Density 2,7 MWh/m (average in Finland)
- Investment costs: **58 M€**
- The costs of the biomass boiler are about as high as of the network



2. Economy of DH

2.2. Impact of heat sales density to investment costs (3)

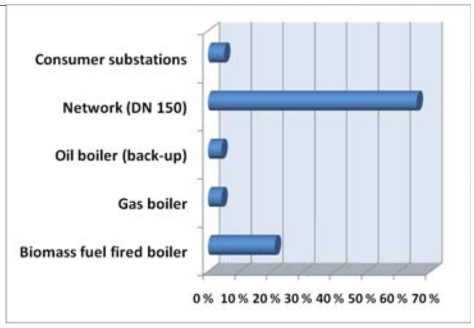
- Density 4 MWh/m – a densily built city
- Investment: **48 M€**
- The cost share of the network has substantially reduced



2. Economy of DH

2.2. Impact of heat sales density to investment costs (4)

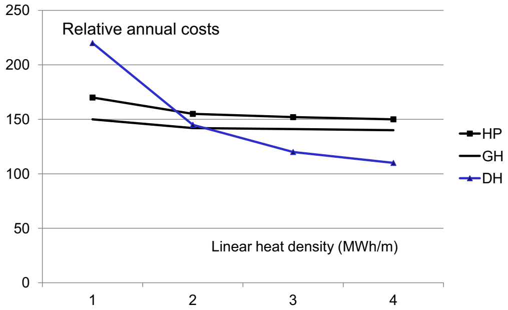
- Density 1 MWh/m – low density suburb
- Investment: **95 M€**
- The investment costs of the network becomes dominant.



2. Economy of DH

2.3. Heat sales density relative to heating mode

- Economy of DH depends on the length of the DH network
- Competitiveness depends on the relative prices of electricity (HP), gas (GH) and DH
- Examples (MWh/m):
  - Germany: 4,0
  - Finland: 2,7
  - Helsinki: 6,0



- HP: Individual heat pumps
- GH: Individual gas heating

Source: Arcieves of Finnish Aalto team

Source: www.helen.fi

Source: Country and city comparisons, EuroHeat&Power Country by Country Survey 2011, www.euroheat.org

2. Economy of DH

2.4. Primary energy factors: DH with CHP vs heat pump (1)

Primary energy factors

As an example, the average primary energy factors used in Finnish energy industry are as follows:

Electricity	2,0
District heating	0,7
District cooling	0,4
Fossil fuels	1,0
Renewable fuels	0,5

Source: (Raportti B85, Rakennusten energiatehokkuuden osoittaminen kiinteistöveron porrastusta varten. Teknillinen korkeakoulu, LVI-tekniikka, Espoo 2009)

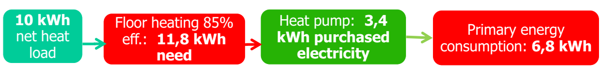
2. Economy of DH

2.4. Primary energy factors: DH with CHP vs heat pump (2)

Example of an individual heat pump:

- Let us suppose the heat demand of a small house is 10 kW.
- At 85% efficiency, the house needs 11,8 kW of heat
- Heat is generated by a geothermal heat pump with coefficient of performance (COP - energy output per energy input) being typically 3,5. Thus, requiring 3,4 kW of electricity
- Electricity from the grid requires primary energy of 6,8 kWh (primary energy factor=2)

As conclusion, the heat pump can be very energy efficient for average conditions.



2. Economy of DH

2.4. Primary energy factors: DH with CHP vs heat pump (3)

Individual heat pump in the CHP/DH system:

The heat pump requires electricity. This is actually generated by the local CHP plant – even though purchased from the grid.

The heat energy produced by the heat pump reduces the heat production of the CHP plant

A part of the CHP power turns to separate (condensing) power due to reduced CHP heat production

The heat pump needs electric energy to generate heat

As conclusion: the primary energy consumption increases while the heat pump takes over heat load from the CHP plant.

In the next slide: a CHP plant of 40 units of electricity and 100 units of heat production is assumed as base case.

2. Economy of DH

2.4. Primary energy factors: DH with CHP vs heat pump (4)

Electricity				Heat			Primary
Total	CHP	Separate	Heat pump	Total	CHP	Heat pump	energy
40	**40**	0	0	100	**100**	0	158
43	36	4	3	100	90	10	163
46	32	8	6	100	80	20	168
49	28	12	9	100	70	30	172
51	24	16	11	100	60	40	177
54	20	20	14	100	50	50	182
57	16	24	17	100	40	60	187
60	12	28	20	100	30	70	191
63	8	32	23	100	20	80	196
66	4	36	26	100	10	90	201
69	0	40	29	100	0	100	206

Explanations:

CHP: power to heat ratio=	0,4	
Heat pump: heat/power=	3,5	
Boiler efficiency of the CHP plant	90 %	
CHP electrcity used for internal process in CHP =	6 %	of CHP electricity generation
Separate electricity generation: efficiency =	33 %	

3. Best Practice Cities with DHC and CHP

3.1. Criteria

Criteria for Best Practice:

- High overall efficiency of energy supply through DH and CHP
- High level of RES used in the DH/CHP
- High level of CHP connected with DH
- High level of DC to complement Tri-generation

3. Best Practice Cities with DHC and CHP

3.2. Vienna, Austria

Municipal waste incineration:

- Three waste incineration plants
- Municipal waste as fuel
- Wien Energie –company handles 800.000 tonnes of various waste annually
- The plants are situated inside the city area
- The waste incineration plant in picture on right was designed by the architect Hundertwasser
- The plant is located near to a large hospital (200 m)
- Tourist attraction

Source: www.wienenergie.at

3. Best Practice Cities with DHC and CHP

3.3. Helsinki, Finland

Comprehensive DHC and CHP:

- DH covers 93% of the total heat demand in Helsinki with the remainder coming from individual heat pumps, oil and electric heating;
- 1230 km of underground heating networks and more than 10.000 customers (buildings) exist in the integral DH system;
- More than 90% of DH energy is produced by CHP
- The annual (!) energy efficiency of CHP exceeds 90% which is one of highest in the world;
- 7 large CHP units, 5 heat pumps and more than 10 peak load boilers are connected to one integral network
- Fast expanding district cooling system despite being a capital with cold climate conditions;
- The EU has ranked DHC and CHP in Helsinki as Best Available Technology.

Source: www.helen.fi

Helsingin Energia

- **Helsingin Energia's smart CHP/DH system** is the **most energy-efficient solution** for heating Helsinki city.
- Helsinki's solution combines CHP, district heating (DH) and district cooling (DC) in the **most energy-efficient way in the world.**
- In CHP DH is produced concurrently with electric energy with an **efficiency rate of more than 90%.** DH covers over 90% of Helsinki's heating need. **CHP accounts for over 90% of DH** production.
- Produced in the same processes with DH, DC is the most energy-efficient form of cooling properties by far. In Helsinki, the **heat gathered from properties with rapidly expanding DC is used fully in DH**:
  - DH and DC are produced from the waste heat of purified sewage water and from sea water in the Katri Vala heating and cooling plant.
  - The data centre concept: The heat produced by computers cooled with DC is conducted to the DH network to provide heat to buildings in Helsinki.
  - Light district heat is a heating solution for low-energy houses built in the extremities of the DH network. The building automation of these houses supports the concept of lower temperature of the circulating water in the smart DH system.
- ***In accordance with Helsingin Energia's development programme towards a carbon-neutral future 2050, increasing use of bio-renewable energy is being introduced in the DH system project by project.***

4. DH and CHP internationally

4.1. European Union

Drivers in the EU:

- Prevention of energy import to EU growing from the current 50% to 70% by year 2020
- Reduction of energy related emissions to fight the Climate Change.

Development per country in three categories:

1. New member countries: Rehabilitation of extensive and old DH systems (PL, HU, RO, EST, LV, LT, CZ, SK, …)
2. Older member countries and Norway: Fast development of DH (DE, NO, IT, FR,..)
3. Nordic countries and Austria: Increased fuel flexibility of already modern and extensive modern DH systems (FI, SE, DK, AU)

4. DH and CHP Internationally

4.2. Statistics (1)

The numbers for Russia are indicative, but the others are based on Euroheat & Power statistics and ministerial statistics of China.

Country	Production capacity GW	Length of networks Mm	DH floor space Mm2	Total DH delivered PJ	Share of CHP in electricty production
China	**224,6**	**88,9**	**3006**	**2250**	
Czech Republic	36,1	6,5	109	144	10 %
Denmark	17,3	27,6	204	103	53 %
Estonia	2,8	1,4	30	26	8 %
Finland	20,4	11,0	297	108	34 %
France	17,4	3,1		80	
Germany	57,0	100,0	440	267	13 %
Japan	4,4	0,7	49	10	
Korea (South)	13,3	4,7	142	199	23 %
Latvia		2,0	38	24	40 %
Lithuania	8,3	2,5	34	29	21 %
Norway	1,4	0,9		11	
Poland	67,8	18,8	540	425	16 %
Romania	53,2	7,6	70	67	11 %
Russia		**176,5**	**5900**	**6100**	
Sweden		17,8	215	169	5 %

4. DH and CHP Internationally

4.2. Statistics (2)

China: strong growth while replacing small and polluting coal fired boilers with DH and facilitating expanding cities with DH services

Russia: growing need to modernize the existing old and deteiorated DH systems to reduce losses and improve reliability

USA and Canada: Small DH systems exist mainly between state owned builfings (hospitals, military, university, office) but not much on residential area. Low prices of energy and low interest at private sector and relatively weak municipalities make DH expansion challenging.

The UP-RES Consortium

Contact institutions for this module: **Aalto University**

- **Finland : Aalto University School of science and technology**
  www.aalto.fi/en/school/technology/
- **Spain : SaAS Sabaté associats Arquitectura i Sostenibilitat**
  www.saas.cat
- **United Kingdom: BRE Building Research Establishment Ltd.**
  www.bre.co.uk
- **Germany :**
  AGWF - German Association for Heating, Cooling, CHP
  www.agfw.de
  UA - Universität Augsburg www.uni-augsburg.de/en
  TUM - Technische Universität München http://portal.mytum.de
- **Hungary : UD University Debrecen**
  www.unideb.hu/portal/en